PROCEEDINGS

of the

ENGINEERING INSTITUTION OF ZAMBIA
2022 CONFERENCE

Hosted by
The Engineering Institution of Zambia

Theme:
"Engineering for a Changing World"

ISBN: 978-9982-70-908-5

Wednesday 20th to Saturday 23rd April, 2022
Avani Victoria Falls Resort, Livingstone, Zambia

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YOUNG ENGINEERS' FORUM PAPERS

Foreword

Welcome to the 2022 Engineering Institution of Zambia (EIZ) 65th National Symposium at Avani Victoria Falls Resort, Livingstone, 22nd April 2022, under the theme, **"Engineering for a Changing World**". The symposium will be preceded by the Zambia Women in Engineering (ZWES) and Young Engineers/Innovators' Forum (YEF) conferences on 20th April 2022 at the same venue. The Symposium will be followed by the Annual General Meeting of the Engineering Institution of Zambia on 23rd April, 2022.

The 2022 EIZ 65th National Symposium reflects on the findings and recommendations of the various research reports concerning the profession of engineering, the technology and innovation needs of the society, and the role played by human and intellectual capital, into an analysis of the changing nature of engineering practice, research, and education.

The world is changing. And so is engineering. In the past few years, the nature of engineering – as well as its research agenda – has been changing, especially in response to the many crises that haunt our present-day world. Historically, the role of the Engineering Professionals has been regarded positively, almost affectionately. By contrast, the role of Engineering Professionals in development in lower income countries like Zambia in the last half century arouses a more mixed response. Large scale projects from dams to highways have sometimes become icons of inappropriate solutions to the needs of the poor, or been shown to be ineffective, unaffordable burdens on countries like Zambia. Despite some achievements in the provision of essential infrastructure, the reputation of engineering has been tarnished by such failures.

This *Book of Proceedings* has been compiled to highlight some of the many ways in which Engineering Professionals can contribute to improving the quality of life in Zambia and the world at large. The aim is not to provide a comprehensive treatise on the relationship between engineering and international development. It is certainly not to argue that Engineering Professionals alone hold the key to poverty eradication. Rather it is to suggest that Engineering Professionals are key to the development and delivery of a wide range of solutions, as contributors in complex and multidisciplinary teams.

The programme for technical paper presentations is in two parallel sessions. All the technical papers in this book of proceedings were refereed through a double-blind review selection process. In addition to these technical paper presentations, we are glad to inform you that the programme includes plenary and keynote presentations.

Finally, we would like to express our thanks to the authors and reviewers of the technical papers, whose work and dedication made it possible to put together a programme that we believe is very exciting and of interest to the engineering community and the nation at large. Personally, I wish to express my appreciation to the members of the EIZ Publications Committee for coping with extra workload and in ensuring that all the technical papers were ready for the Symposium.

We wish you all an exciting 2022 EIZ 65th National Symposium.

Eng. Prof. John Siame
Chairperson, EIZ Publications Committee
April 2022

Sustainability of hydropower generation for future energy needs in Zambia

Eng. David Zimba[1], Eng. Vincent C. Mbewe[2], Eng. Bryan Kalundu[3]

Abstract

In Zambia, 89.9% of electricity is generated from hydropower. The droughts experienced in the years 2014/15 resulted in long hours of load shedding and an estimated economy wide loss of 20% GDP. This situation repeated itself in 2018/19 and highlighted the vulnerability of the major source of electricity in Zambia. In this regard, a much more reliable and stable source of electricity is therefore needed to meet the current and future energy demand.

Presented in this paper are the challenges with the current sources of electricity generation in Zambia. These range from climate change, current location of major Hydropower stations, Policy around Independent Power Producers (IPPs), ageing Infrastructure and financing of new electricity sources. Opportunities for sustainability are also presented and include mixed generation, cascade development, employing new hybrid technologies such as Floating Solar PV and geographical positioning of Hydropower stations by exploiting the northern parts of the country.

Key Words: **Hydropower, Sustainability, climate change, cascade development, decentralized grids.**

1. Introduction

Zambia has for a long time depended on hydropower for its electricity needs. This reliance on hydropower faces several challenges such as climate change, increased demand due to increased economic development and low tariffs.

The energy mix of a country is an important determinant of its energy security (Akrofi, 2021). Energy security means having available energy, sufficient affordable quantities and without any adverse economic or environmental impacts. As was experienced in Zambia in the years 2014/15 and 2018/19, the availability of electricity as an energy source was challenged when long hours of load

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shedding were experienced across the country dampening economic development. In 2014, the total energy sent out was 14,453 GWh and in 2015 it reduced to 13,440 GWh which represents a 7% reduction. During the period, the generation mix was dominated by 94.1% Hydro at 2,269 MW and the 5.9% shared by Heavy Fuel Oils (HFO), Diesel and Solar PV (ERB, 2015).

In 2018/19 the scenario was repeated with further load shedding being experienced countrywide, new power stations had been commissioned and the generation mix outlook was more diverse. The installed capacity in 2018 was 2,898.23MW and increased to 2,981.31MW in 2019 out of which 80.45% was Hydro. The remainder comprised coal (10.06%); HFO (3.69%); Diesel (2.80%); and Solar (2.99%).

Many challenges exist with the current electricity generation sources set-up; for example, most of the major hydropower stations are located in the southern part of the country where rainfall patterns have been unfavorable. This climate change to shorter rain seasons and prolonged dry seasons, creates a shortage of available water for power generation; and the power stations do not produce at their full capacity. Thus, to ensure security of supply, sustainability of hydropower is needed through the incorporation of different solutions which are presented in the sections below.

2. Zambia's Electricity Energy Generation Outlook

Zambia had 3,030 MW of installed electricity capacity as of December 2021. The breakdown by generation type is shown in Table 1.

3. Challenges with the current electricity portfolio

3.1. Government policy

Private sector participation is mainly in generation, leaving the burden of offloading the produced electricity to the utility. IPPs have long term Power Purchase Agreements (PPAs) which are dollar dominated with offshore investors. ZESCO the off-taker carries the local currency inflation risk since it sells most of the IPP power to the local market in local currency. In 2020 IPPs accounted for nearly 26% of the total electricity generated. As more IPPs join generation, there will be a greater burden on the off-taker to sell this power.

3.2. Private sector investment

The electricity energy sector has been hampered by tariffs that are not cost reflective. This has created slow interest by investors in the sector.

Table 1 : Power generation sources, showing capacity, owner, date of commissioning and location.

Station	**Type**	**Capacity**	**Location**	**Owner**	**DOC**
Kafue Gorge Upper	Hydro	990MW	Kafue	ZESCO	1973
Kariba North Bank	Hydro	720MW	Siavonga	ZESCO	1977
Kariba North Extension	Hydro	360MW	Siavonga	ZESCO	2014
Kafue Gorge Lower	Hydro	300MW	Kafue	ZESCO	2021
Itezhi Tezhi	Hydro	120MW	Itezhi Tezhi	ZESCO/TATA	2016
Victoria Falls	Hydro	108MW	Livingstone	ZESCO	1936
Mulungushi	Hydro	32MW	Kabwe	LHP	1932
Lusenfwa	Hydro	24MW	Kabwe	LSPC	1932
Lunzua	Hydro	14.8MW	Serenje	ZESCO	1960
Musonda Falls	Hydro	10MW	Mansa	ZESCO	1960
Chishimba Falls	Hydro	6MW	Kasama	ZESCO	1960
Lusiwasi Upper	Hydro	15MW	Serenje	ZESCO	2021
Lusiwasi Lower	Hydro	12MW	Serenje	ZESCO	1967
Shiwangándu	Hydro	1MW	Mkushi	ZESCO	2015
Zengamina	Hydro	0.76MW	Mwinilunga	Zengamina	2007
Maamba	Coal (Thermal)	300MW	Maamba	MCL	2016
Ndola Energy	HFO(Thermal)	105MW	Ndola	Ndola Energy	2015
Bangweulu PV	Solar	53MW	Lusaka	Neoen	2019
Ngonye PV	Solar	34MW	Lusaka	Enel	2019
Samfya PV	Solar	0.06MW	Samfya	REA	2009
Dangote Power Plant	Coal	30MW	Ndola	Dangote Industries	2020
Total		**3,235.62MW[4]**			

3.3. Government prioritization to develop large projects

Governments usually prioritize large infrastructure projects over small and medium ones because they employ more people, create more news worthy ripples, and have larger economic outcomes i.e. fishing, water tourism and prime real estate on shores of large lakes created. However, these large projects cost more money, the feasibility studies take long to finalize, and are susceptible to material shortages. Small to medium sized projects, however, are left for private investors. Private investors as has been observed take long to mobilize even after the implementation agreement have been

[4] *The 3235.62MW includes on-grid and off grid power stations. Dangote, Samfya, are not connected to the Grid. Maamba injects 240MW into the grid and uses 60MW for local supply.*

signed. Thus, the government through ZESCO and REA can still develop small to medium sized projects.

3.4. Drought and climate change

From Table 1 and the preceding sections, 82% of electricity in Zambia is produced from hydropower, which depends on rainfall. The changes in the climatic conditions have affected generation. As of 2020, the highest power deficit was at 810 MW. This was attributed to the reduced water levels in the main water reservoirs for power generation, which are located in the southern part of the country experiencing low rainfall. Climate change has also created a strain on the water resources from competing needs such as farming, this further reduces the amount of water available for power generation.

3.5. Ageing infrastructure

Hydropower is a very old science. In Zambia, Hydropower plants have been in operation for more than 40 years. These hydropower stations were built with 80s technology which requires effective and efficient maintenance. This means that the equipment has become old and unreliable. To assure safe and reliable production of electricity, the rehabilitation of existing hydropower plants becomes a major factor to consider when talking about security of supply.

3.6. Financing

Hydropower projects are capital intensive and as such are usually financed by multilateral lenders who often give high interest loans at the expense of other social government responsibilities. The lead times to financial close are also usually long and complex. Hydropower asserts, however, are long-lived generation asserts with minimal operation costs. To be able to develop hydropower, properly developed market mechanisms are needed to attract investors and to facilitate quick rollout of hydropower projects.

3.7. Lack of research in alternative energy sources

Despite the country experiencing electricity challenges for a considerable period, efforts towards research into new renewable technologies and impacts of climate change on energy sources is slow. Demand has been growing and it is known that projects take time to actualize, but research is still very slow.

According to the PwC Batoka Gorge Hydroelectric Scheme Feasibility Study report the projected electricity demand up to 2045 with a medium outlook of about 3.97% per annum will come to 44,951GWh. This demand needs to be fulfilled, in a quick and efficient manner and research is at the center of this realization.

4. Opportunities for sustainability of hydropower

There are a number of opportunities for sustaining Zambia's electricity energy needs from hydro plants. The paragraphs below outline some of the ways in which this can be achieved to secure future energy needs.

4.1. Exploiting northern region for hydro

The northern part of the country continues to record good rainfall patterns. However, most rivers in the north are smaller compared to those in the south. Nonetheless, a lot of potential exists for hydropower on rivers like Kalungwishi, Luapula, and the upper reaches of the Zambezi in Kabompo and Mwinilunga. A number of project sites have already been identified and are at various project stages from pre-feasibility to procurement stage. This potential could be a future reliable source of hydropower.

4.2. Cascaded hydropower development

The already existing rivers and reservoirs can be maximized by developing additional hydropower stations within their reaches. Along the Kafue River, three hydropower stations have been built. The Kafue Gorge Upper Power Station commissioned in 1970, Itezhi Tezhi Power Station commissioned in 2016, and the Kafue Gorge Lower Power Station under construction with the first 300 MW of the 750MW already commissioned in 2021. Figure 1 gives the cascaded hydropower stations on the Zambezi

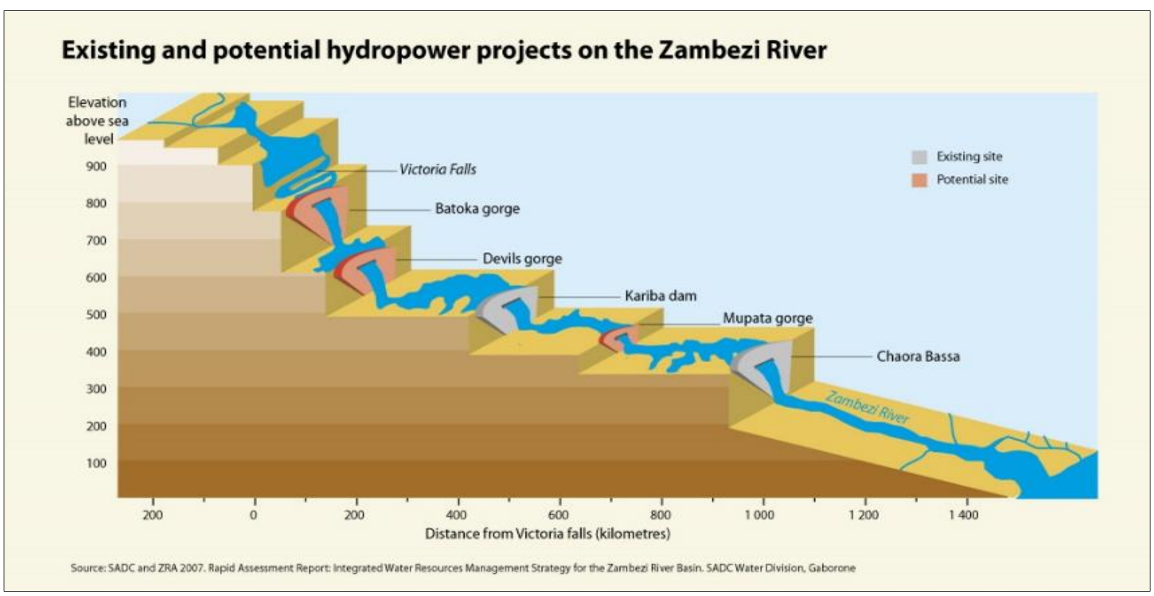

Figure 1: Cascaded hydropower stations on the Zambezi (Source: ZRA Website)

The Luapula River has cascade hydropower potential on several sites including Mumbututa CX, Mumbututa CY and Mambilima VB, and Y. The Kalungwishi River is another river with cascade development potential. Economically feasible identified sites on this river are at Kabwelume Falls and Kundabwika Falls.

4.3. Hybrid floating Solar PV

The water surface on reservoirs created by hydropower can be used to hold floating solar panels in a new technology called floating solar. On average, solar power uses 1Ha per megawatt of power produced. This will mean clearing large parcels of land for power generation for solar. Floating PVs are still relatively new but are being applied extensively in other countries like China.

4.4. Mixed generation

Mixed generation will entail adding renewables like solar and wind to the traditional power generation options available. Renewables such as solar and wind suffer from intermittency when the weather is unfavorable. Hydropower will be needed to provide grid stability because of its dispatch capabilities by coming in during such times when other renewables are off. Further, added power generation from other sources can make hydropower generation to rest and thereby conserving water to be used at a later time when renewables are not producing.

Figure 2 shows the existing sources of electricity of which 82% is hydro and the remaining 18% shared by other sources.

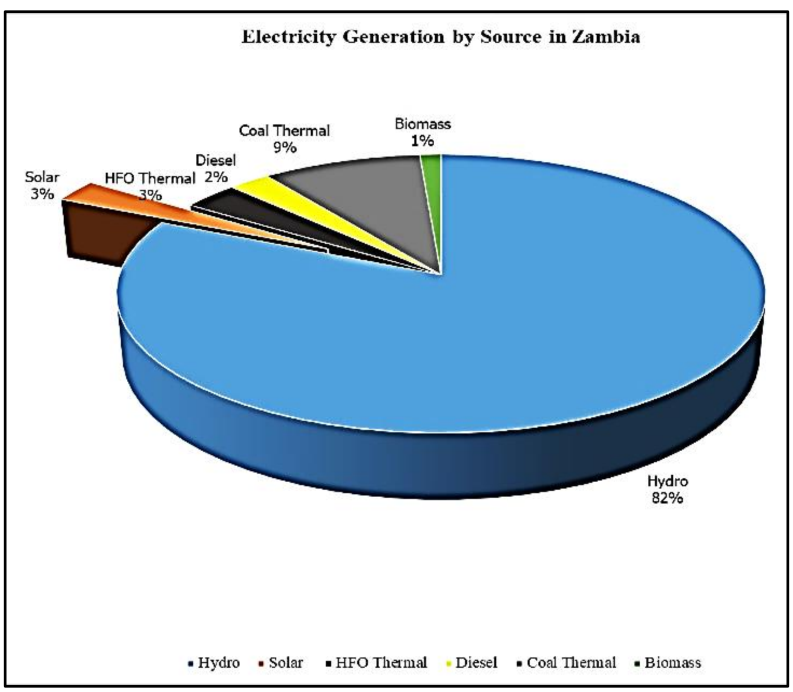

Figure 2: Electricity Generation sources in Zambia in 2021

Mixed generation from renewables drive cost of tariffs lower because they are usually quick to implement and are cheaper. They also benefit from climate funding like the Green Carbon Fund that seeks to promote climate change mitigation projects. The percentage of renewables needs to increase proportionally to hydropower going forward.

4.5. Refurbishing and uprating existing power stations

The already existing power stations can be uprated to get the most of the already existing potential. For example Kafue Gorge Upper Power Station was uprated from 900MW to 990MW. At Itezhi Tezhi dam there is potential for heightening the dam that would lead to increased storage capacity of the reservoir and increased power generation at Itezhi Tezhi Power Station. Chishimba Falls Power station is also being uprated and is at procurement stage.

5. Conclusion

Currently hydroelectricity power generation sources in Zambia face many challenges, which threaten security of supply and reliability. It has also vulnerable to climate change. With all the major hydropower stations located in the low rainfall zones of the country, geographical diversification is needed by exploiting the northern parts of the country, which have much better rainfall patterns. Cascade development of hydropower plants should exploited.

The shift towards renewables like Solar and Wind into our electricity grids will need the capabilities of hydropower to balance out when intermittency occurs. Hydropower can also rest when the other renewables are at peak, and then be ramped up when they are down. The two can complement each other.

To achieve the Sustainable Development Goals, National Development Plans and Vison 2030, sustainability of hydropower generation is needed. Technology is always advancing and the recent years have seen marked improvements such as pumped storage schemes, hybrid hydro and hydro-kinetic projects. In this global village, Zambia cannot afford to stand back and just watch, but should also participate in research, and implementation of new hydropower generation sources.

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Small scale photovoltaic (PV) capacity

Mweetwa Mundia Sikamikami[1]

Abstract

Zambia's stable economic development and rapid population growth have led to power sector demand more than doubling between 2000 and 2020. Projections indicate that these trends will continue in the future which means Zambia will need to invest in adequate power supply to meet the country's growing demand. As part of its long-term energy strategy, the Zambia government plans to exploit the country's abundant solar and wind resources and reduce its reliance on commodities' imports. The 2015 update to the New Energy Strategy sets out an ambitious target for 52% of the total installed capacity to come from renewables by 2030, equivalent to 12 GW of renewable capacity. Studies indicate that Zambia is one of the most attractive countries in the Southern African region in terms of solar power potential which means small- scale PV could play a key role in meeting future energy needs and the 2030 target. However, the weak regulatory environment and specifically the lack of regulation for low-voltage connection is reducing attractiveness of the investment and slowing-down uptake of the PV self-consumption scheme. The goal of this study is to identify the main policy and regulatory barriers which are delaying investment in small-scale PV in Zambia. The focus is on self-producers such as Micro Small Medium Enterprises (MSMEs) and on the public sector. The study proposes a number of remedies – based on learnings from international experience – which could be introduced to overcome the policy and regulatory barriers which are preventinginvestment in small-scale PV and delaying the country transition to a renewable-based electricity system.

Keywords: Solar Photovoltaic (PV), Zambia, Energy, Development, Renewable.

1. Introduction

Zambia is undergoing a strong economic development, which is also impacting its power sector. Zambia electricity demand has increased from 14 TWh in 2000 to 39 TWh in 2020 (average annual growth of 5.3%) and projections indicate that this trend will continue in the future.

Zambia will need to invest in adequate power supply to meet the country's growing demand. In achieving this goal, the Zambian Government aims at avoiding the worsening of its dependence on commodities' import which, as declared by the Ministry of Energy website, is higher than 90%.

Taking advantage of the fact that the Country is one of the most attractive in the Southern African region interms of renewable potential, the Government of the Republic of Zambia (GRZ) has set the ambitious target to reach 42% share of renewable capacity on the total installed capacity by 2020 and 52% share by 2030. At least in 2020, Zambia registered a consistent growth of installed capacity in RES, mainly driven by large centralized plants, reaching 70% of the selected 2020 target; however, as far as solar power development is concerned, despite Zambia's high potential, only 36% of the target has been installed.

International experiences have shown that small-scale PV development may accelerate the surge of RES capacity. ZESCO estimated that such segment alone may be enough to respect the 2030 targets for solar capacity and hence represents a unique opportunity for Zambia. In this context, the Micro Small Medium Enterprise (MSME) and the public buildings represent the chance to

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increase the RES capacity rapidly and,at the same time, to raise awareness on small-scale PV among the population, pushing for residential deployment of rooftop small-scale PV at a later stage.

On one hand, the MSME sector is one of the key pillars of the Zambian economy; MSMEs represent 95% of all companies in the Kingdom. The tertiary sector accounts for more than 10% of the Zambian electricity consumption, with an estimated small-scale PV potential higher than 1 GW. Moreover, the MSME sector may access financing instruments more easily than residential, opening small- scale PV deployment paths in all sectors.

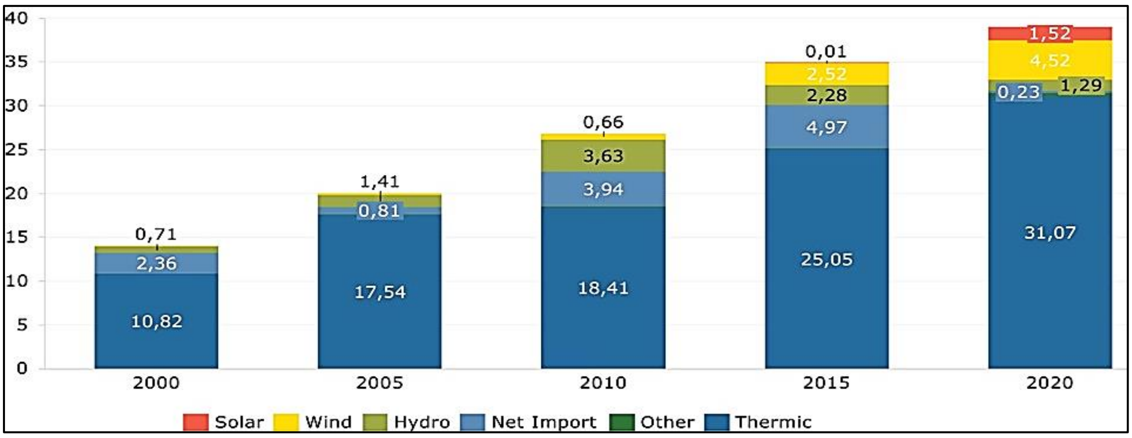
Despite the chance this segment would represent for Zambian power sector, the small-scale PV market is still almost absent in the country. The causes behind the lack of development of small-scale PV are to be found in the existence of several barriers of different nature: from the lack of the adequate regulatory framework, to the absence of incentive schemes, and the lack of awareness for this opportunity.

2. Background Of Project

The electricity demand and production are rapidly growing, driven by sustained economic development and an increase in population. Zambian GDP was higher than 110 billion USD in 2020, about three times the Zambian GDP assessed in 2000 (World Bank). Zambia's population reached about 18 million people, growing by 30% in the last 20 years.

In this context, electricity demand grew from 14 TWh in 2000 to 39 TWh in 2020 (Figure 1), with energy consumption per capita almost doubled. National electricity net import consistently decreased in the last five years, from 5TWh to 0.23 TWh, with an export growth from 0.16 TWh in 2015 to 0.6 TWh in 2020. National electricity production increased over time, especially thanks to thermal power production, that in 2020 produced 80% of the national electricity demand.

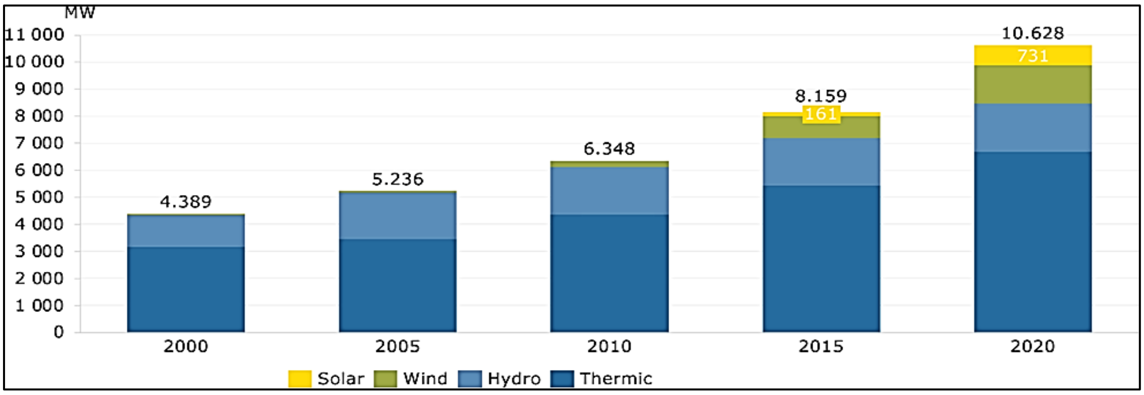
Figure 1: Electricity demand over the past decade.(Source: AFRY Management Consulting)



Alongside national demand, Zambian capacity grew from 4.4 GW in 2000 to more than 10 GW in 2020, as shown in Figure 2. However about two third of the installed capacity is thermal, and 40% derives from coal.

Zambian growth is not limited to an increase in installed capacity, but also to a significant expansion of the grid and a growing off-grid capacity, achieved over the last few decades. In 1996, the government launcheda 15-year rural electrification program Rural Electricity Authority – REA; Act of Parliament in 2003, with the aim to increase rural electrification to 80% by 2010, starting from the 18% of 1995. The authority performed better than expected, achieving 81% of rural electrification 5 years in advance and obtaining almost 97% of electrification in 2010. The program included off-grid PV kits, micro grid and the extension of the regular national grid.

Figure 2: Installed capacity. (Source: AFRY Management Consulting)



Having accomplished this remarkable goal, GRZ set other ambitious target for clean energy production. In 2008 the Ministry of Energy defined the decarburization roadmap in terms of RES capacity. The strategy set the goal of 42% of RES capacity at 2020, targeting 2 GW for each technology: wind, solar and hydro.

Zambian commitment showed satisfying results in terms of renewable installed capacity where nearly 70% of the target capacity has been deployed, especially thanks to hydro and wind installation. Despite the high potential of Zambian solar power development, however, only 36% of the target has been installed. In this context small-scale PV deployment may accelerate the installation of new solar capacity.

More recently, the Zambian government imposed a target of 52% of total capacity by 2030 coming from renewable sources. In this framework, 20% of the installed capacity should derive from solar power, reaching around 5GW by 2030.

3.0 Aim and Objectives

The aim of the project was to contribute towards increased access to modern energy services and improved energy security across the country, through promotion of market based uptake of renewable energy (RE) and energy efficient (EE) technologies and energy services.

3.1 Objectives:

The main Objective of this project is the development of a re-skilling plan in support of a just energy transition, a holistic view of skills linked to renewable energy employment opportunities particularly assessed for Solar Photovoltaic (PV), that contribute to Zambia’s energy transition.

3.2 Didactic Objectives:

- Building human capacity for the development and implementation of new energy technologies, i.e., micro-grids and off-grid solutions
- Stimulating regional cooperation and knowledge-exchange
- Offering long-term behavioral changes to promote green practices
- Focusing on social inclusiveness, specifically integrating re-skilling opportunities for youth and;
- Women participation
- Focusing on a comprehensive spillover effect to social development efforts.

4.0 Literature Review

Currently, installed solar energy capacity in Zambia amounts to 760 MW approx., of which about 300 MW is photovoltaic. Solar power installed capacity mainly comes from the Chipata power station - Global Energy Monitor - GEM plant in Eastern Zambia. Small-scale PV has first made its entry into the Zambian market through the rural electrification authority's - REA program, which deployed solar mini grid systems, and solar home systems in the most isolated areas, where access to the grid was not possible to achieve. Solar kits consist of two solar panels of 290 watts and two batteries with a total capacity of 300Ah, providing up to three days of energy supply. More than 50 thousand off- grid PV systems, covering more than 100 thousand homes, are being installed during the ongoing program, and REA assessed a total off-gridPV capacity higher than 20 MW.

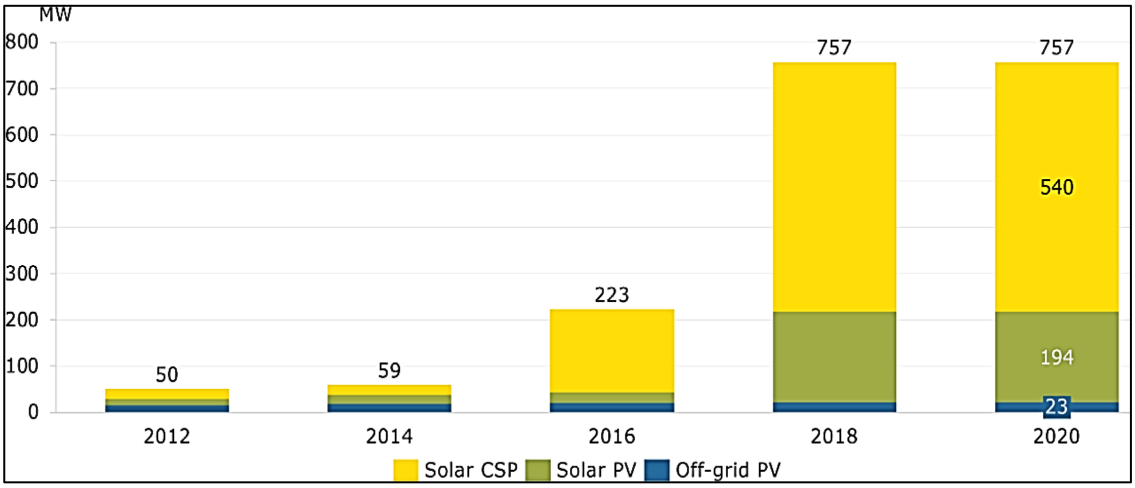


Figure 3: Solar installed capacity in Zambia. (Source: IRENA)

5.0 Methodology

In 2019 the Ministry of Energy launched the program scaling Up Renewable Energy Programs (SREP) and the Investment Plan (IP). This program, commissioned by the German Federal Ministry for Economic Cooperation and Development (BMZ), and led by MEME, had the goal to develop the energy efficiency andthe renewable energy production resource for electricity generation and agro-industrial activities and improve affordability of geothermal electricity generation by mitigating investment risk. The Zambian government was able to increase energy efficiency, train solar installers and raise awareness among the population on this opportunity, especially thanks to Kalahari GeoEnergy Ltd (KGE).

Moreover, this program was able to train and hire almost 300 employees that are now suitable for solar project installations and to upgrade almost 900 buildings in terms of energy efficiency and energy production via small-scale PV installations. In addition, thanks to the Ministry of Religious Affairs, guidelines presenting arguments for energy efficiency and the increased use of renewable energies from a religious perspective have been defined. More than 800 women preachers may use such guidelines to spreadthe knowledge they have acquired about energy efficiency to their communities.

6.0 Data Analysis

The solar industry is already in place in Zambia; many players are positioned at different stages of the value chain in the Zambian market, as shown in Figure 4. Indeed, several local companies assemble and mount solar collectors or produce complementary equipment to photovoltaic panels such as batteries and solar equipment. Operators produce batteries, electric cables and switches. In addition to this, local producers, are actors who act as intermediaries for the marketing of imported products. In most cases for installation, importers deal directly with service providers. Design, maintenance, servicing and after-sales services, on the other hand, are in most cases subcontracted to local companies. Despite the presence of a handful of local companies able to produce PV panels, Solar-Aid reported that in 2018, 100% of the solar panels used were imported. The large-scale development of small PV represents a growth opportunity for this already established market. The unexploited chance to develop a local PV panel producer market, however, could make Zambia dependent on imported PV panels, causing an increase in the upfront investment cost.

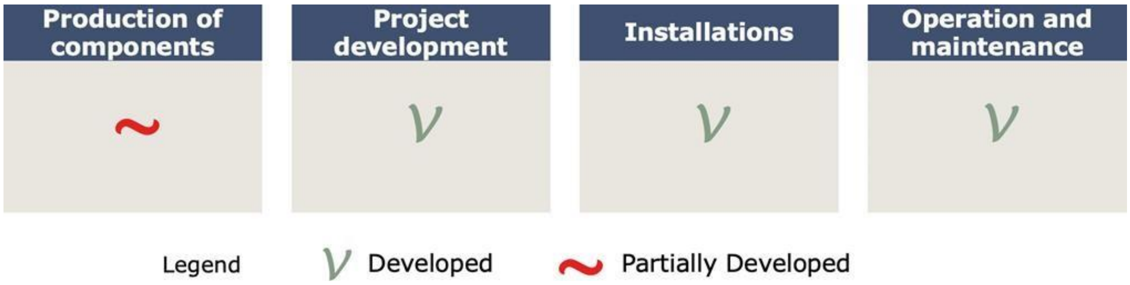


Figure 4: Zambian PV market status. (Source: AFRY Management Consulting)

From the end-user point of view, the comparison between electric tariffs and LCOE of rooftop-PV in Zambia has been thoroughly investigated by a study performed by GIZ in 2017. Taking into account the assumed LCOE evolution for consumption bands above 300 kWh per month, to which the tertiary sector currently belongs, and comparing them with current electricity tariffs for MSMEs connected to low voltage, LCOE is about 30% lower than electricity tariffs. A similar outcome emerges from the study performed in 2020 by the local stakeholder Cluster-Solaire too. They observed that since 2014, the cost of the photovoltaic kWh has become competitive compared to the cost of the electric kWh, encouraging consumers to replace their source of electricity supply, especially for consumers whose need is predominantly during the day such as tertiary and industry (e.g. schools, universities, administrations, hospitals, factories, etc.). In terms of small- scale PV development, it is thus expected that MSME and public sector could be the pioneers due to a more similar profile between power consumption and PV power generation. The electricity sector is still vertically integrated, but significant steps towards the liberalization have been done. In 2009 the GRZ developed laws containing provisions to liberalize the electricity market, renewable energy and energy efficiency. The sector is dominated by the state-owned operator: ZESCO which acts as a producer, distributor and retailer of the water and electric power.

ZESCO can give concessions to private operators with purchase guarantees and has the status of single buyer of electricity produced. The Ministry of Energy has a responsibility to set up the energetic strategy and the general framework while there's in charge of the supervision of the autonomous utilities of distribution. Since 1994 Zambia has entered in a long period of energy market reform, aiming to progressively introduce competition at the different levels of the sector value chain as well as reform the sector governance framework. The reform, still undergoing, aims to establish a new industrial organization and new market functioning in order to achieve: A more competitive market, and most recently; Ambitious targets for renewable energy in 2020 and 2030. In terms of energy transition, electricity to be produced, soldand exported by any private producer as long as they utilize renewable energy sources. Moreover, the establishment of the Rural Electricity Authority – REA; Act of Parliament in 2003 is a further step towards liberalization of the market, and aims to regulate both electricity and gas market, with clear responsibilitiesto the regulator:

- The definition of commercial and technical rules of the electricity market;
- The adoption of a grid code and grid access rules;
- Network and retail tariff methodologies.

The result of the Zambian energy reform is a hybrid market model where a regulated market, supplied by the single-buyer and distributors companies, coexists with a free retail market supplied by renewables producers and self-producers.

Currently, three main routes-to-market are present for RES in Zambia, for both large installation and distributed generation:

- A TSO Procurement scheme where the IPP sells directly to the single buyer ZESCO;
- A Retail Direct-Sales model;
- A Self-production model.

In case of small-scale PV for both public sector and MSMEs the most suitable route-to-market is represented by the self-production model for a renewable plant, whose regulation is detailed Figure 5.

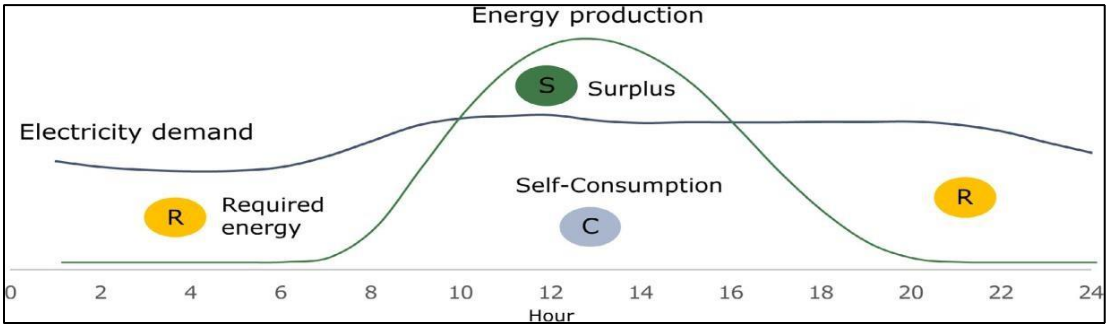


Figure 5: Sketch of the self-consumption energy balance. (Source: AFRY Management Consulting)

Net-metering scheme:

The net-metering scheme allows to completely recover the energy surplus. With a net-metering scheme the electricity bill paid by the prosumer is made by only the net amount of energy considered between energy surplus and energy required. In case of production surplus greater than the required energy surplus, the energy surplus is virtually stored for months. A sketch explaining the net metering scheme is shown in Figure 6.

A good example of the effectiveness of small-scale PV is represented by Mexico where the net-metering scheme is in place for plants smaller than 500 kW. In Mexico net-metering is set on a monthly basis, while the excess of generation, with respect to surplus of energy required is stored up to 12 months in the virtual energy bank. After 12 months, is paid to the customer. Thanks to this mechanism Mexican distributed PV recently took-off reaching 1.8 GW of installed distributed PV in 2021, with a CAGR of 31% in the last five years, as shown in Figure 7.

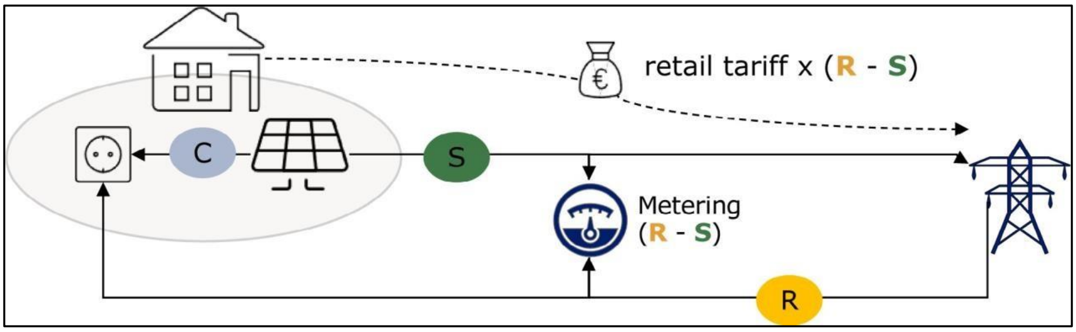


Figure 6: Sketch of the net-metering scheme. (Source: AFRY Management Consulting)

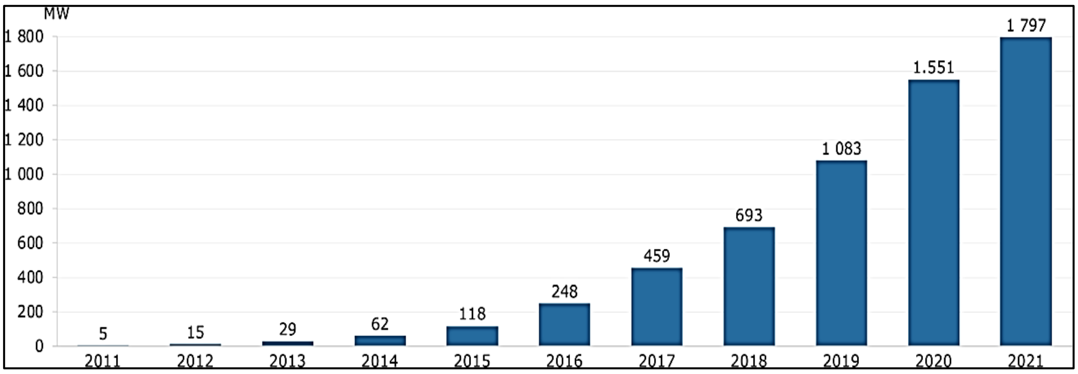


Figure 7: Mexican small-scale PV installation. (Source: AFRY Management Consulting)

While consumers have widely appreciated net-metering and Feed-In-Tariff schemes, their compensation mechanisms are not reflective of the cost of electricity at the injection instant and can distort the system if the quantity injected is significant. For example, the injection of excess renewable electricity into the grid is more valuable for the system during peak load hours than during off-peak hours. Similarly, oversupply during hours of low demand could lead to curtailment of the power plant or reduce electricity prices. For these reasons, once the small- scale PV market is already established, several countries interrupted the above- mentioned schemes and adopted the net-billing scheme, illustrated in figure 20. Similarly to feed-in- tariff, two counters are required in order to differentiate the energy required from the surplus. The energy required is paid at retail price while the surplus is sold at wholesale price. Net billing is a market-based compensation mechanism, as prosumer compensation is based on the actual market value of the energy consumed or injected into the grid, Figure 8.

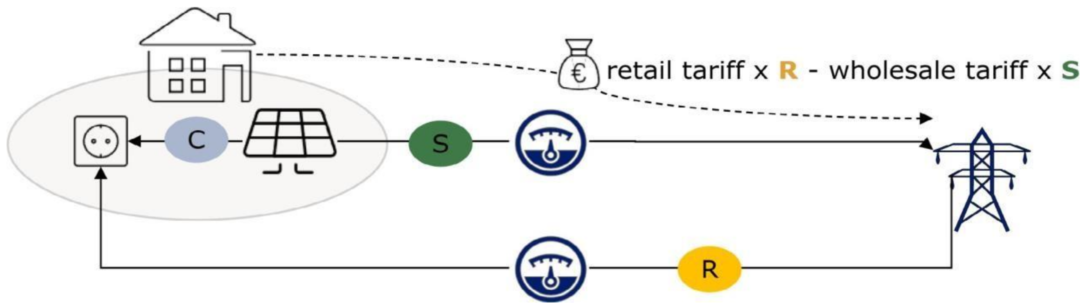


Figure 8: Sketch of the net-billing scheme. (Source: AFRY Management Consulting)

The whole amount of energy surplus required is bought at retail price by the consumer, while the surplus is sold directly to the utility at wholesale price. From an algebraically point-of-view, a net-metering scheme is equivalent to sell the surplus at a retail price, including network, transmission and distribution charges. With net-billing on the other hand, surplus is sold at wholesale price excluding network, transmission and distribution charges. For this reason net-billing is less attractive for the prosumers. Different version of the net- billing scheme is implemented in several countries, adopted especially after the successful deployment of the small-scale PV market. Net-billing represents in fact a cost-reflective mechanism that assure a sustainable and more stable mechanism which avoids oversupply and distorted price-signal.

7.0 Conclusion

The analysis of international key enablers has underlined that the metering scheme represents one of the main features of the self-consumption regulation. Once the RES plants can connect to Low Voltage, several aspects should be considered as well in order to pick the most suitable scheme, among which the increase of system costs. Moreover, in order to facilitate the correct evolution of the market, both project and market governance should be clearly defined allowing flexibility in the project management on one hand, and a transparent and independent regulation of the market on the other hand. Finally, in order to unleash the small- scale PV potential, other issues should be addressed, such as the introduction of incentive schemes to reduce the upfront costs of the investment, enabling the development of the market during the first stages. In this context, the impact of the absence of a well-established PV panel producer market should be monitored. To let small-scale PV become a key player in reaching the ambitious Zambian RES targets, the awareness of this opportunity should be increased among the population.

All the above-mentioned barriers can be removed guaranteeing an open, attractive and ready small-scale PV market.

The first action required to unleash the small-scale PV Zambian potential is the availability of connecting RES plants to the Low Voltage grid. In case the delay in Low Voltage connection is due to grid instability, an intermediate solution may be the implementation of zonal connection, allowing small-scale PV to connect the Low Voltage grid only in areas where the grid can sustain it.

A key enabler for small-scale PV is represented by the metering scheme. Net-metering may represent the first option to promote small-scale PV deployment, followed by the most advanced virtual net-metering scheme. However, the cost for the system and the technical feasibility of the scheme may represent an issue. Similarly, a feed-in-tariff, characterized by a simpler implementation, can only be considered as a transitional measure to launch the market during the initial stages. Finally, net-billing may represent both a long-term solution, and a short-term key enabler. Thanks to the high solar potential, small-scale PV may bealready attractive in some region even without other form of incentives. Moreover, even with net-billing scheme, virtual schemes that allow remote self-consumption or shared generation may be a key factor, especially in a country where MSMEs and public building represent a significant share of the small-scale PV potential.

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Absolar - associação brasileira de energia solar fotovoltaica https://www.absolar.org.br/en/

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Impact of the rapidly evolving technologies on local refined products: A case of Indeni Refinery, Zambia.

Misengo Abel Chisanga[1]

Abstract

INDENI, Petroleum Refinery Limited (IPRL) was designed with an annual process capacity of 1.1million metric tons of feedstock. The design configuration was to process commingled feedstock composed of Crude oil (77.5%), gasoil (22%) and Naphtha (7.5%) (INDENI. 2020). These proportions were dictated by the Zambian market of the 1960's. Products such as; Petrol, Diesel, heavy fuel Oil (HFO), Kerosene, Aviation fuel (jet-A1), Bitumen and Liquefied petroleum gas (LPG). Evolving of technology and rise in consumer demand for petrol and diesel since early 90's to 2021, has impacted change to the feedstock composition moving from commingled crude above 77.5% to spiked crude of 43% and less, impacting negatively on cost, yield yet meeting current market demand.

The aim of study was to assess impact technology and market change has on local distillates compared to imported ones, provide mitigating factors to reduce the impact. A mixed study was used, a case study strategy with structured questions and interviews. Population of this study was two levels of employees of IPRL management. Murban feedstock brings out quality refined products that meets current market requirements. The removal of domestic tax on feedstock/ crude, would reduce the cost of products at pump. Variations in Procurement of crude makes IPRL uncompetitive. Bad feedstock/crude negatively affects process throughput and plant efficiency.

The study concluded that IPRL can only retain its quality and cost-effective products demanded by the current market through recapitalization. Recapitalization will lead to plant modernization, which will take care of demands of evolving technologies in the petroleum market. It will bring about: installation of units such as diesel hydrotreater (sulphur removal) for low sulphur diesel production (LSD), a technological up grade. Expansion of the plant to install a residue (mild) hydrocracker, to convert excess heavy fuels (HFO) to Gasoil.

Keywords: Feedstock, market, cost, evolving, recapitalization.

1. Introduction

Feedstock/Crude oil composition has a complementary role on the refinery's process plant design. The rapidly evolving technology and consumer behavior globally, has impacted new market demand on petroleum products in the recent past years. International and local Regulatory

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body requirements such as; African Refiners & Distributors Association (ARDA), Energy regulation board (ERB) demand for compliance on quality products. This consequently impact negatively on old refining models like that of IPRL and positively on models for distributors, and oil marketing companies (OMC) like never before.

Table 1.1 shows feedstock, Aghajari for old model to process Crude oil (77.5%), gasoil (22%) and Naphtha (7.5%); these proportions were dictated much by Zambia Industrial Mining Cooperation ZIMCO group of companies and infrastructure development projects. Such created market demand at that time (past effects of industry structure). Table 1.2 and 1.3 shows new model with feedstocks, Murban and Iranian Heavy both with compositions of spiked crude at 43%, gasoil 44% and naphtha 13%, compared to the figures of commingled in the old model. The values shown on the tables are for the purpose of illustration only and does not reflect actual cargo values. Feedstock, Murban on table1.2 has been meeting much of the market requirement in the most recent past with favourable yield though at an elevated cost than that for Aghajari. The composition of feedstock has evolved over time. The proven hypothesis states "H1 industry structure has a time-specific effect on firms, and these effects are not exclusively negative" (Claver *et al.*, 2002).

The above bottlenecks to IPRL opened opportunity to distributors, (OMC'S) to take up the market share gaps, more new market entrants. It included products never produced such as (LSD), biofuel and ethanol blended products. (ERB, 2016). Demand for white products has kept rising such that in 2020 "the waiver to import 1.9 billion liters of diesel and a total of 934 million liters of petrol was given to 81 (OMC's)", said Energy Minister Nkhuwa in parliament in 2021. (Parliament, 2021) (new market entrants).

Table1.1 Feedstock Composition by Design of 1973. (Past effect of industry structure) Source: Copyright © 2012 Published by Elsevier Ltd.

COMPONENT	FEEDSTOCK % Composition	MT	AGHAJARI USD/MT	TOTAL COST USD/MT
Crude	77	84.70	63.98	5,419.10
Gasoil	22	24.20	556.00	13,455.20
Naphtha	7.5	8.25	576.21	4,753.73

Cargo size of 110,000 metric tons 'total cost =$ 23,628.03 Source: author 2020.

Table1.2 Feedstock composition and cost driven by current trends (present effect of industry structure) Source: Copyright © 2012 Published by Elsevier Ltd.

COMPONENT	FEEDSTOCK % Composition	MT	MURBAN USD/MT	TOTAL COST USD/MT
Crude	43	47.30	63.98	3,026,254.00
Gasoil	44	48.40	556.00	26,910,400.00
Naphtha	13	14.30	576.21	8,239,803.00

Cargo size of 110,000 metric tons' total cost = $ 44,237,230.00 Source: author 2020.

Table1.3 Feedstock composition and cost driven by current trends (present effect of industry structure). Source: Copyright © 2012 Published by Elsevier Ltd.

COMPONENT	FEEDSTOCK % Composition	MT	IRANIAN HEAVY USD/MT	TOTAL COST USD/MT
Crude	43	47,300	61.21	2,895,233.00
Gasoil	44	48,400	556.00	26,910,400.00
Naphtha	13	14,300	576.21	8,239,803.00

Cargo size of 110,000 metric tons' total cost = $38,045,436.0 Source: author 2020.

2. Literature Review

INDENI has been having challenges of high-cost supplies of light, easy-to-refine crude oils when consumption of gasoline and other light products was rising. In order to keep pace with demand INDENI intended to produce more gasoline, gasoil and less high-sulphur and residual oils relative to its national market demand "Zambia national broadcasting corporation (ZNBC) website, www.znbc.co.zm" In order to achieve that cost effectively, crude with the right composition would suffice. today Murban feedstock responds well to the current market requirement as well as plant design output though at a higher cost since its light feedstock. (Indeni planning and control department, 2020)**.**

2.1 Petroleum Refining Industry around the World

The refining industry is strategic for the economy, as it is an opportunity to add value to oil. Its distillates are the foundation to supply countless activities in which human beings engage, including, most notably, transportation, power generation, and activities that require heat.

As of the end of 2014, the United States had 142 refineries, which represented a drop of 53% as compared to 1982, of which 139 were operating and three were not. The number of refineries shrunk by virtue of technological obsolescence and falling profitability, the capacity of coking plants rose to triple over 1980, as well as that of desulphurization and diesel production. No big refinery has been built, but new smaller capacity plants have been added (Chesnes, 2015).

In Canada, the refining industry is an important boon to the economy, having contributed 4% of the Gross Domestic Product (GDP) in 2013, (Canadian Fuels Association, 2014). Since 1970, the country has undergone a restructuring process, which has led to the closure of more than 20 refineries, although others were expanded or upgraded, but no new refinery has been built since 1984. Some plants are more than three decades old and produce a high percentage of fuel oil (20% of total processed products), which means they have low efficiency levels.

Refining in Mexico is facing a complex situation, derived from its reliance on public funding and a set of factors tied to its development throughout the entire value chain. The most relevant are: The types of crude petroleum supplied by Pemex Exploración and Producción (PEP) do not meet the technical considerations required for the configuration of the refineries, which were designed to process light crude, which leads to difficulties when it comes to feeding them the right mix of crude. In operating the refineries, there are problems that restrict their profitability, such as: low level of usage of installed capacity, due to unscheduled shutdowns and technical problems, there was also a failure to update the technologies used in the equipment and processes, which is a constraint on the capacity to process qualities of crude with high sulphur and metal content, which is what is available in the country; refineries have also seen low yields on products of high value in the market and surplus production of fuel oil, which cannot be sold in the national market due to quality problems and the trend to use natural gas in power generation rather than the fuel. At the management level, there are obstacles in implemented strategies and programs chosen in a way that would bring about operational improvement, (Romo,2011).

Lagoven refinery in Venezuela wanted flexibility in coping with fluctuations in the residual fuels market by refining additional heavy crudes and increasing gasoline production capacity. Venezuela was running low on supplies of light, easy-to-refine crude oils when consumption of gasoline and other light products was rising. In order to keep pace with demand, Lagoven intended to produce more gasoline and less high-sulphur and residual oils. Recapitalization by installation of new units at Amuay included a 52,000 barrel-per-day Exxon-patented FLEXICOKER (the largest of three in existence at the time), a 74,000 barrel-per-day FLEXICRACKER (Latin America's largest), a 14,200 barrel-per-day alkylation unit, a 7,500 barrel-per-day isomerizer, and six Merox units needed to desulphurize naphthas and gases from the light-ends recovery section. These components were crucial to process a greater proportion of heavy oils, to reduce the volume of high sulphur residual fuel oil production, and to substantially increase gasoline production (Romo, 2016).

2.2 Petroleum Refining Industry in Africa

Kenya currently spends approximately 6% of its GDP on fuel imports with the total amount spend in 2014 being Ksh 334.37 billion (Republic of Kenya 2015). Being net importer, there strain to the foreign reserves creating an inflationary pressure on prices of goods and services in the market. Refining the crude could therefore reduce this strain and have a positive impact to the economy. Despite that Kenya has been forced to increase importation of refined fuel as a result of increased domestic consumption while at the same time, the refinery collapse meant that the country had to rely fully on imports. This was due to failure by the refinery to produce fuel of its capacity of about 80,000 barrels a day. Apart from production below its domestic requirements, it could not even produce unleaded fuel for the market, except for heavy metal leaded petrol which has since been phased out in the region for health safety and environmental consideration. The refinery is currently being used as a storage facility. The refinery has remained inactive since 2013, after plans to pump KSh121 billion, into the plant to upscale its operations were abandoned. An upgrade of the refinery was expected to cost $1.2 billion, an amount that was seen as too high to undertake, (LAPSSET Feasibility report 2010).

Chevron South Africa believes that the future of its refinery in Table View is under threat because of a license granted to Burgan Cape Terminals by the National Energy Regulator (Nersa). Burgan Cape Terminal was awarded a license to build a fuel storage facility in the Port of Cape Town’s Eastern Mole. Chevron says that it does not oppose incremental storage facilities, but opposes those which undermine local refining and go against South Africa’s government policy. Chevron feels that Burgan’s fuel storage facility capacity is a threat to 13,500 jobs at Chevron and to other refining jobs nationally.

2.3 Petroleum Refining Industry in Zambia

IPRL annual throughput has varied from as high as 870,000MT in 1976 at the height of economic activities in the country due to increased mining activities, to as low as 16,848MT in 2000 during the refinery closure arising from the fire in 1999 (ERB, 2020). While 2019 and 2020 recorded 329,366 MT and 629,823MT in 330days and 174 days respectively (ERB, 2020). The 174 days processing was due to lack of feedstock supply. This was attributed to lack of funds by the government. It was envisaged that continuous closure up to the time of this study was to help the government dismantle debt. The debt was reported to be $524 million by October 2021 according to a ministerial statement issued by energy minister Chibwe Kapala in parliament. (Parliament, 2021). At the time of closure, on 15 December 2020, the government owed the supplier of feedstock and finished products a staggering $800 million. Minister finance then Bwalya ng'andu issued a statutory instrument removing 16 % value added taxes on imported petrol and diesel effective January 1,2021 (Zambia Daily mail, 2021). In 2021 it was reported that $650m was required to recapitalize INDENI. It risks becoming obsolete in the next few years, unless remedial action is taken to cut down on the production losses and address the product quality issue (Energy Sector Report, 2007).

2.4 Capital-intensity and Complexity

In general, the refining industry is capital-intensive, and size and technological complexity, as well as wage costs and environmental regulations, are all relevant to its viability. The industry is composed of a set of large continuous production plants, where crude oil is separated into different fractions; for example, oil is physically and chemically processed to produce finished products, which range from very light—like liquefied petroleum gas—to the heaviest—like asphalt or petroleum coke. The refining industry also encompasses the transportation and storage of processed products, as well as delivery to consumers through distribution points.

a) Changes in Business Environment**:** In response to market conditions, the refining industry has gone through various stages, such as surplus production capacity at the end of the 1980s and the beginning of the 1990s, or plummeting profit margins in the early years of the past decade.

b) Flexibility and Technology Upgrade**:** In general, the international refining industry continues to reinvent itself, whether by expanding capacity, renovating and/or upgrading it, in order to expand its useful life and competitiveness, with processes aimed at higher value-added products, like gasoline and diesel, and limiting the production of heavy byproducts; or the use of flexible technology to process crude oil in light of problems with disposal at refineries and price volatility.

c) Strategy for Market and Competitiveness**:** In particular, strategies have been implemented to improve the positioning of refining companies in the market. Along these lines, the international oil companies are standout examples. In addition to earning significant profits in the refining business, they have robust processing, storage, and transportation systems for petroleum-based products and even, in some cases, have upstream integration in their activities, or may focus only on refining.

d) Business, Competition and Profitability: The refining business operates in a free market world, even in those cases where the government intervenes. In the latter cases, some units barely manage to break even or may lose money.

3. Concept of Strategy

The direction and scope of an organization over the long term, which achieves advantage in a changing environment through its configuration of resources and competences with the aim of fulfilling stakeholder expectations". (Johnson Scholes & Whittington, 2008). Strategies are therefore the means by which companies aim to achieve their long-term objectives. The author integrated the model to find solutions faced by the firm in the case study of INDENI. Porter's Five Forces is a model that identifies and analyzes five competitive forces that shape every industry, and helps determine an industry's weaknesses and strengths. Frequently used to identify an industry's structure to determine corporate strategy, Porter's model can be applied to any segment of the economy to search for profitability and attractiveness. (Porters,1990)

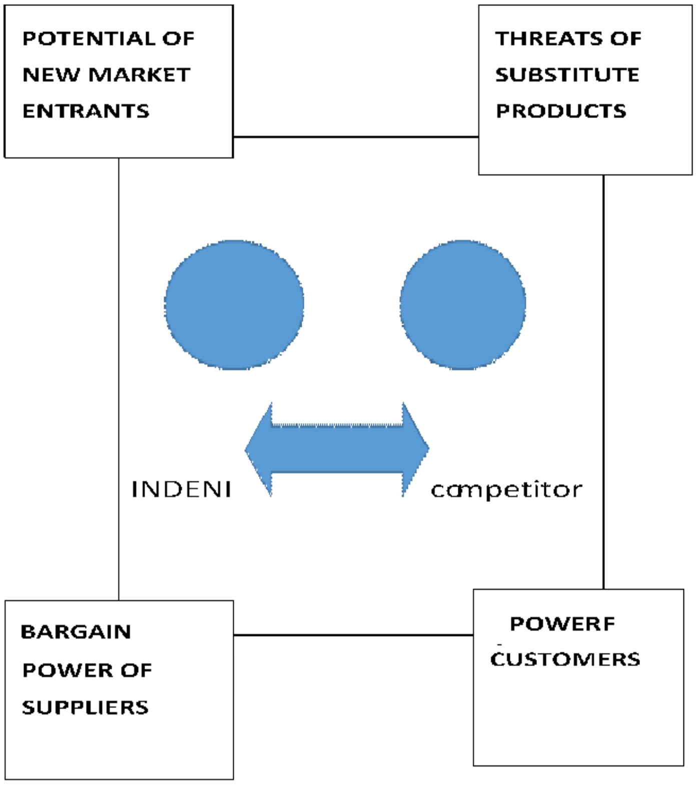

Figure 2.1 M. E Porter's Theoretical Model. Source, author 2021.

Porter identified five undeniable forces that play a part in shaping every market and industry in the world. The forces are frequently used to measure competition intensity, attractiveness and profitability of an industry or market. These forces are:

a) Competition in the Industry: The importance of this force is the number of competitors and their ability to threaten a company. The larger the number of competitors, along with the number of equivalent products and services they offer, the lesser the power of a company. Suppliers and buyers seek out a company's competition if they are unable to receive a suitable deal. When competitive rivalry is low, a company has greater power to do what it wants to do to achieve higher sales and profits.

b) Potential of New Entrants into an Industry: A company's power is also affected by the force of new entrants into its market. The less time and money it cost for a competitor to enter a company's market and be an effective competitor, the more a company's position may be significantly weakened. An industry with strong barriers to entry is an attractive feature for companies that would prefer to operate in a space with fewer competitors.

c) Power of Suppliers: This force addresses how easily suppliers can drive up the price of goods and services. It is affected by the number of suppliers of key aspects of a good or service, how unique these aspects are, and how much it would cost a company to switch from one supplier to another. The fewer the number of suppliers, and the more a company depends upon a supplier, the more power a supplier holds.

d) Power of Customers: This specifically deals with the ability customers have to drive prices down. It is affected by how many buyers or customers a company has, how significant each customer is, and how much it would cost a customer to switch from one company to another. The smaller and more powerful a client base the more power it holds.

e) Threat of Substitutes**:** Competitor substitutes that can be used in place of a company's products or services pose a threat. For example, if customers rely on a company to provide a tool or service that can be substituted with another tool or service or by performing the task manually, and if this substitution is fairly easy and of low cost, a company's power can be weakened.

There are three types of variables namely, independent, mediating and dependent. Porters five forces are independent legal and regulatory frameworks are mediating while the firm, INDENI is a dependent variable. The legal and regulatory framework are important in this study. The two principal Acts relevant to this study are, The Competition and Consumer Protection Act, No. 24 of 2010 which re-peals and replaces the Competition and Fair-Trading Act, No. 18 of 1994; and The Energy Regulation (Amendment) Act, No. 23 of 2003 which amends The Energy Regulation Act, No. 16 of 1995. These two pieces of legislation establish the Competition and Consumer Protection Commission (CCPC) and the Energy Regulation Board (ERB).

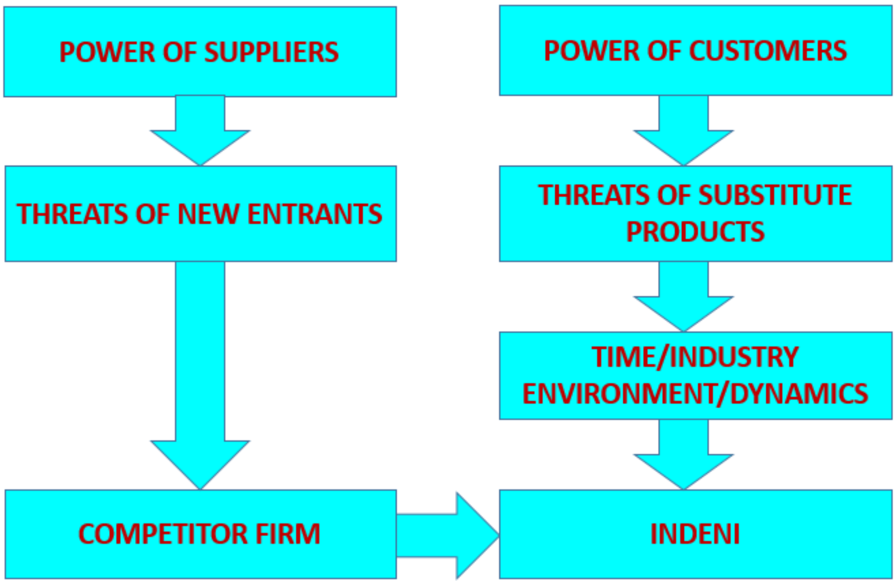

Figure 2.2 Developed Theoretical Framework

4. Study Population

Mixed research methods were employed, Data analysis was both quantitative and qualitative using excel through narrative and content analysis (Donald R. Cooper and Pamela S. Schindler,) The data collection tools included interviews with structured questionnaires, to a target population of 100 top management and middle management professionals in various departments were considered. These are involved in both strategic management and implementation of works at INDENI.

Table: 3.1The frame includes the following units shown.

S/N	DEPARTMENT	SAMPLE SIZE
1	Top Management	20
2	Finance & Audit	11
3	Operations	23
4	Maintenance & Eng.	18
6	Process & Lab	12
7	Supply & Sheq.	16
	TOTAL	100

Source: Author (2021)

5. Discussion of Findings

To Avoid procurement of crude with high organic chlorides. So as to reduce operation costs. The removal of domestic tax on crude oil at least from 25% to 5% can help reduce the cost of distillates at reduced pump. Murban feedstock runs well in the process plant with reduced mass balance. Additionally, technical configurations are easily attained. Corporate strategies on performance looked at geographical expansion, merger and acquisition in order to realize funding for recapitalization through an equity partner. The following undertakings were to be considered: Recapitalize IPRL in order to modernize it, so as to achieve the following:

a) Set up of Hydrotreater for low sulphur diesel production (LSD), an upgrade in technology.
b) Diesel Hydrotreater (desulphurizer) will improve the quality of IPRL diesel which has sulphur content of between 0.35 per cent to 0.5 per cent while most countries in the region use diesel with sulphur content of 0.02 per cent and below.
c) Expansion of the plant to bring in a residue(mild) hydrocracker.
d) Mining industry then was highly dependent on heavy fuel and ordinary diesel hence INDENI had ready market for such products.
e) Overall cost leadership will help INDENI sell product at low cost when capacity increases.
f) While Customer focus will help INDENI supply low sulphur diesel (LSD) after installation of diesel Hydrotreater, to meet customized services.

The sixth factor to be considered at Porters five forces is the ability of the firm to perform based on the past, present and future business environments. Such factors have a bearing on the performance of a firm either positive or negative. It is imperative that these dynamics can allow mixed models alike to be in use. Demand for HFO and LPG rose in 2019 to 2020 due to draught as a factor of Climate change, as a result plants that support climate change and green economy such as: INDENI, Ndola Energy, AFROX and Industrial Mine Gases (IMGCL) and others performed better while meeting customer needs in difficult time.

6. Conclusion and Recommendations

The study conclusions were to recapitalize Indeni Petroleum Refinery Company Limited as soon as possible for both rehabilitation and modernization. It should be enhanced to enable it meet legal requirements by regional agreement protocols (SADC), and ARDA specification for unleaded petrol and low sulphur diesel (LSD). To reduce process losses to acceptable limits. The expansion and upgrade of IPRL will increase throughput to command greater economies of scale, hence become attractive and command high investment opportunities. Increase of quality distillates on the market can be realized through the installation of hydrocracker unity which will give high yields of light products; though it is considered to be a huge capital investment. The alternative, diesel isomerizer is lower in cost but can be of help. To reduce the predictive of much heavy – fuel which has less market again a diesel isomerizer shall be of help to convert heavy distillate to lighter ones for diesel production. Removal of domestic import duty on Murban feedstock so as to reduce tax from 25% to 5%. This will also take care of the import parity-model at pump.

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Investigating incentive drivers for promoting energy efficient buildings: A case of Zambia

Chipozya Kosta Tembo[1], Franco Muleya[2] and Mark Mafuleka[3]

Abstract

Zambia is heavily dependent on hydropower which has been affected by poor rainfall patterns amidst rising demand in various sector(s) of the economy. Continued construction of relatively high energy consuming buildings has contributed to the energy deficit. There is need to incentivize construction of energy efficient buildings at various levels namely administrative, technical and financial to increase the demand of such buildings. A quantitative survey of contractors, consultants, local authorities and energy supplier was undertaken resulting in a distribution of a total of 93 self-administered questionnaires distributed randomly to consultants and contractors, and purposively to the local authorities and energy supplier. The findings were used to identify the needed incentives from the 65% response. The findings indicate that the most required incentives to drive demand for energy efficient buildings are actually non-financial such as capacity building & awareness programs, priority permitting and subsidies to professionals and building owners/developers requiring mainly technical support. There is need to have more incentives bordering on technical and administrative aspects to drive the demand for energy efficient buildings upward.

Keywords: **buildings, energy efficiency, demand, incentives, Zambia**.

1. Introduction

The global population is expected to grow to 9 billion by 2040. This growth is expected to push the energy demand in emerging markets and developing economies according to Baldwin *et al.*, (2015). Zambia is a developing economy with a population of 18,843,890 based on World meter elaboration captured in May 2021. Residential and commercial buildings consume approximately 60% of the total world's electricity (Energy sector report, 2019). This case is not so different for Zambia. Baldwin *et al.*, (2015) indicated that heating, ventilation, and air conditioning account for 35% of total building energy; lighting (11%); major appliances (water heating, refrigerators, and freezers, dryers) account for 18% with the remaining 36% in miscellaneous areas including electronics. These figures could be reduced by 20% through the use of cost-effective technologies in building construction mainly arising from energy efficient materials, products and designs (ERB, Energy sector report, 2019). Zambia predominately depends on electricity for energy supply**.** Oke *et al*, (2019) states that Zambia's electricity generation mix is predominantly hydro, accounting for 80.45% of installed capacity as of 2019 with the balance being coal (10.06%); HFO (3.69%); diesel (2.80%); and solar (2.99%). The current energy deficit stands at 810 megawatts. This deficit has resulted in the need to increase on the number of energy efficient buildings. This

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can partly be achieved by designing new buildings that are energy efficient and converting existing or retrofitting into energy efficient buildings.

The market for sustainable materials and products/technologies in Zambia is low, according to Cooper, (2020), this has been attributed to the high culture of resistance to change, fear of higher investment cost, non-availability of green or energy efficiency certification, lack of government policies or supports, lack of financial incentives and ignorance about life cycle costing. The aforementioned therefore intimated that there is an urgent need to investigate the incentive-based strategies that may encourage energy-efficient residential buildings in Zambia. The study of Energy Efficiency (EE) is important because it gives an opportunity to save on energy costs, reduce greenhouse gases and reduce the reliance on non-renewable energy sources (Hanania *et al* 2015). Additionally, an energy efficient building will lower maintenance costs, increases comfort for occupants and increases the property value (UNIDO, 2009). Unfortunately, much of Africa including Zambia lacks policies and regulatory framework to drive demand for energy efficient buildings (UNECE, 2020); therefore motivating this study to consider possible incentives that can drive change in this sector.

1.1 Incentives that can promote energy efficiency

The broad categorisation of incentives to promote energy efficiency are financial and non-financial, according to UNECE, (2020). The various categories for incentives are financial, fiscal, administrative (structural) and technical. The primary drivers working in most countries such as Malaysia and Japan are structural, technical and financial employed at local government level (Powell, *et al*, 2015). Financial incentives are direct incentives given to developers willing to participate in energy efficient construction, (Choi, 2009). The financial incentives include subsidies, grants, loans and mortgages (Hashim et al, 2016; Choi, 2009; Abdin and Azizi, 2016). These can be provided to a wide range of factors or developers for various products and services. Practically, homeowners' or developers can take advantage of loans and mortgages to finance a variety of technologies in a new or existing building. Subsidizing of energy efficient equipment has been done in Japan and the USA while preferential loans to finance EE developments have been applied in Japan and Germany (Hashim et al, 2016; Choi, 2009; Abdin and Azizi, 2016).

Fiscal incentives include partial or full income tax refunds, tax credit and tax deductions according to Hashim *et al*., (2016), Choi, (2009); and Abdin and Azizi, (2016). These incentives are normally combined into the financial incentives (Abdin and Azizi, 2016). The fiscal incentives are normally classified as: profit based, capital based, labour based, sales based, import or export based depending on where and how they are applied (Abdin and Azizi, 2016; Perkins and McDonagh, 2012). Tax refunds, income tax or property tax rebates are used for housing requirements such as solar water heating, rain water harvesting and others. Utility companies can offer rebates to projects to meet energy efficiency. Tax reductions can be used for double glazed windows, sunshades and wall insulation material. South Africa has used tax refunds; USA has utilized tax credits and France tax deductions as fiscal incentives to promote EE in buildings. It has been argued that fiscal is more predictable, wider reaching, low cost administratively and more accessible hence viewed as more effective (Hashim *et al*.,2016) yet governments tend to favor non-financial solutions to EE.

Administrative or structural incentives can also be used to promote EE in buildings. This could be done through priority process such as permitting, and relaxing of some standards like heights to enable installation of energy efficient installations (Hashim et al, 2016). This is practiced in the USA to streamline the permitting process for building plans and site permits. The focus in this type of incentive is to review and approve plans, a measure mostly applied by local authorities. Technical incentives include capacity building, awareness programs, energy award, and design assistance incentives (Choi, 2009). The capacity building targets professionals and/or contractors, while energy efficiency award is strictly for an EE design awarded to professionals such as architects for their competency. Free or reduced technical assistance for training in EE designs is also helpful. Energy efficient design awards are being given in the USA, Sri-Lanka and Germany for exceptionally well designed and sustainable buildings by professional institutes (Choi, 2009; Hashim et al, 2016; Yang, et al., 2018).

1.2 Drivers in promoting energy efficiency

Incentives can be driven by the private sector or public sector mainly government. Governments tend to favour the provision of non-financial incentives because of the absence of the involvement of direct costs. Subsequently, the most effective incentives from prior studies seem to be non-financial incentives such as expedited permitting or technical assistance even though cost incentives need fiscal and financial incentives in place (Abdin and Azizi, 2016). Arguments are around risk reduction and cost reduction due to reduction in risks by the developers (Perkins and McDonagh, 2012), notwithstanding those economic incentives that are only effective when an economy is performing well and positive. This is because results are not yet known for when there is an economic downturn, (Qian 2012). It has however been pointed out that to counter the financial incentive (taxes, subsidies) that government offer, it should operate with a wider local and national framework and context (Likhacheva et al., 2019). Barriers hindering EEs have been observed such as low technical capacity, lack of knowledge and weak enforcement regimes (Yang, et al., 2018; De Blaauw and McGregor, 2008). This can be curtailed by supportive governmental activities and clear guidelines through financial, fiscal incentives and policies (UNIDO, 2009). This in turn positions government incentives as motivational and grounds for influencing commitment to EE buildings (Simpeh and Smallwood, 2015). Further, governments can influence the private sector through the introduction of building codes that incorporate energy efficiency. Further, governments can help provide technical capacity to design, appraise and finance EE buildings (Yang, et al., 2018). From the review, it appears that governments play a pivotal role in supporting and incentivizing EE buildings as it is the driver of most of the changes that need to be made to promote EE in buildings (Simpeh and Smallwood, 2015). Nevertheless, identification of the right incentives is essential to make a significant and positive impact on EE.

1.3 Various ways buildings can be energy efficient

An energy-efficient building conserves energy, reduces unnecessary; energy consumption, greenhouse gas emissions and demand for non-renewable resources (*Green Building 101).* Technological improvements in buildings design and appliances offer new opportunities for energy savings (UNIDO, 2009); however, according to Cooper (2020), the biggest challenge is resistance to change and the cost of implementing energy savings. The are many ways to make a building energy efficient; better insulation, more efficient windows, doors, skylights, air conditioning, furnaces and use of the right appliances with thermostats (Crongie, 2014 and Heimonen et al., 2019). A holistic approach to designing and constructing an energy efficient building is to consider (Crongie, 2014) firstly, bioclimatic architecture, secondly, high performing building envelope and lastly, high performance-controlled ventilation. These could be considered in the early stages of design. These measures work well with a reasonable energy consumption rate.

The current consumption per household in Zambia averages 3,674kWh/year (Heimonen, et al, 2019). Consumption rates vary from province to province with Lusaka and Copperbelt Province being the highest consuming provinces of the ten provinces. Most households have lighting, radios, television sets, cookers, pressing iron, electric kettles and refrigerators as main appliances consuming energy while offices and commercial buildings have refrigerators and lighting, air conditioning, and electric kettles as items consuming energy. Majority of the appliances used and designs for the buildings are not EE, therefore, the application of EE interventions in energy consumption can be reduced by having EE building and appliances hence the need to research on how best the demand for EE buildings can be up-scaled.

2. Methods

The study was undertaken using a positivist philosophy utilizing quantitative design. This therefore entailed that the study's approach was deductive using a survey strategy. The data collected was cross-sectional in nature with the mono-method of data collection using questionnaires. Data was collected from consultants (quantity surveyors, architects and civil engineers), regulators/overseers of housing development (Local Authorities, Ministry of Housing and Infrastructure development and Ministry of works and supply) and regulators of energy in Zambia (Energy Regulation Board). Additionally, contractors in the building category of grades three and four were also approached as these are the vast majority of those involved in the construction of residential buildings. Various selection and sampling techniques were used depending on the number of people in a given population. Purposive sampling was used for consultants to only get those who had engaged in residential housing development while stratified sampling was used for contractors as they had been divided into groups of three and four of those likely to engage in residential housing projects. A census was done for regulators and overseers from the various identified government institutions and ministries.

To ensure reliability and validity of the data some measures were taken. The same questionnaire was distributed to all respondents to ensure consistency of measure. A Cronbach alpha test was also done to measure the reliability of the instrument whose value should be 0.7 and above (Taber, 2018). To ensure validity of the instrument a pilot study was done to ensure that the questionnaire was measuring what it was designed for. To analyse the data, descriptive statistics were computed namely means, and standard deviations. These were used to rank the incentives so as to find out which was the most efficient in terms of the respondents' perception. Inferential statistics were not conducted as most the sampling was not randomized.

3. Results

This section presents the results for the study from the perceptions of the respondents. The Cronbach's alpha for the instrument was 0.734**.** This value surpassed the reliability's desirable value of 0.7 (Taber, 2018). This highlights an acceptable internal consistency of the measures and therefore suggests that the construct is statistically reliable. Data collection was a challenge due to the pandemic (Corona virus) which made it difficult to access respondents; hence the response rate was found to be 65%. From the respondents, the sample comprised of architects (12%), quantity surveyors (32%), Civil engineers (8%), and Government institutions, council's regulators and enforcers (17%) of which 75% were male and only 25% were female. In terms of qualifications the majority (81%) held a Bachelor's degree or equivalent, 15% were Masters' holders and 4% held diploma's. Consultants were mainly Bachelors' and Masters' degree holders while diploma holders were found among the contractors. These demographics indicated that the respondents were knowledgeable in the area thereby giving credibility to their responses.

Table 1: Perception of respondents on energy efficiency incentives in buildings

Description	N	Mean	Std. Deviation	Rank
Incentives or (motivations) to homeowners & developers can improve residential energy efficiency.	60	3.73	1.205	7
Governments can speed up the energy-efficient building if they help ensure Local authority incentives are in place.	60	3.92	1.062	4
The ideal place for energy-efficient incentives is at the Residential housing sector	60	3.33	.968	12
Subsidies and grants provided to a wide range of actors or developers for diverse products and services promoting energy-saving building.	60	3.98	.983	2
Energy-efficient loans and mortgages to stimulate investment in underdeveloped Housing market areas.	60	3.48	.983	10
Partial refunds on income tax to developers who engage in energy-efficient housing including requirements. e.g., solar water heating, and passive designs.	60	3.78	1.027	5
Tax credit or energy incentives for the solar light and solar geysers of residential energy efficiency.	60	3.68	1.017	8
Tax deduction for housing projects incorporating double-glazed windows, sun shades and wall insulation material	60	3.53	1.308	9
Low-Income Home Energy Assistance Program; Free Guide or reduced training in energy efficiency for architects, engineers, clients, and developers	59	3.46	1.208	11
Priority development permitting (Fast-track) processing for energy-saving housing at the local councils	60	3.92	.889	3
Capacity building & awareness programs for professionals and homeowners on Energy-saving building.	60	4.13	.982	1
Energy Efficient Award by design institutes to award Architects engaging in Energy-efficient building projects.	60	3.77	1.079	6

The top incentive was that of capacity building and awareness programs for both professionals and homeowners as seen in table 1 which is non-financial. From this, it could be deduced that there is insufficient knowledge on both professionals and homeowners of the various modes that can be used to attain energy efficiency in buildings through design, fittings and appliances. However, more capacity and knowledge is needed especially for professionals to be able to give informed advice to would be property developer. The designers can further be motivated to offer this service through getting an award for an EE design (ranked 6 in Table 1).

The second incentive was on subsidies and grants that can be offered to a wide range of actors for diverse products and services in the promotion of EE. Especially on energy efficient materials to make them more affordable for homeowners to purchase. Currently the EE products and services are seen as very expensive hence the continued reliance on non-EE efficient products and services. This costly nature of the aforementioned has made non-EE products, materials and services more attractive resulting in the construction of less energy efficient buildings. Thirdly, priority permitting was seen as a way of increasing the demand for energy efficient homes. This can be implemented by local authorities and give priority in terms of building permits to those designs that have aspects of energy efficiency. Local authorities need to be given incentives for making energy efficient building such as being able to carry out awareness campaigns, have more knowledge that the public can utilize for free to educate the public about energy efficient buildings. The fifth was to offer some form of tax refund of energy efficient developments. This would motivate home developers as they would be able to recover part of their investment costs.

4. Discussion

Various incentives have been identified as influencing the demand for EE buildings. The findings show that technical incentives, administrative incentives, financial incentives and lastly the Fiscal incentives implemented in that order would drive the demand for EE buildings upward. Findings in Table 1 and 2 are consistent on how fiscal incentives are viewed. This shows that having capacity and being aware of how you could have designs, materials and component are more important than the fiscal aspect. Therefore, having the much-needed technical knowledge of how to design includes EE materials and components is vital in achieving an EE building. This help could be sourced from designers and local authorities who can get some incentives such as awards for helping in this area. Capacity building was noted as a barrier by past researchers (Yang, et al., 2018; De Blaauw and McGregor, 2008). The Zambian construction industry being able to identify this as a barrier is a step towards EE buildings once this barrier is overcome. Implementation of policies that can include curriculum at college and university levels to embrace theories and practice of EE buildings are vital.

The second drive was identified in administration; this is also congruent with other findings by Choi, (2009). The prioritizing of EE buildings in terms of permitting would drive the demand for EE buildings. This would be the pivotal role of local authorities since it has been noted that governments tend to favour the provision of non-financial incentives technical and administrative incentives would work well in promoting EE buildings UNIDO (2009). Nevertheless, corresponding fiscal and financial incentives need to be implemented to ensure success. Financial and fiscal incentives were ranked third and fourth respectively, therefore, incentives in these areas would be around lowering interest rates on loans and mortgages (financial) for EE buildings and tax deductions and refunds (fiscal). These have worked well in USA (Hashim et al, 2016) and are therefore expected to have a similar positive effect. The government has been pointed out in the literature to be very important in implementing all the incentives as the main driver. Therefore, for the attainment of EE buildings in Zambia the government has to come up with incentives in the areas of Technical assistance, administration, financial and fiscal to ensure that there is success in the attainment of EE buildings. These findings are similar to UNIDO, (2009); governments need to implement policies and incentives that create an enabling environment for EE in buildings.

5. Conclusion

In the Zambian context, it can be concluded that the biggest deterrent to EE building implementation appears to be technical expertise which is in some cases is lacking and in others is inadequate. It is therefore important to build capacity and awareness of how to achieve energy efficient buildings. This could be supported by clear and fast permitting processes by the local authorities. Government needs to implement financial and fiscal policies that would promote EE in buildings. Future research could focus on what aspect of building should be a priority in achieving energy efficiency.

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Issues and Anxieties of Engineering interns: A Departmental Perspective.

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Abstract

Some industrialists are of the viewpoint that engineering graduates trained in local universities do not meet the quality standards in terms of hands on experience. This opinion is puzzling because most engineering schools are of the opinion that internships are used as a mitigatory measure to address the problem. In this regard a pilot study to evaluate the internship curriculum of a particular engineering department in Zimbabwe was undertaken in order to check its effectiveness in addressing the issues that some industrialists were raising. The study employed the Context, Input, Process, Product (CIPP) model for programme evaluation. The study used qualitative and quantitative descriptive survey methods. The study used a questionnaire to solicit data from all the 39 students who had undergone internship in the past year. Departmental lecturers and workplace supervisors were also interviewed. Although the internship curriculum was still effective some issues that impinged its effectiveness were unearthed. The issues of interns were financial constraints, being used as cheap labour on repetitive or irrelevant duties, marginalisation and poor supervision by industrialists.

Key words: Engineering, Interns, Curriculum Evaluation, Industrialists.

1.0 Introduction

Most engineering schools in Zimbabwean Universities subject their students to a supervised and examinable internship. The duration of the internship ranges from 8 to 12 months depending on the University. The universities believe that work related learning should enhance students' cognitive, psychomotor and affective domain skills. It can be argued that the skills obtained from work related learning should assist the intern to have a smooth transition from the academic world to the working environment (Chiweshe *et al*, 2011). However one would wonder why there are many complaints that the engineering graduates produced by local universities are of poor quality and are irrelevant (Langa, 2015, New Zimbabwe staff reporter, 2015).It begs the reason why such a strong consensus has emerged among industrialists yet they are engaged in the training process of prospective engineers through provision of work related learning. This conundrum provides an interesting research question in its own right. Therefore the industrialists' viewpoint compels the researchers to question the quality of the internship experience. Hence it was quite necessary to evaluate the engineering internship curriculum using an engineering department as a pilot study.

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2.0 Research questions

- What are the responsibilities of both the academic and the workplace supervisors during the internship period?
- Do the workplace mentors have knowledge of the procedures of internship assessments expected by the department?
- How do the students rate the quality of the industrial attachment?
- How do the industrialists rate the quality of engineering interns after finishing the attachment tenure?
- What are the challenges faced by interns during their attachment period?
- How can challenges faced by interns be solved?

3.0 Theoretical Framework

Pragmatism is a theory that has a view that knowledge is derived from interaction among groups of individuals and their environment, which together create a reality (Wilkins 1959). It can be seen that internship stem from the theory of pragmatism. Internship allows student engineers to go and interact with real engineering environment and also with individual engineers and this exposes students to reality in work practise. Internship is known by a number of terms of which some of which are work related learning, experiential learning and industrial attachment.

3.1 Internship Curriculum

Considering the above literature internship curriculum can be viewed as all aspects of planned and unplanned practical concepts, real world content, skills, work habits and means of internship assessment. It also includes attitudes of academic and workplace instructional strategies that influence the cognitive, affective and psychomotor growth of students.

4.0 Curriculum Evaluation Models

Some of the models of curriculum evaluation include the Scriven goal free model, CIPP (context, Input, Process and product) model, Tyler's model and Kirk Patrick's model. This Study used the CIPP model because it is the most used in evaluating programmes (Rajeev *et al*, 2009) and it provides a comprehensive framework for guiding formative and summative evaluations. The phases of the CIPP evaluation are Context evaluation, Input evaluation, Process evaluation and Product evaluation.

5.0 Research Design

The study used both qualitative and quantitative descriptive survey methods. (Bukaliya ,2012) had a view that descriptive surveys are instrumental in obtaining information concerning opinions of people and the effects that are evident or trends that are developing. Therefore it was prudent to employ the descriptive survey method because the fundamental purpose of the study was to evaluate the strength and inadequacies of the internship curriculum offered to student engineers in the department under study. This strongly relies on the opinions of people.

6.0 Population and Sampling

The target population was composed of all 39 students (35male and 4 female) who had undergone internship the previous year. The respondents also included nine lecturers (seven male and two female) in the department under study. The study also used the views of 12 workplace supervisors who once worked with the engineering interns from the department under study.

7.0 Research Instruments

.A combination of self administered questionnaire and both structured and unstructured interviews were used. The questionnaire which was administered to the students composed of a four point likert scale to ascertain students' degree of agreement on quality of industrial attachment and open ended questions to address the challenges faced by interns during attachment. The four point scale ranged from strongly disagree (coded as 1) and strongly agree (coded as 4). The mean of the scores was determined by adding the scores and divided by 4 to get an average of 2.5. A mean score of 2.5 and above indicated agreement with the item statement while a mean of 2.4 and below indicated disagreement. The workplace supervisors and lecturers were subjected to face to face interviews.

8.0 Results and Discussions

The results presented are based on the CIPP model. Table 1 to 4 contains the abbreviation SA which means Strongly Agree, A means Agree, D means Disagree, SD means Strongly Disagree and std means standard deviation.

8.1 Context Evaluation

This category was used to evaluate the engineering department and host organisation's attitude towards the internship. The responses are shown in Table 1.

Table 1: Results For Context Evaluation

Statement	SA	A	D	SD	MEAN	variance	Std	remark
1.The department was instrumental in helping me to find internship place	0	6	13	12	1.81	0.54	0.74	disagreed
2. I was able to find attachment on time (within three weeks opening semester)	5	5	8	13	2.06	1.22	1.22	disagreed
3.Eight months of industrial attachment is adequate	12	16	3	0	3.29	0.40	0.63	agreed
4.The host organisation gave me enough pre-attachment orientation	16	13	0	2	3.39	0.62	0.79	agreed

In responding to the binary question; "*whether the interns received monetary compensation"*. 48% of the students agreed, 48% did not agree and 2% were neutral.

8.1.1 Discussion

The positive findings in this category were that the students were satisfied with the attachment duration of eight months and also that host organisations gave proper orientation to students. However majority of students noted that they did not receive any assistance from the department in finding placements and as a result they failed to secure internship on time. The danger of letting students find their own attachment is that they are chances of them being attached to irrelevant organisations that do not expose them to adequate skills training expected by the department. Literature indicates that compensated interns have more fruitful internships (Phoebe,2010, True,2010).Even if it is a small amount compensation acts as a reminder that interns are in the real world where they are mandated to think and feel like professionals.

8.2 Input Evaluation

The questions on the questionnaire sought to evaluate the quality of the workplace supervisors and the degree of responsibility of the host organisation.The results are shown in Table 2.

Table 2: Results For Input Evaluation

Statement	SA	A	D	SD	Mean	variance	std	remark
1.There was adequate supervision by the host organisation	18	12	0	1	3.52	0.44	0.66	agreed
2.My workplace mentor was adequately skilled	18	10	2	1	3.45	0.57	0.75	agreed
3. Workplace mentor was generally not knowledgeable and was of a lower qualification than myself.	1	3	12	15	1.68	0.61	0.78	disagreed
4. Workplace mentor not the right person to supervise students on industrial attachment.	3	2	12	14	1.81	0.87	0.93	disagreed

8.2.1 Interview Results

In this category the lectures were interviewed in order to validate the claims of students and check for consistencies. The academic supervisors were subjected to interviews in order to solicit their opinions on whether the interns were attached to relevant organisations with industrial resources suitable for engineering. The lecturers had two opinions .They agreed that a majority of the students were attached to very relevant companies where they were exposed to a very good engineering environment. The lecturers were displeased that some students were attached to very small organisations that did not have enough resources in terms of machinery, relevant human resources and engineering systems.

....I assessed a student that was attached to a small beverage manufacturing company that had five workers and four very simple machines. One can just tell that the student is here to fulfil the degree requirements ... (one of the lecturers said).

8.2.2 Discussion

Most interns agreed that the quality of supervision was good and adequate. This further suggests that a lot of host organisations give interns very good experiences which enabled them to choose their career paths. However 16% of the interns lamented that their supervisors were not the right persons to supervise them and 10% pointed out that their supervisors did not have enough skills. This is in congruence with what the lectures observed when they pointed out that some interns were attached to substandard organisations without enough resources. The same view was expressed by Chinyemba *et al* (2012) when they expressed that visits by academic supervisors were for the purpose of ensuring that interns were engaged in relevant aspects of work and to meet workplace supervisors to discuss any problems of concern.

8.3 Process Evaluation

In this category the motive was to evaluate the quality of the supervision by both the academic and the workplace supervisors. The results are shown in Table 3.

Table 3: Results for Process Evaluation

Statement	SA	A	D	SD	MEAN	variance	Std	remark
1. Attachment coordinator' s communication with students was enough	2	27	1	1	2.97	0.22	0.47	agreed
2.There was adequate supervision by the academic supervisor both in project and in report writing	6	20	4	0	3.07	0.33	0.57	agreed
3.Student visits by the academic supervisor were done on time	4	21	6	0	2.94	0.32	0.57	agreed
4.The visits helped me to have helpful interaction with my academic supervisors	3	24	4	0	2.97	0.22	0.47	agreed
5.Workplace mentor did not give me enough help with my project	2	8	13	9	2.16	0.80	0.89	disagreed
6.The academic supervisor did not reply to e-mails of project work on time	1	4	15	11	1.84	0.58	0.76	disagreed

8.3.1 Challenges Faced by Interns

The students were asked to respond to an open ended question which requested them to describe the challenges they faced during internship. The students' responses were put into key themes which are shown in figure1. The main challenges were financial constraints where 45% of the participants reported having problems associated with finance. Some of the challenges cited were lack of transport allowances and accommodation expenses. The other burning theme which emerged was lack of adequate supervision by workplace supervisors with 29% of the population citing various challenges under this category such as "too much idle time" and "supervisor too busy". Inadequate communication between the workplace supervisor and students was another challenge cited by 13% of the respondents. The other problem cited was that of inadequate engineering resources which suggested that some students (13%) had been attached at companies with limited engineering applications. Some other students (7%) expressed opinions that reflect that they were subjected to duties that were not relevant. In addition another 7% of the students felt that they were used as cheap labour whilst another 7% felt that they were marginalised

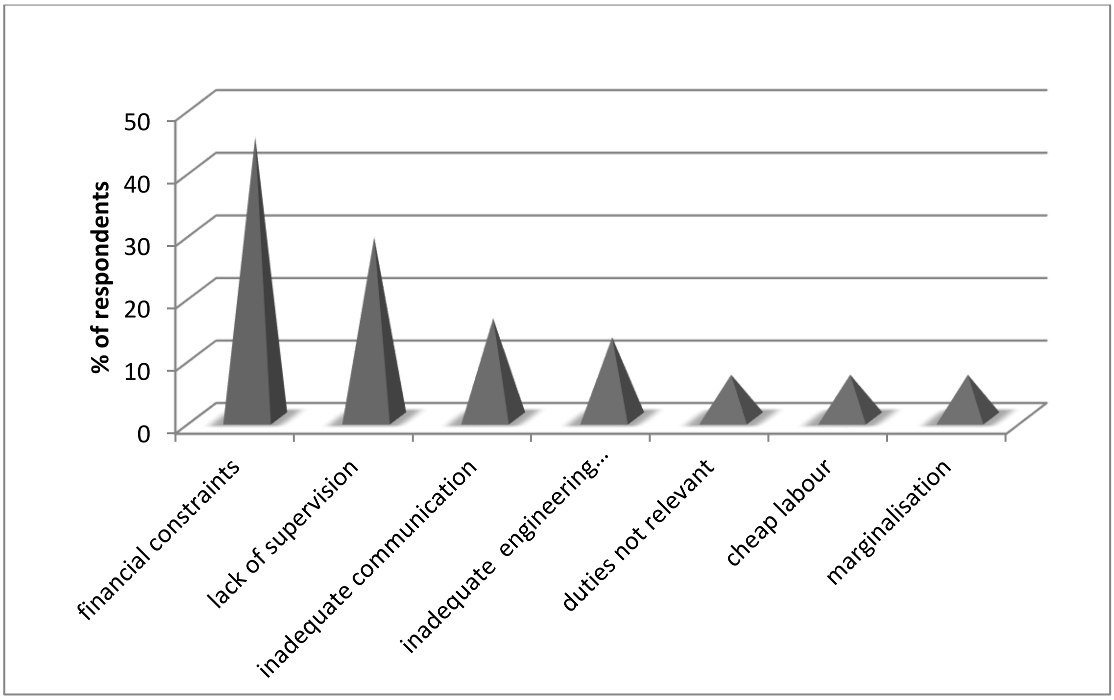

Fig. 1: Challenges faced by interns during work related learning

8.3.2 Discussion

The major finding in this category was that both the academic and workplace supervisors performed their roles well. This is in line with what Risner (2015:65) suggested "*internship should be a joint effort which should be normally shared by the on-site supervisor and the department supervisors*". Lack of supervision was one of the challenges mentioned by some students when they responded to open ended questions. This implies that intern supervision has some issues which need to be addressed.

Most student informants cited financial challenges in meeting internship costs such as housing and transport .This seemed not to be the main problem of these interns alone as Chiweshe *et al* (2011) found that 52% of the interns in the B.ED.Technical Education programme experienced financial problems too.

8.4 Product Evaluation

This category of questions sought to evaluate the product. The product of internship is the student. Therefore the questions were aimed to ascertain student competencies in the engineering field after attachment. Results are displayed in Table 4.

Table 4: Results For Product Evaluation

Statement	SA	A	D	SD	Mean	variance	std	remark

16. I acquired knowledge from the job duties I performed	17	13	1	0	3.52	0.31	0.56	agreed
17. The internship helped me to have the ability to connect the academic work to the real world.	18	12	1	0	3.55	0.31	0.56	agreed
18.The internship helped me to develop specialised technical skills for specific job functions	13	16	2	1	3.39	0.54	0.73	agreed
19.The internship helped me to broaden my future employment possibilities	14	8	6	3	3.06	1.03	1.01	agreed
20.I would recommend other interns to the organisation	16	10	2	1	3.19	0.59	0.77	agreed

8.4.1 Most Valuable Aspects of Internship to Students

Students were asked to describe the aspects of internship that were most valuable to them. This open question was meant to evaluate the learning outcomes from internship experiences. The responses of the students were grouped into three themes that emerged. The themes were technical skills attained, team player and networking with established professionals. The results showed that the students valued the technical skills they attained with 90% of them describing various technical skills they learnt. Some of the skills they described included PLC programming, engineering maintenance, SCADA system monitoring and fault finding techniques. All the skills mentioned were relevant to engineering. 12% of the students felt that they had established valuable links with established professional engineers whilst 10% valued the concepts they learnt that enabled them to become effective team members.

8.4.2 Interview results

In a bid to ascertain whether internship was of help to the students under study, the lecturers were asked to compare the skills of students before and after internship. All the lecturers concurred that the students showed great improvement in terms practical skills and discipline after internship: One of the academic supervisors said:

"*....The students are now able to understand what engineering is, and have shown great improvement in terms of hands on work...*"

But when the lecturers were asked about their view on the quality of the projects, most of them concurred that the quality of projects were on the low side.

"...Students projects are generally not good; it seems they concentrate much on their internship work...." (One of the academic supervisors said).

In order to ascertain the competence of students that came from the internship programmes the work place supervisors were asked whether they had followed up on any student project and developed it further to solve challenges they faced in their organisations. The general response was that the companies did not make any follow ups. One of the key informants said:

“*....Your students never return to us to present their findings or their engineering solutions to us .It seems they do their projects for academic purposes only...”*

The extract might suggest that the projects would have failed to produce meaningful solutions to existing problems and therefore were of poor quality.

8.4.4 Discussion

In this part the major outcome was that the majority of students were satisfied with their internship experience .They agreed to have benefited from internship in that they were able to connect their academic work to the real world, they improved their technical competencies, were able to broadened their future employment chances and were able to establish useful relationships with professionals. This is in agreement with the interview results from academic supervisors. In a related study Jackson R and Jackson M (2009) and Bukaliya (2012) also found that majority of students benefited from internship experiences.

However a few students (10%) mentioned that they failed to acquire any specialised technical skill .This finding is in line with the outcome from input evaluation in which it was found that some students were attached to irrelevant organisations. The same scenario was found by Bukaliya (2012) and Chiweshe et al (2011) when they found that some organisations do not have qualified staff that can effectively and efficiently contribute to meaningful and successful student internship.

9.0 Conclusion

The internship programme in the department under study was evaluated using the CIPP model. The evaluation identified issues and concerns of engineering interns. Most of the weaknesses were in the preliminary phase of the internship curriculum. The weaknesses in the preliminary phase do not mean that the whole internship curriculum is weak. But it reveals that some students can pass through the internship phase without getting proper practical experience as is argued by some industrialists. The study managed to reveal some positives, that students were receiving quality supervision from both workplace and academic supervisors and have gained specialised skills. The students were also found to be satisfied by the supervision and the skills they got. Therefore the study revealed to a large extent that it was not necessarily true that engineering graduates were practically handicapped and unsuitable for our local industries.

10.0 Recommendations

The pilot study brought out some disturbing issues that warranted the study to be done at national level and the results obtained would give a true reflection of the issues and concerns affecting engineering attachees.This will enable stakeholders to work out lasting solutions to engineering interns’ problems at national level. However for this pilot study it is recommended that organisations that employ interns should offer to pay them some transport and subsistence allowances. Academic supervisors should encourage workplace supervisors to assist student interns with their industrial based projects. The academic supervisors, workplace supervisors and the student must agree on a structured training programme that would guide the intern during training. The structured programme would form the basis for supervision and performance evaluation.

Universities should build and capacitate learning factories. The learning factory would house models of real life industrial processes and environments. The universities would use the learning factories to develop competencies of all students through prototyping and experimentation with technology. Moreover the academia and the industry should also engage in collaborative research and lecturer industrial attachments during vacation or contact leave. Industrial attachments for lecturers will enable the academic staff to keep abreast with changing technologies and this would culminate in lecturers imparting relevant knowledge to students.

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Roughness measurement along the Lusaka Inner Ring Road using an Android smartphone

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ABSTRACT

Pavement Smoothness is one of the main factors when it comes to rating the nation's highways. Therefore, for pavement maintenance management, cracking, rutting, and roughness are important indicators of a particular condition of a road. Many road authorities usually collect road condition data either by using an automated data collection system or by manually rating their road network. These data collection systems consist of the longitudinal profiling subsystem, transverse profiling subsystem and digital video distress collection subsystem which usually comes at a high cost. In recent years, with the spread of smartphones, a new response type of measurement method has been developed, and it has been adopted as actual evaluation of pavements condition by some local governments. In this paper, a response type roughness measurement technology and measurement repeatability are discussed by using developed IRI class 2 method named "BumpRecorder software" which is a simple, friendly, and quality Pavement Maintenance Management software using an Android Smart Phone. The service can measure the International Roughness Index (IRI) which is a measure of the condition of the road and reflects its riding quality. In this method the smartphone is fixed on the vehicle dashboard and driving through the pavement. The BumpRecorder utilizes the vibration of a running vehicle at about 20 -120Km/h and data captured is uploaded to the server. The uploaded measured data can be checked on the map of the Web analysis service site BumpRecorder Web in about 10 minutes which provide an efficient and fast decision-making mechanism for road authorities. The study further presents results obtained from a demonstration conducted on Lusaka Inner Ring Road (Tokyo Way) which provided the indicative IRI successfully. This paper recommends that this response type roughness measurement can reduce data collection time and analysis costs for pavement maintenance management for road authorities in Zambia.

Keywords: **International Roughness Index, Response Type Measurement, Pavement Maintenance Management, Android Smartphone, BumpRecorder**

1. INTRODUCTION

Pavement Smoothness is one of the main factors when it comes to rating the nation's highways. In this regard, irrespective of technology employed, the general accepted standard for measuring pavement roughness is the International Roughness Index (IRI). [1]
Many techniques are available for measuring road smoothness, most of which measure the vertical deviations of the road surface along a longitudinal line of travel in a wheel path, known

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as the profile. According to ASTM International, E867-06 (2012) standard, pavement roughness is defined as the deviation of a surface from a true planar surface with characteristic dimensions that affect the vehicle dynamics and ride quality. As such, it is a quantitative representation of distress in pavement and major parameter for pavement surface (**ASTM International, 2012**).

Thus, early researchers have established that the World Bank standard of IRI was the method used in assessing road conditions. It serves as a means of evaluating the conditions and level of serviceability of a road network. Sayers and Karamihas (1996), described IRI as a mathematical representation of the accumulated suspension stroke of a vehicle, divided by the distance traveled by the vehicle during a particular test. The units are metre/Kilometer (m/Km) or millimetere/metre (mm/m) (**Sayers and Karamihas, 1996).** Therefore, for pavement maintenance management, cracking, rutting, and roughness are important factors which basically defines the condition of the road and reflects the riding quality. That is why, road authorities require to determine maintenance strategies that minimize the long-term costs of preserving the road network in a desired condition (**Zvjezdan Lazic, 2003).** This process begins by obtaining adequate information about the road network being analyzed so that the right decisions can be made at the right time.

Previously, when it comes to pavement inspection, only the human visual inspection used to be applied. In this case, the result was not quantitative and difficult to compare with other inspections. Thus, many road authorities have resorted to using sophisticated systems for collecting road condition data either by using an automated data collection system or by manually rating their road network. These data collection systems consist of the longitudinal profiling subsystem, transverse profiling subsystem and digital video distress collection subsystem which usually comes at a high cost. At present, the laser profiler is mainly used to identify road roughness, but the laser profiler is expensive and has the possibility of high breakdowns which are usually caused by bad road conditions (**Wei Zhou *et al.*, 2020**). The prohibitive cost associated with data collection including the cost of maintaining such equipment, its level of expertise needed and difficulty for regular network scale deployment have rendered most of these data collection approaches unsustainable.

On the other hand, the response type roughness measurement and road condition monitoring system by using an Android Smartphone is one of the solutions to these problems which come at a high cost and are time consuming. It can measure quantitative data by using a car that is tougher than an inertial profiler. Thus, for roughness measurement, the smartphone measurement application called BumpRecorder can be used. This measures vehicle vibration by using smartphone built-in accelerometer and global positioning systems (GPS) . Then road roughness such as IRI can be calculated. This convenient method brings routinely inspection and screening of pavement data much easier. "BumpRecorder" is one of the applications that can easily be downloaded from google play store on any android smartphone. Many modern smartphones are usually equipped with sensors that range from gyroscope to GPS and sensors like magnetometers and three-dimensional accelerometers as well. These sensors can be used to measure the level of serviceability of a road pavement by measuring the International Roughness Index (IRI). In this paper, the measurement principle using the BumpRecorder software application installed on an android smartphone is discussed and the results from demonstration on Tokyo way in Lusaka are presented.

2. BACKGROUND

1.1 Response Type Roughness Measurement

During a half century of development, engineers and researchers have invented several techniques and methods for measuring road roughness. On the other hand, several smart phone-based road condition monitoring systems have been developed in the recent past as experimental projects by individuals, corporations with even fully commercial systems. For example, **Astarita *et al.* (2012)** and **Vittorio *et al.* (2014)** used the smart phone accelerometer and GPS sensors to detect road anomalies, especially speed bumps and their relative locations using some algorithms. According to the Central Road Research Institute, CSIR, the measurement devices can be divided into four general types: response-type road roughness measuring systems (RTRRMS), direct profile measurements, indirect profile measurements and subjective rating panels **(Sayers *et al.*, 1986a, 1986b, CSIR**). The World Bank sponsored International Road Roughness Experiments (IRRE) conducted in Brazil in 1982 also categorized these devices into 4 classes, namely Class I, II, III and IV. The BumpRecorder Smartphone-based gathering of roughness data which is proposed in this study is a response-type road roughness measuring system (RTRRMS) which falls under class II. The differences between the four generic classes of road roughness measuring methods in use and their respective descriptions are summarized in Table 2.1

Table 2.1 IRI Classification of Roughness Measuring Devices (Central Road Research Institute, CSIR)

S/N	IRI Classification	Description
1	**Class 1: Precision profiles.**	This gives a higher standard of accuracy which enable precision measurement of pavement surface profile e.g., Rod and level, TRRL beam, Dipstick, Merlin, and Walking profiler.
2	**Class II: Other Profilometric methods.**	This class includes all other methods in which the profile is measured as the basis for direct computation of the IRI, but which are not capable of the accuracy required for a Class 1 measurement.
3	**Class III: IRI estimates from correlation equations.**	This class includes all roughness measuring instruments capable of generating a roughness numeric reasonably correlated to the IRI. In order to estimate IRI, a calibration is needed which is performed on actual road surfaces. The IRI values of the calibration sites are obtained using a Class 1 or Class 2 method.
4	**Class IV: Subjective ratings and uncalibrated measures.**	This class includes roughness measures that have no verifiable link to the IRI scale. For example, human visual inspection, ride experience etc.

The IRI is a common international roughness evaluation index, which makes it possible to evaluate the pavement roughness by IRI scale as shown in Figure 1 (**Sayers and Karamihas, 1998).** The lower the calculated IRI, the smoother the pavement will ride. The higher the IRI, the rougher the pavement will ride.

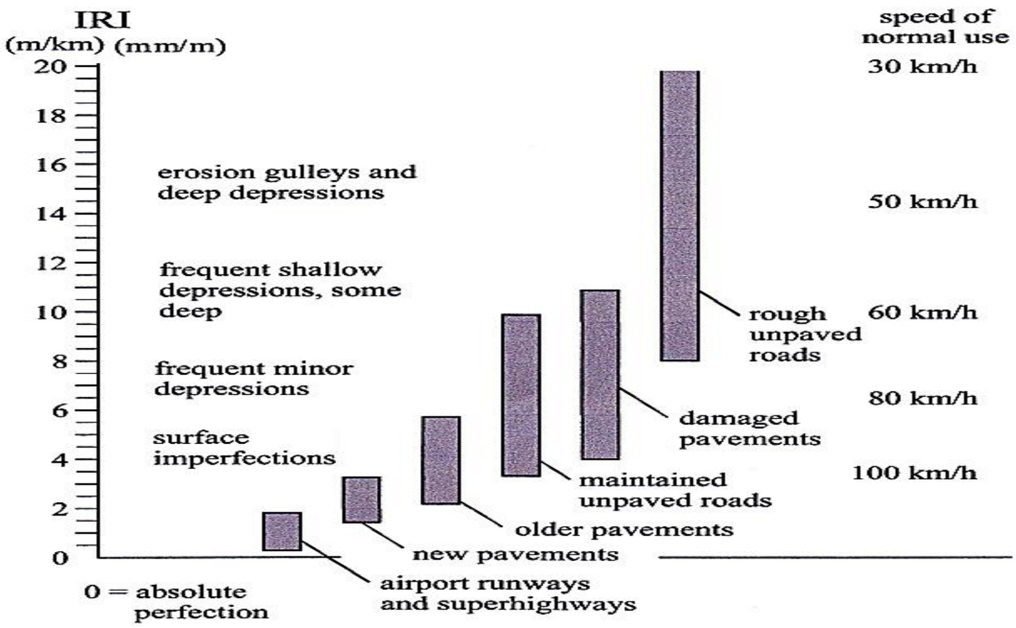

Figure 1: IRI Scale (Sayers and Karamihas, 1998).

The correlations between road roughness and IRI are shown in Figures 2, 3 and 4 respectively.

Figure 2: Correlation between road surface conditions and IRI (IRI=0 ~ 3): A condition of satisfactory asphalt paved road surface

Figure 3: Correlation between road surface conditions and IRI (IRI=6 ~ 8): A condition that the paved road surface has gradually been eroded from bad to worse.

Figure 4: Correlation between road surface conditions and IRI (IRI=11 ~ 12): A condition that the paved road has already been eroded and it has resulted in a series of potholes.

3. EXPERIMENTAL PROCEDURE

BumpRecorder as earlier indicated is a smart phone-based road condition monitoring and mapping commercial application that employs the use of sensors to collect roughness data, photos, and video. The application algorithm taps into the smart phone's gyroscope, accelerometer, and GPS data in order to automatically evaluate pavement roughness. The experimental procedure adopted for this study first involved an initial validation of the smartphone application. This was done by undertaking field experiments to evaluate the reliability of the BumpRecorder application software downloaded on google play store for measurement of IRI values using different available android smartphones namely; Nexus 5, Nexus 5X and Xperia Z3 Compact. Generally, any android smart phone can be used for data collection purposes provided the software is installed on it. The second experiment for evaluating the reliability of the application software was done using different light weight vehicles for the measurement of IRI specifically the Audi A4 and Suzuki Belano over a stretch of 1.2Km. Upon completion of the reliability and validation process, IRI measurements were collected on a 4Km stretch along the Lusaka Inner Ring Road (Tokyo way) using a Toyota Hilux Van for demonstration of IRI values and correlation of the condition of the road. The Toyota Hilux van is within the limit of the lightweight vehicles like what was used in the validation process. The measurements were collected starting from the traffic lights located at Kamwala-Tokyo way junction going towards the eastern direction for approximately 4km on both directions. This road was selected based on convenience and preliminary pavement condition. In addition, the selected 4Km section has numerous pavement distresses due to premature failure of the road. To measure the roughness index along Tokyo way, a Samsung Galaxy Note 10 Plus model android smartphone running with the BumpRecorder software application was placed on the vehicle dashboard which is located over the vehicle suspension. The application software was started and the record button initiated to start collecting pavement condition data. The vehicle operational speed was maintained within 20-80Km/h for collection of roughness data. "BumpRecorder" does not require any form of calibration before taking measurements as the case maybe when using the inertial profiler. BumpRecorder is IRI Class 2, which also increases measurement convenience and repeatability. The data collected is saved with corresponding GPS data to enable the location of the road anomaly. From the accelerometer data, signal analyses allow the generation of the globally recognized IRI. The data and results can be transferred to the web server for further processing and visualization within 10 minutes.

4. RESULTS AND DISCUSSIONS

Figure 5 shows the reliability and repeatability results for IRI measurements obtained using different android smartphones namely; Nexus 5, Nexus 5X and Xperia Z3 Compact running with the BumpRecorder software. As can be seen from the results, the calculated IRIs are the same implying that the software is stable and in terms of reliability and repeatability results are equally stable even when one uses different android smart phones.

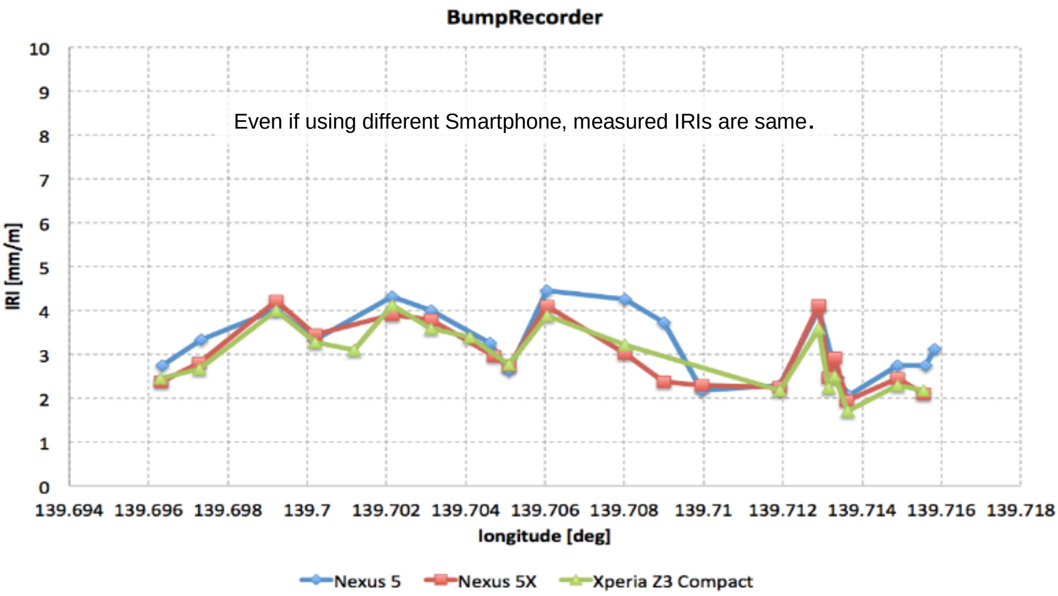

Figure 5: IRI Measurements using different android smart phones

Figure 6 further shows the IRI measurements obtained by using different vehicles specifically the Audi A4 and Suzuki Belano over a stretch of 1.2 km. The measurements this time around were done repeatedly 3 times using different vehicles. As can be seen from Figure 6, the IRI measurements were stable and with minor deviations.

From the data collected by BumpRecorder application along the Lusaka Ring Road (Tokyo way) using a Toyota Hilux Van, the total surveyed length was 4km which was sufficient to present the indicative results. The survey started from the traffic lights located at Kamwala-Tokyo way junction going towards the eastern direction for approximately 4km on both directions. After analysing the data, it showed that the IRI values obtained for both directions could be classified in different condition category. Most of the IRI values were classified as poor to fair as can be seen in Figure 7.

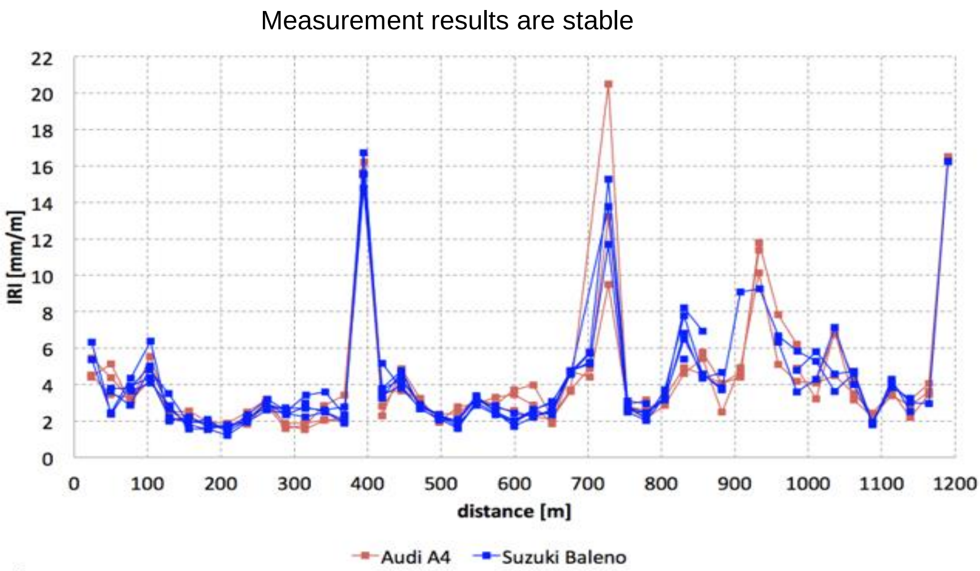

Figure 6: IRI Measurements using different vehicles

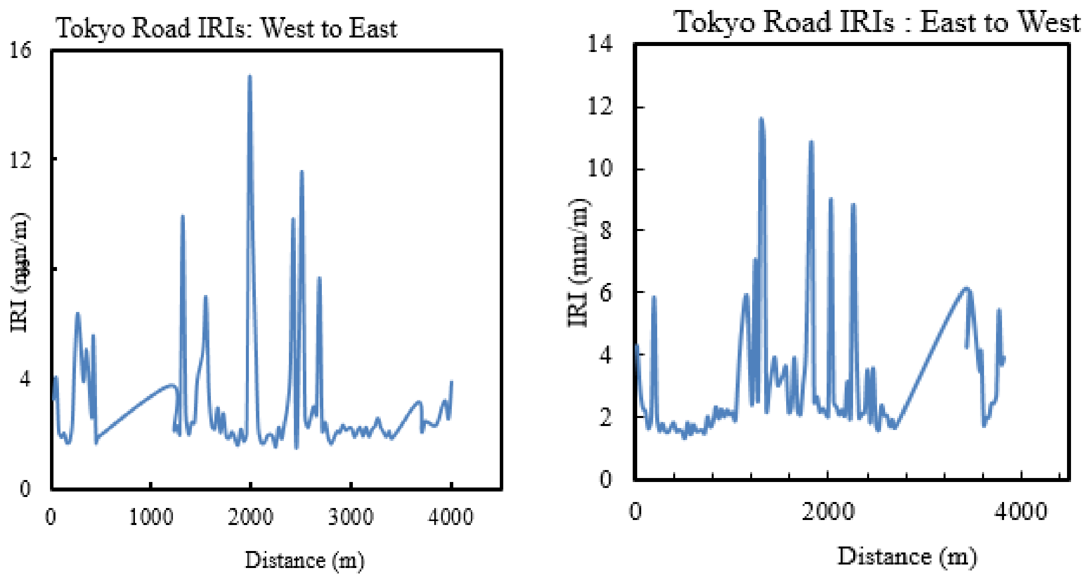

Figure 7: Calculated IRI values on Tokyo Way Road

A typical mapping of IRI values (Figure 9) obtained on this stretch of the Lusaka Ring Road (Tokyo way) further shows that a good number of sections are still in fair condition with IRI values ranging from 0 ~ 3 mm/m implying that the asphalt paved section is still in satisfactory condition. Results from the mapping exercise also shows sections which have developed serious depressions, and these can be seen on the map in red. For such sections the application software classified the IRI values between 8 ~ 10 mm/m indicating a condition that the paved road has already been eroded and it has resulted in a series of potholes. The BumpRecorder application software flagged such sections with a higher roughness index implying that the passengers in the vehicle can easily feel the vibrations during travelling and hence a sign of discomfort. For such sections, travelling at high speed, the passenger notices a strong suspension motion of the vehicle and as such this roughness measurement most likely indicates a damage to the vehicle.

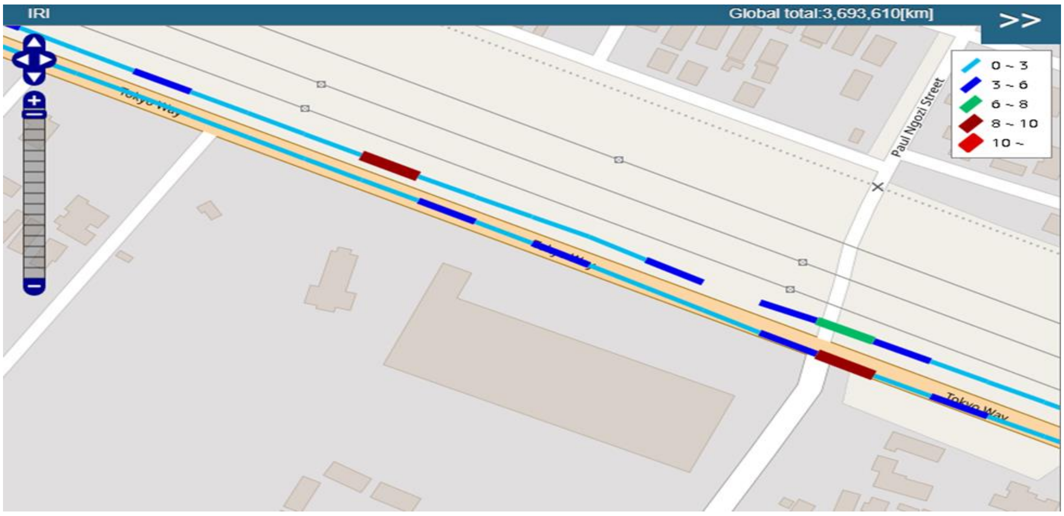

Figure 8: Screenshot of Typical Mapping of "IRI" values on Lusaka Inner Ring Road

5. CONCLUSIONS

In this paper, the smartphone android application phone running with the BumpRecorder application software has been used to measure the International Roughness Index of the pavement along the Lusaka Inner Ring Road (Tokyo way). The study reveals that the use of android smartphones can be adopted as an inexpensive way of collecting roughness data of the pavement for local road authorities. BumpRecorder is a simple, friendly, and quality Pavement Maintenance Management Tool which uses an android smartphone to collect pavement data. It achieves this by fixing the smartphone to the vehicle and driving through the pavement. The vibration of a running vehicle is transmitted with the smartphone application called BumpRecorder and data is uploaded to BumpRecorder Co. Ltd server. The uploaded measured data can be checked on the map of the Web analysis service site BumpRecorder Web in about 10 minutes. The application costs only 1 USD/Km for each data file of IRI downloaded.

6. RECOMMENDATIONS

Road surface defects such as potholes, corrugations, speed bumps etc.., have become a source of public concern. Thus, many road authorities have attached great importance to maintenance of roads to ensure safety and comfort for all road users. However, current pavement data collection systems are usually costly, labour intensive and time consuming. Thus, many road authorities do not collect road pavement condition data on an annual basis for large portions of their road network because of these high costs. This paper suggests that this simple and cost-effective technology can reduce data collection time and analysis costs for pavement maintenance management for road authorities. It is therefore recommended that the application can be adopted by road authorities to assist in creating their quarterly and annual plans about roads that require repairs or complete reconstruction. The collected data can also be used by road authorities to inform road users on the status of roads or sections of roads that are in poor condition and even avoid accidents which may result in injuries and fatalities.

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Quick concrete design - A new mobile application for concrete mix design using either the British, American or Indian codes.

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Abstract

The advent of mobile computing devices such as smartphones and tablets has provided engineers with unprecedented opportunities to simplify the design, analysis and modelling of engineering processes. This paper summarises the development of a mobile application named Quick Concrete Design (QCD) that can be used in the design process of concrete mixes. Manual concrete mix design methods involve heavy usage of empirical curves and tables which is time-consuming and error prone. Development of the software has been done in Java programming language using Android Studio as the integrated development environment (IDE). Three design methods, namely DOE, ACI 211 and IS 10262 have been incorporated. The developed QCD ensures quick calculation of concrete proportions and facilitates efficiency and a measure of accuracy in the concrete mix design process.

Keywords:

Smartphone and Tablet, Mobile Applications, Quick Concrete Design, Concrete Mix Design, Software

1 Introduction

The history of using concrete as a building material is as old as Civil Engineering itself. The employment of concrete-like materials in construction dates to ancient times when Nabatean traders discovered the self-cementing properties of hydraulic lime (Al-Bashaireh, 2008). Over the years concrete has undergone a lot of modification and is now one of the most frequently used building materials in the world (Sarker, 2009). Consumption of this precious material is twice that of wood, steel, aluminium, and plastics combined (Cockburn, 2021).

Modern concrete consists mainly of four materials namely cement, water, construction stones, and sand. These constituent materials are mixed in certain proportions to obtain concrete of desired properties and grade (Mindess, 2008). The technique of approximating these ratios is called Concrete Mix Design. American Concrete Institute Committee 211 (1991) and (Bureau of

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Indian Standards (2019) are some of the standard codes that outline the guidelines for performing Concrete Mix Design. In these design codes, various empirical curves and tables are used to come up with mix proportions for the required concrete properties and the given properties of constituent materials (Kett, 2009).

In today's world, almost all engineering designs, modelling, and analyses are performed using computer programmes or software packages. Various software packages are available for different engineering problems and different platforms (Salih & Ahmed, 2014). This approach has proven to be cost-effective, fast and accurate. Most of these "computer programmes" run on conventional computing devices such as desktop and laptop computers. However, software packages designed to run on mobile devices such as phones and tablets have also become prevalent in the recent past. These mobile applications popularly known as apps were originally intended for productivity assistance such as calling, emailing, calendar and contact databases. But over the past ten years, they have rapidly expanded into other sophisticated applications such as mobile games, Global Positioning System (GPS) services, factory automation, engineering design, engineering estimation, system modelling, to name but a few. The expansion began in 2008 when Apple and Google introduced customer environments for distributing these mobile applications (Eyiah-Botwe & Adjei, 2016). A study by Azhar et al. (2015) reported a total of 13,000 mobile applications related to design and construction for Apple's iPad and iPhone by 2015. The study took note of a total of 205 mobile applications that were applicable in the life cycle of a construction project for design, construction, and facility management. Furthermore, the study observed the availability of many calculator-based apps on the market. However, these types of apps were of little use to construction managers.

For concrete mix design, the number of available mobile applications is quite limited and among these, a lot of them have some deficiencies. For example, one app called *Concrete Mix Design & Concrete Calculator* developed and maintained by EigenPlus uses the IS 10262-2009 design code. This design code is outdated and has been replaced by IS 10262-2019. Furthermore, the mobile app does not stringently follow the design code. For instance, it requires that the user supplies the water cement ratio as one of the inputs, but the design code stipulates that the water cement ratio should be calculated from consideration of the average 28-day compressive strength of concrete and the type of cement. Other available apps such as *Concrete Mix* (AppsGear, 2018) and *Concrete Mix Design* (Ahmed, 2019) have similar deficiencies. Furthermore, all the available apps are based on one design code, making each one of them only applicable in certain countries. For instance, Zambia mostly uses British standards hence all the mobile applications based on the Indian Standards need not be used. Considering the above-highlighted application deficiencies, the study presented in this paper is aimed at developing a mobile phone/tablet application dubbed Quick Concrete Design (QCD) that can be used to undertake concrete mix design using any one of three design codes, namely, the Indian, American and British codes.

2 Literature Review

2.1 Innovation and Technology in Civil Engineering

In 2007, the American Society of Civil Engineers held a summit dubbed "The Vision for Civil Engineering in 2025". The outcome of this summit was a plan of action called Vision 2025, an ambitious roadmap for civil engineers which set an aspirational target for a new global civil engineering state of affairs. Five goals were outlined in this roadmap as follows: Civil engineers as a body of professionals will be (1) master planners, designers, and constructors; (2) stewards of the natural environment; (3) innovators and integrators of technology; (4) managers of risk and (5) leaders in shaping public policy (American Society of Civil Engineers (ASCE), 2009). The third goal is particularly worth noting given that civil engineers seem to be reluctant to embrace new technologies and approaches due to concerns about possible liability and litigation. While that may provide a certain level of comfort, it slights a lot of potential benefits that new technologies may bring. In this regard, civil engineers have been encouraged to envision, adapt, and integrate new technologies such as the use of mobile computing within and across projects.

Technology applied through smartphones has pervaded almost every individual's life in every part of the world. According to Statista (2020), there are over 3.5 billion users of smartphones- nearly half of the world population. Today, smartphones and tablets are bundled with advanced operating systems which are as powerful as those used in traditional computers. Thus, they are not only useful for communications through phone calls and texting but are also being used to deliver computing facilities.

Additionally, due to their lightweight, compatibility, relatively low cost, high performance and user-friendliness, smartphones and tablets are quickly becoming common in industries such as manufacturing, production and construction (Ekow & Kofi, 2016). For example, large software providers such as Autodesk, are making efforts to improve the availability of building information models on mobile devices for job site use (Sattineni & Schmidt, 2015).

The integration of mobile tools and technologies into construction operations and management can help enhance job site efficiency, quality and productivity (Azhar & Cox, 2015). Mobile computing devices have emerged as the most prominent tools to improve information accessibility, enhance management effectiveness and increase operational efficiency (Son, et al., 2012). Sharma (2014) highlighted the potential civil engineering areas or projects wherein smartphones can be used to improve accuracy and efficiency. This publication further presented some civil engineering case studies in which smartphones have been used. For example, an android application called *Smart Compass-Clinometer* was successfully used for rapid geological site investigation (Sangho, et al., 2013).

From the foregoing, it is increasingly evident that the integration or application of mobile devices such as smartphones and tablets in the construction industry is here to stay.

2.2 Concrete in the Construction Industry

Concrete is a major component of the construction industry. Every year around ten billion tonnes of concrete are produced globally (Miller, et al., 2016). This is about twice the amount of steel, aluminium, wood and plastic combined, produced every year. The demand for this material can be attributed to many desirable concrete properties that other materials do not possess, such as resistance to weathering, erosion and other natural disasters. Furthermore, concrete is relatively strong, durable, economical and requires very little maintenance if it is designed properly.

When likened to wood, plastic or other materials used for construction, concrete outlasts them by decades; in fact, concrete gains more strength as it ages (Radhi, et al., 2015). Concrete is also very versatile and, therefore, is used for various construction projects such as buildings, bridges, dams, tunnels, pavements, runways and roads.

Another matter worth noting is the fact that concrete is locally produced. In most cases, concrete used on a particular project is produced on or nearby the site and very little cement or concrete is traded or transported internationally.

Lastly, concrete, as a product, is environmentally friendly. Decades after being cast, concrete can be recycled into an aggregate that can be used for other different purposes. For example, crushed recycled concrete can be used for backfilling or constructing a new concrete pavement or road base (Kim, 2021).

2.3 The Concrete Mix Design Process

Concrete is a composite material consisting of four major ingredients namely cement, water, fine aggregate and coarse aggregate (Kent, 2010). In some cases, a fifth material, an admixture, may be added to the mix to enhance certain properties (Thomas, 2016).

Two of the major factors that influence the properties of concrete are the properties of the constituent materials and the proportions in which these constituent materials are mixed. A mix design is done to come up with the ratios that will produce concrete of desired properties for the given constituent material properties (Day, 2005).

There are various methods available for designing concrete such as the ones listed below. All these methods have their advantages and disadvantages.

Various Methods of Designing Concrete

1. Arbitrary proportion
2. Fineness modulus method
3. Maximum density method
4. High strength concrete mix design
5. Mix design based on flexural strength
6. Road note No. 4 (Grading Curve method)
7. American Concrete Institute (ACI) Committee 211 method
8. Department of Environment (DOE) method
9. Mix design for pumpable concrete
10. Indian standard recommended method IS 10262-82

Of all the above methods, only the ACI Committee 211 method, the DOE method and the Indian standard recommended method IS 10262-2019 are commonly used (Shetty & Chand, 2008). The other methods are rarely used due to difficulties or drawbacks in the procedures for arriving at satisfactory results.

3 Conceptual Design of QCD

3.1 Functional Requirements

To ensure that all the intended functionalities of QCD are incorporated, the following functional requirements were defined.

Table 3.1 Functional Requirements

No.	Functional Requirement Description
1	The software should present to the user the available functions when it is launched. These functions are: • Concrete Mix Design by the British Method • Concrete Mix Design by the American Method • Concrete Mix Design by the Indian Method
2	When the user selects the desired method of mix design, the software should do the following: • Display a list of mix designs previously performed using the selected method • Provide a button where the user can click to start a new mix design.
3	When the user clicks on one of the mix designs, the results of that mix design should be displayed.
4	When the user clicks on a button to start a new mix design, the software should automatically assign a label to that mix design and provide an option for the user to edit the label. The user should then click "yes" to proceed with the mix design.
5	The software should request for user input. i.e. the desired properties of concrete and constituent materials.
6	When the user is done entering all the parameters, the software should check if anything is missing and if the data entered is consistent. If any of the two conditions is not met, the software should ask the user to edit the data.
7	Once the user input is verified, the software should calculate the amounts (in kilograms per unit volume of concrete) of cement, water, fine aggregate and coarse aggregate.
8	The calculated amounts should be saved to the database and displayed to the user in form of a pie chart or bar graph.
9	The software should generate a report of the mix design and export it to PDF format for printing.
10	Generic functions such as share designs, delete designs, help, etc should be available in the software.

3.2 Hardware and Software Specifications

The operating system of choice is the android operating system since it is the most commonly used operating system for mobile devices. Since QCD includes certain functionalities like publishing the results of mix design in pdf format, it will only run on android version 4.4 (also known as KitKat) and above. Lastly, the software is developed to only support the English language for a start. Support for other languages may be added in future.

3.3 User Interface

For the functionalities of QCD to be performed, the user needs to interact with it. This interaction is done through the software's user interface. The goal of the user interface is to allow effective operation and control of the software from the human end, whilst the software simultaneously feeds back information to the user. Fig. 3-1 shows selected wireframe sketches of the user interface of QCD.

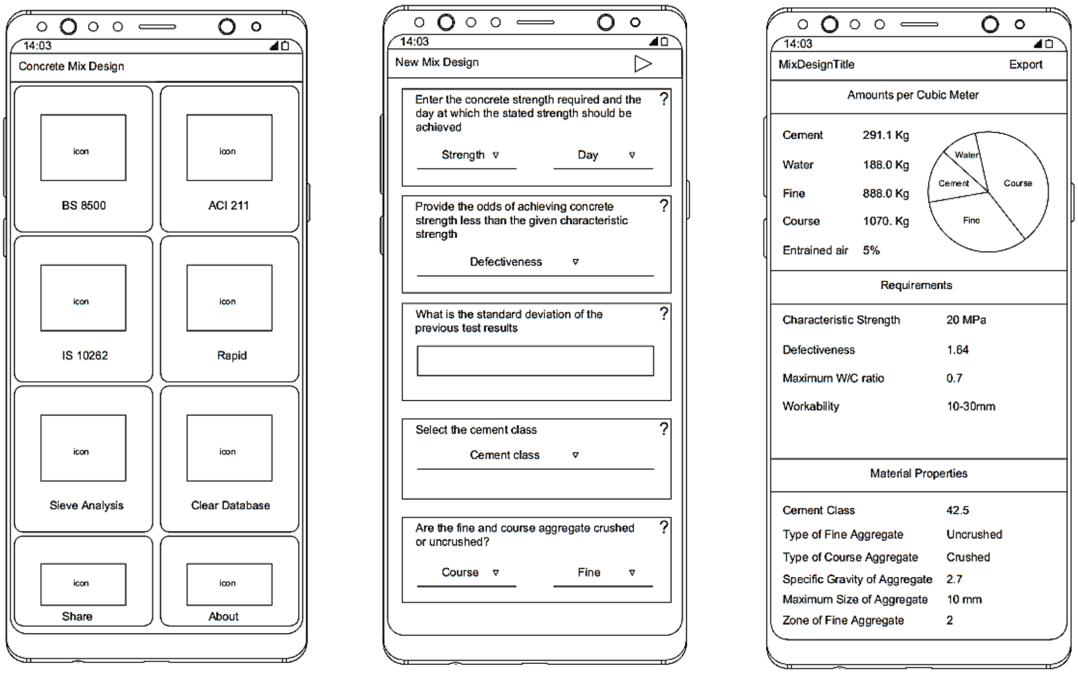

Fig. 3-1: Wireframes of selected Screens

4 Design and Development

4.1 Programing Language and Integrated Development Environment

Extensible Markup Language has been used to develop the user interface of QCD. Fig. 4-1 shows some mock-ups of the resulting user interface. The logic to get user input, carry out the design, and display the results to the user has been implemented using Java programming language. All this has been done using Android Studio as the integrated development environment.

4.2 Final Features

Three design methods namely DOE, ACI 211 and IS 10262 have been incorporated and implemented in the mix design software, including additional features such as the Nominal Mixes component which shows a list of mix ratios for selected concrete grades. A Sieve Analysis component which can be used to analyse coarse and fine aggregates in terms of their particle size distribution has also been included. Lastly, there is a discussion forum that allows users to interact with one another and discuss concrete related issues which they may encounter in the course of using the mobile application.

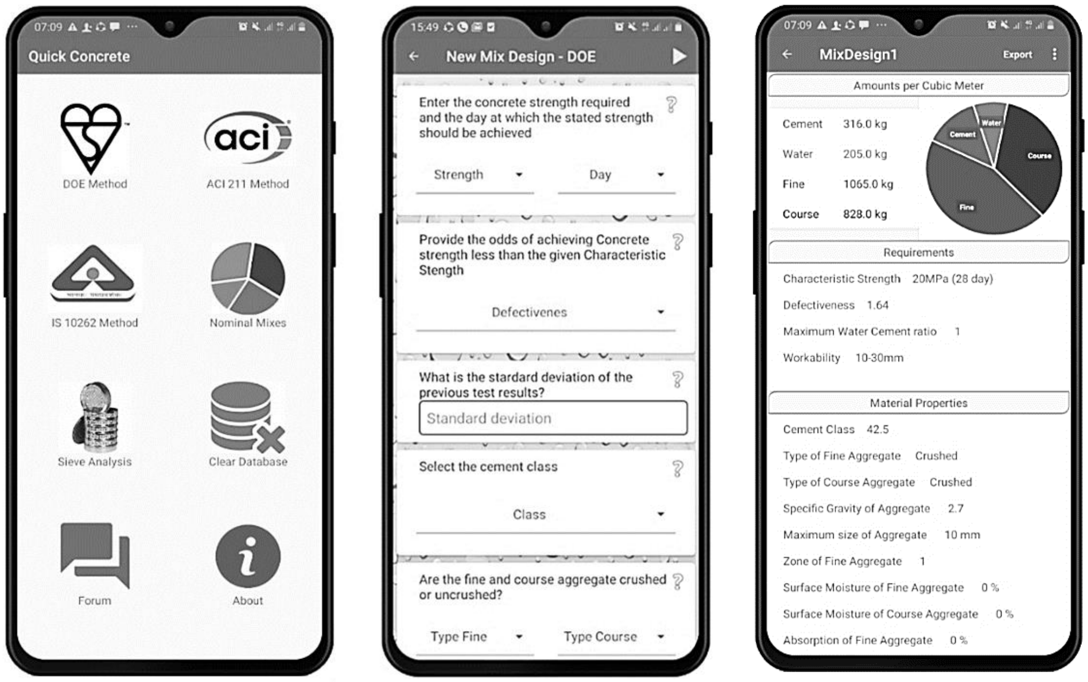

Fig. 4-1: Final user interface of selected Screens

4.3 Algorithm Flowcharts

Fig. 4-2, Fig. 4-3 and Fig. 4-4 show some flowcharts of the main functionalities of QCD such as getting user input, performing the design and displaying the results to the user.

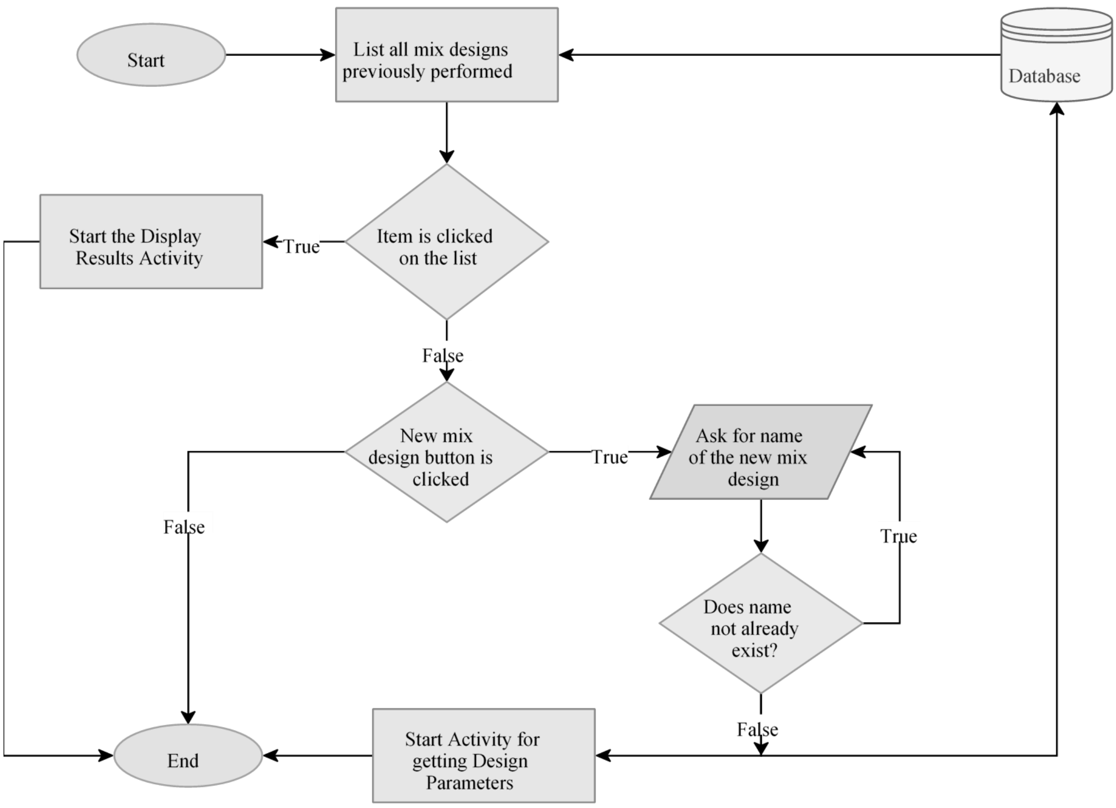

Fig. 4-2: Flowchart for Launching New Mix Design

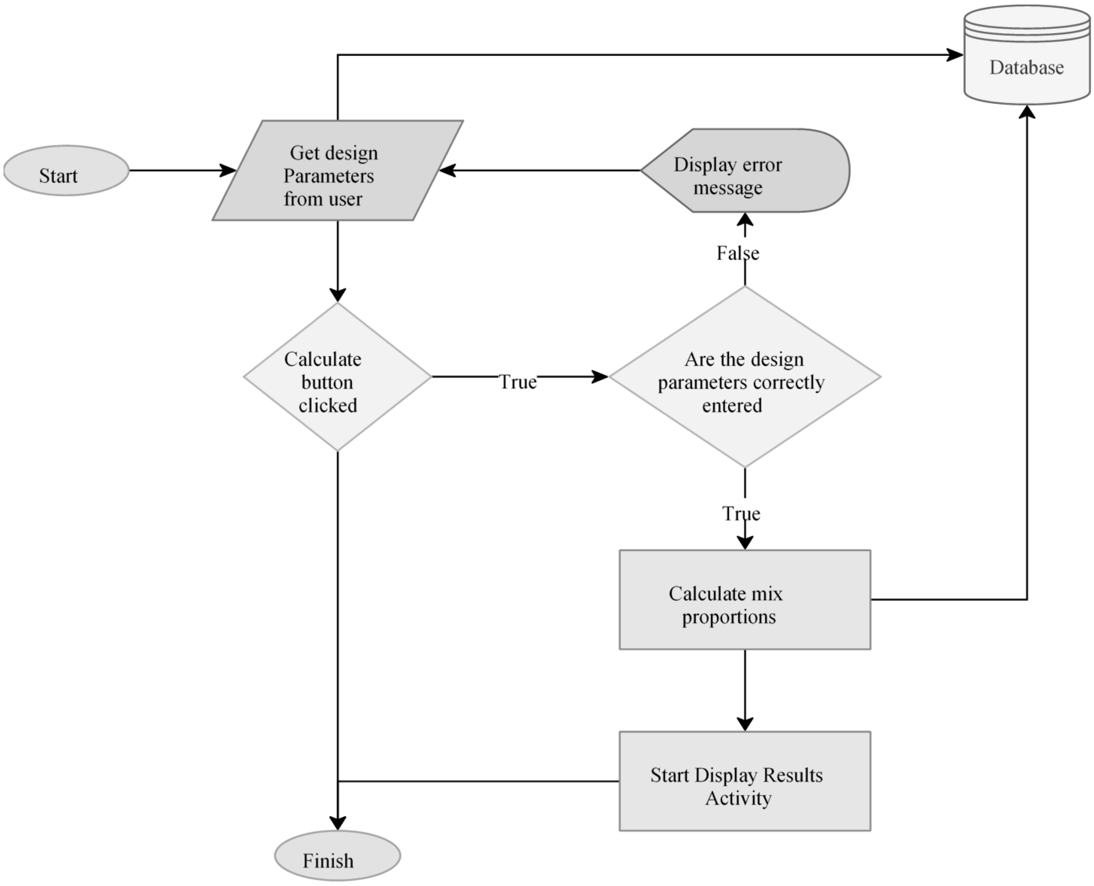

Fig. 4-3: Flowchart for Getting Design Parameters

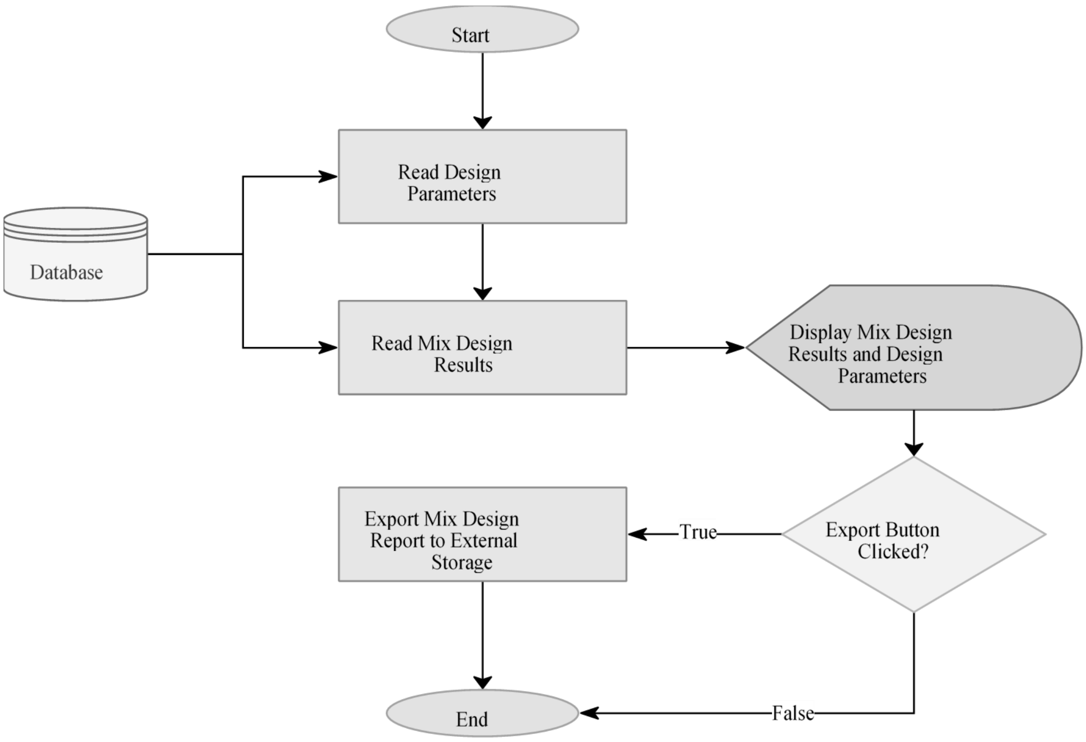

Fig. 4-4: Flowchart for Displaying Mix Design Results

5 Testing

A number of tests such as unit tests, integration tests and compatibility tests have been conducted during the development process. The idea behind this section is to check if the mobile application achieves its main functionality which is to produce as accurate concrete mix proportions as possible. Usability tests will also be conducted to show how the mobile application handles certain errors such as incorrect or incomplete input of design parameters by the user.

5.1 Usability Testing

When the user launches the mobile application and initiates a mix design, the system will ask for design inputs through clear and concise prompts. The user interface is very intuitive and provides text input fields and other user interface elements like lists and spinners that can assist the user to enter the parameters more accurately. Hints are also provided to the user for guidance on the acceptable range of design inputs. For example, the specific gravity of aggregates is confined within the range of 2.4 to 2.9 and this information is displayed to the user. Another feature that has been implemented is provision of different colours for design parameters that may not be needed in all cases and those that are always needed for design. For instance, the characteristic strength should always be provided but other parameters like the absorption properties of the aggregates can be omitted depending on the kind of aggregates available. Consequently, the prompt texts for optional parameters are shown in the colour of green and for the mandatory ones the prompt texts are shown in red. Additionally, a prompt text automatically turns to black when a parameter entered is correct, and the parameter is saved to the database. When the user clicks on the “Calculate” button, the system checks the design parameters once more and if some input is missing, an error message is shown to the user. If everything is correct, the design calculations take place.

5.2 Functional Testing

The main functionalities of the mobile application have been tested by comparing the design results produced by QCD and those produced by hand calculations for the same design parameters. Table 5.1 shows design parameters for three different characteristic strengths of concrete (M35, M30 and M50) while Table 5.2 shows the results of the required amounts of the concrete constituent materials evaluated by hand calculations and those evaluated using the mobile application. As can be observed from Table 5.2

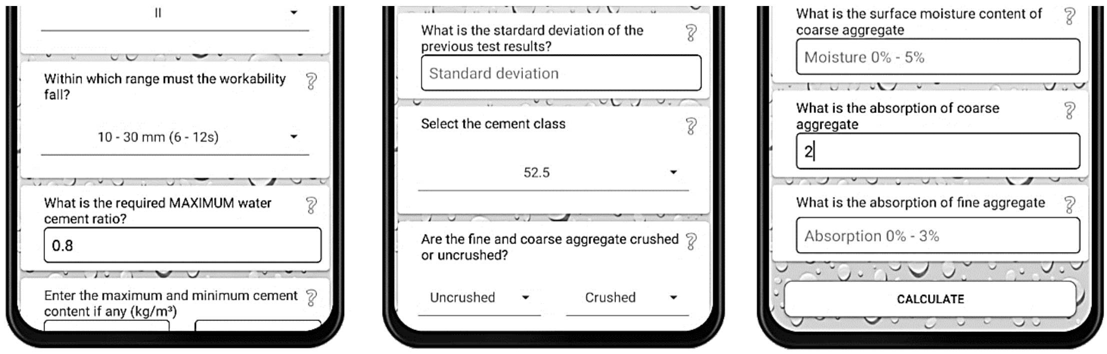

Fig. 5-1: Showing User Interface for getting design parameters , the results obtained using QCD and those from hand calculations are very identical. This indicates that QCD has passed the functional tests. Additionally, more testing has been performed by comparing the design outputs of QCD for the same design parameters but using different design codes. Column five of Table 5.1 shows design parameters for the M35 concrete characteristic strength, while Table 5.3 shows the results of the required amounts of constituent materials required to make one cubic meter of M35 Concrete as designed by IS 10262, ACI 211 and DOE methods. The three design methods produced similar results although the DOE method gave a lower cement content. This is attributed to a higher water-cement ratio for this mix design method. The DOE method also gave a higher total aggregate content as compared to the other two methods.

Table 5.1: Design Parameters for Functional Tests

Design Parameter	**DOE**	**ACI 211**	**IS 10262**	**DOE, ACI & IS**
Characteristic Strength	35MPa (M35)	30MPa (M30)	50MPa (M50)	35MPa (M35)
Degree of Site Control	-	Fair	-	-
Standard Deviation	-	-	-	5.7
Concrete Type	-	-	Reinforced	Plain
Dry rodded density of coarse aggregate	-	1645kg/m^3	-	1700kg/m^3
Cement Class	52.5	-	OPC 53	OPC 43
Type of Fine Aggregate	Natural sand	-	-	Natural sand
Type of Coarse Aggregate	Crushed	-	-	Crushed
Specific Gravity of Coarse Aggregate	2.65	2.7	2.8	2.8
Specific Gravity of Fine Aggregate	-	2.6	2.7	2.7
Maximum Size of Coarse Aggregate	20mm	25mm	10mm	20mm
Zone of Fine Aggregate	II	-	IV	II
Fineness Modulus of Fine Aggregate	-	2.45	-	2.75
Workability	10s vebe	160mm	90mm	35mm
Maximum Water Cement Ratio	0.8	-	-	-
Minimum Cement Content	200kg/m^3	-	-	-
Air entrainment	6%	None	None	None
Surface Moisture of Fine Aggregate	2%	0.50%	1%	1%
Surface Moisture of Coarse Aggregate	-	-	1%	-

Absorption of Coarse Aggregate	3%	-	2%	0.5%
Exposure Condition/Environment	-	Water	-	-
Exposure Degree	-	Mild	Moderate	Mild

- ***Not specified by the design code***

Table 5.2 Amounts of constituent materials required to make one cubic meter of concrete as designed by hand and by QCD for different grades of concrete.

	DOE (M35 concrete)		**ACI 211 (M30 concrete)**		**IS 10262 (M50 concrete)**	
	Hand Calculations	Using QCD	Hand Calculations	Using QCD	Hand Calculations	Using QCD
Water	175.3 kg	175.0 kg	202.5 kg	202.0 kg	215.2 kg	215.0 kg
Cement	271.7 kg	270.0 kg	484.2 kg	482.0 kg	617.2 kg	612.0 kg
Fine aggregate	666.7 kg	665.0 kg	514.1 kg	516.0 kg	677.2 kg	680.0 kg
Coarse aggregate	1347.3 kg	1345.0 kg	1159.7 kg	1160.0 kg	917.5 kg	919.0 kg
Entrained Air	6%	6%	-	-	-	-

- ***Not specified by the design code***

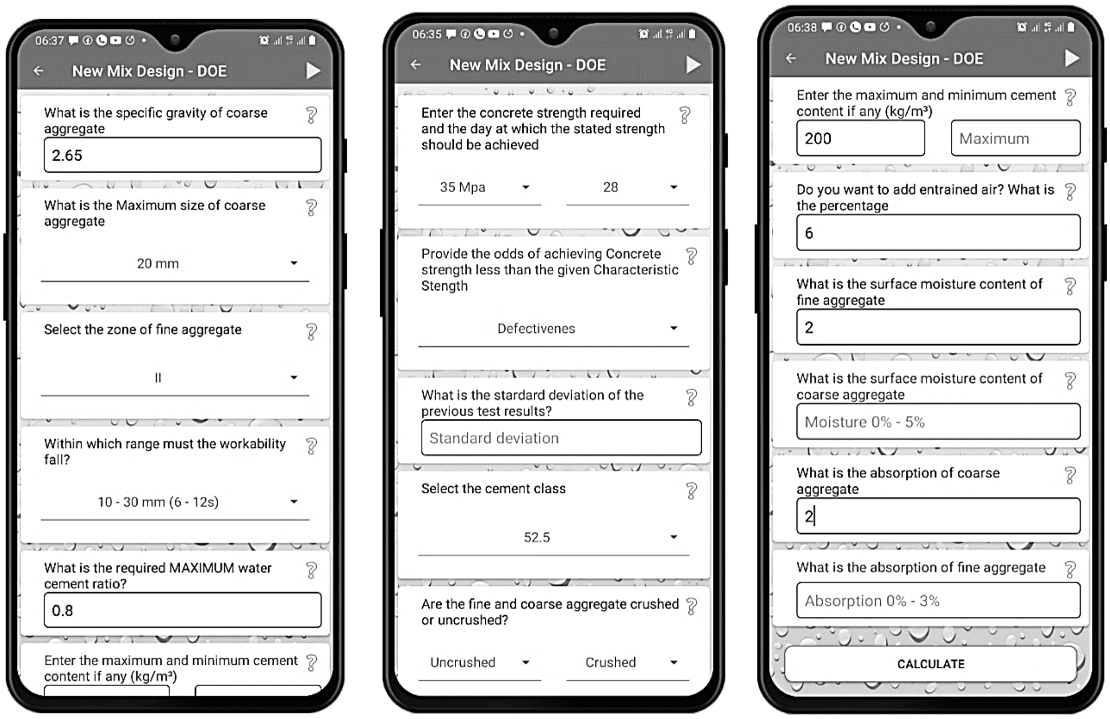

Fig. 5-1: Showing User Interface for getting design parameters

Table 5.3: Amounts of constituent materials required to make one cubic meter of M35 concrete as designed using QCD in accordance with IS 10262, ACI 211 and DOE methods

Method	**Water Cement Ratio**	**Cement Content (Kg/m^3)**	**Water Content (Kg/m^3)**	**Fine Aggregate (Kg/m^3)**	**Coarse Aggregate (Kg/m^3)**	**Total Aggregate (Kg/m^3)**
IS 10262	0.38	484	182	634	1174	1808
ACI 211	0.39	473	183	724	1057	1781
DOE	0.54	353	189	727	1234	1961

6 Conclusion

A mobile application, Quick Concrete Design (QCD), for performing concrete mix design has been designed and developed. The development of QCD has been done in Java programming language using Android Studio as the integrated development environment (IDE). Three design methods, namely DOE, ACI 211 and IS 10262 have been incorporated. Extra functionalities such as a list of nominal mixes, a sieve analysis evaluation and a discussion forum have been included in QCD. Finally, for performance quality assurance, unit and beta tests have been conducted to verify the accuracy and correctness of QCD. In all these tests, the calculation of concrete constituent materials from the software has yielded results that are very similar to those obtained by hand calculations. Furthermore, the mix design process using QCD is extremely quick compared with the use of hand calculations.

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Permeable pavement as a sustainable method for urban flooding and pollution management system – Sustainable engineering

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Abstract

Growing populations and migration towards built areas is driving land use change in the form of urbanisation across the globe, (UN, 2008). Urbanisation has brought about a range of environmental challenges for both the local and wider environment due to changes in hydrological systems, (Fletcher, *et al.,* 2013). This urbanisation has led to an increase in the use of impervious surfaces resulting in reduced infiltration in soils and contributing to higher recurrence of floods, reduced base flow and reduced ground water recharge (Simon and Reynolds, 1982) also a greater magnitude of river flow (Hawley and Bledsoe, 2011). These impervious surfaces have become major contributors to urban flooding and pollution which has negatively altered the urban cycle (Kalnay and Cai, 2003). Permeable pavements are seen to be sustainable methods for mitigating flooding and pollution due to their infiltration characteristics which in turn contributes to groundwater recharge.

Keywords: Urbanisation, Permeable, Infiltration, Flooding, Pavement.

1 Introduction

The rapid increase in urbanization has led to the consequent increase in impervious surfaces due to human settlement and land use in urban areas. This has become a major contributor to urban flooding and it can be mitigated by the alternative use of pervious surfaces. This mitigation can be achieved by constructing permeable pavements directly on the free surface (natural ground) so that storm water can be directed into the ground, (Pratt *et al.,* 1989). Consequently, the use of these porous pavements in mitigating urban flow rates and volume would also result in runoff mitigation, (Legre and Colandani, 1995), thereby making permeable pavements a sustainable method for urban flooding and the pollution management system.

Urban floods may destroy human life and properties and as a result of this, people would suffer from many problems regarding transportation, health, access to goods and services and other types of daily expenses, (Suman, M. *et al.,* 2020). So it is necessary to mitigate urban floods through a sustainable engineering method of use of permeable pavements. This is because permeable pavements would allow runoff infiltration through the pavement and the pavement would be

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reducing runoff which can improve water quality, which is in line with sustainable urban drainage system targets, Bean *et al.,* (2004).

With the rising urbanisation due to modernisation as well as technological trends, there has been rampant population increases in urban areas. This has caused a higher density occupation of land for settlement and other human activities in urban areas hence contributing to a rise in the use of impervious surfaces (Arnold and Gibbons, 1996). In times of heavy rainfall, there is little infiltration capacity high enough to absorb all the rainwater due to this rise in impervious surfaces, (Naef, *et al.,* 2002). To address this, permeable pavements could be an important mechanism of retention and detention of storm water runoff. This is because permeable pavements provide an opportunity for the infiltration of the runoff, in addition to providing a durable and aesthetically pleasing surface.

As a sustainable engineering solution, the use of permeable pavements in place of impermeable pavements, calls for the proper design and construction of all permeable pavements. This is because the proper construction of permeable pavements is critical with regard to their long term performance in the management of storm water. Improper or inadequate erosion and sediment control during construction and immediately following construction of the permeable pavement can cause immediate plugging of the pavement, (Fairfax Count, 2019). It is for this reason that in this paper and for the purpose of this research a thorough consideration of the design and construction of the permeable pavement will be presented. The materials and installation techniques for the different pavements will also be presented and explained. The permeable pavements to be considered in this paper include; Pervious Concrete Pavements (PCP), Permeable Interlocking Pavements (PICP), Concrete Grid Pavers made in form of Terracrete Blocks, Porous Asphalt Pavements (PAP) and Pervious Waste Plastic Pavements (PWPP). These permeable pavements are presented together with their materials and the mix ratios that will be adopted for them.

1.1 Theoretical Reviews.

Increased urbanisation results in impervious areas because development in urbanisation is associated with road connectivity, roofs, industrial areas, parking lots, hospitals, restaurants, parks, buildings and other institutions. These lead to a reduction in land and vegetation that naturally absorbs the precipitation from the surfaces. Reduction in infiltration of rainfall in urban areas results in urban flood or storm water. According to MRLC, up to 40% of land in urban areas or cities is impervious, (Xian, *et al.,* 2011).

India has been rapidly urbanising. In 1950, about 17% of the population lived in an urban area but as recorded in 2016 more than a third part of a total population have migrated to urban areas or cities (Kundu, A., 2011. Many states which are well developed such as Maharashtra, Delhi, Karnataka, Gujarat, Tamil Nadu and Madhya Pradesh have suffered from urban flooding from the last few decades, (Kundu, A., 2011). The human factor is the major cause for urban flooding due to land use change (imperviousness due to urbanisation, deforestation, etc.), which results in surface runoff and sedimentation in urban areas. The lack of proper drainage system is also a cause for urban flooding. The roads, drainage systems overflow due to heavy rainfall and imperviousness of the area. This causes inconvenience as well as life loss, property loss, skin diseases, disruption in transportation, electricity transmission, damage of infrastructures, damage to pavements and drainage systems, (Rogens and Faha, 2007).

When the drainage systems do not have capacity to carry storm water due to intense rainfall they overflow and are converted into surface runoff. Recent urban floods in India include ones in Uttarakhand, Karnataka, Chennai, Assam, Madhya Pradesh, Mumbai and Delhi, (Gupta, K., 2020). Mumbai and Delhi are the cities that are well developed in India and during the rainy season, the whole area suffers from flooding, (Singh, *et al.*, 2013). Due to this urban flooding, it was observed that there are inconveniences to the public in terms of following their daily routine, (Pratt, *et al.*, 1989). The most used permeable pavements are a matrix of concrete blocks or plastic web structures with voids filled with sand, permeable soils and gravel. This reduces the impact of runoff caused by development in the urban area, (Brattebo, *et al.*, 2003). Generally, impervious surface creates more dirt and debris (as compared to pervious surfaces) along with runoff over the surface and directed to the water channels. Normal asphalt repels water to infiltration so it is better to use porous asphalt pavements in such areas as in parking lots, shoulders and footpaths to manage the storm-water, (Cahill, *et al.*, 2003). Mostly, urban areas are covered more by houses, buildings, industries, and impervious pavements compared to trees or forests. This clearly entails that there is a wider area of impervious surfaces in urban areas as there are pervious surfaces. The wider impervious surfaces in urban areas prevents runoff from infiltrating into the ground and thereby leading to urban flood. Choker course is used for infiltration of runoff and creates temporary storage, (McNally, et al., 2005). The pavement constructed over the porous soil allows precipitation to pass into the soil and effectively reduces the runoff from accumulating on the pavements area.

In one study, (Pratt, *et al.*, 1989) described the permeable pavement system with four separate sub-base sections to mitigate the urban flood. The study area was taken as Clifton campus of Trent Polytechnic in Nottingham, England with the objective of determining the discharge rate of permeable pavements. In the sub-base sections, the four types of stones were used to construct the permeable pavement system. The four types of stones used were limestone, Granite, Basalt and Sandstone. The reason behind using these types of stones was due to their physical and chemical properties which are key in the construction of permeable pavements such as strength, hardness, texture structure, porosity and absorption. From the results, it was concluded that the peak discharge rate was about 30% of the peak rainfall. (Legret, *et al.*, 1999) proposed the pervious asphalt pavement in the catchment of Classerie Street in Reze, France with the objective of determining the infiltration rate. The material used for the construction of the structure was geotextile woven, crushed material, porous bituminous-bound, graded aggregates, porous asphalt. In the study, the sidewalks and side parking lots were also constructed as a permeable system. From the study, it is observed that 96% of surface storm water infiltrates immediately and reduces the chances of urban flooding significantly. (Collins, *et al.*, 2008) developed four types of permeable pavements and porous asphalt in eastern north California for parking lots. The pervious concrete, two types of permeable interlocking concrete, and concrete grid pavers were used as permeable pavement systems in the study. These four types of permeable pavement systems reduced the storm water or surface water significantly when compared with asphalt pavement. The surface runoff generation is more in asphalt surface and much lower in the porous concrete surface. It was observed from the study that there are no significant differences between all permeable pavement systems used in the analysis.

Also, (Hamzah, *et al.*, 2012) presented porous parking lots in Malaysia to control storm water. The material used for construction was granite aggregate for the choker. With the compaction of the soil, the coefficient of permeability decreased. A water flow simulator was used in the study and it was able to simulate 1.24-59.89 cm/h rainfall intensity. (Brunetti, *et al.*, 2016) defined the low impact development (LID) techniques to mitigate the urban flood flow in Italy. To define the hydraulic characteristics of the permeable pavement the Hydrus-1D model was used in the study of a comprehensive numerical analysis of the hydraulic behaviour of permeable pavement. The layers of pavement consisted of the base layer and sub-base layer the porous concrete blocks and in-bedding layer the ASTM stone gradation. The top layer of the pavement was more efficient to infiltrate the storm water. (Hammes, *et al.*, 2018) explored the areas of parking lots constructed by porous asphalt to mitigate and store the storm water in an urban area and to re-use the collected water for non-potable purposes in Brazil. The amount of surface water is filtered and infiltrated through the sub-base layers to the storage layer. About 20 litres of surface runoff for each rainfall event in the study was collected and of that, 80% was the runoff water collected from parking lots model.

The literature reviewed above, largely entail the higher infiltration rate obtained from permeable pavements. It can therefore be seen that permeable pavement can largely contribute to urban flooding management and as such there is need for their implementation for it is also in line with sustainable engineering

2 Materials and Methods

2.1 Permeable pavement construction sequence:

Step 1: Construction of the permeable pavement begins after the entire contributing drainage area has been stabilized. It should be made sure by the designer that the site is checked for existing utilities prior to any excavation.

Step 2: The proposed permeable pavement area must be kept free from sediment during the entire construction process. It should also be made sure that construction materials contaminated by sediments must be removed and replaced with clean materials.

Step 3: Where possible, excavation should work from the sides and outside the footprint of the permeable pavement area so that soil compaction is avoided. In carrying out construction, constructing personnel's can utilize a cell like construction approach.

Step 4: The native soils along the bottom of the permeable pavement system can be scarified or tilled to a depth of 0.15m and graded prior to the placement of the aggregate and if geotextiles are to be installed still, they should be installed on the sides of the reservoir layer applications that do not use concrete curbs extending the full base depth.

Step 5: Aggregates of about 0.02m should be provided around underdrain pipes. The underdrains should slope down towards the outlet at a grade of 0.5 percent or steeper. Where an underdrain pipe is connected to a structure, there should be no perforations within at least 0.3m of the structure.

Step 6: A maximum of about 1m should be spread for the reservoir base/subbase or base stone and the aggregate should be moistened during spreading for this can facilitate better compaction. In the case of permeable interlocking concrete pavements which require a 0.15m base layer should be compacted separately from the subbase layer with two passes in vibratory and two in static mode.

Step 7: The desired depth of the bedding layer should be installed depending on the type of pavements. I.e. for pervious concrete, no bedding is used, for porous asphalt, the bedding should be used and should consist of 0.02m of washed No. 57 stone.

Step 8: After the successful installation of the permeable pavements surface, it should be subjected for acceptance tests using the considerable infiltration rate.

3 Discussion and Results

3.1 Pervious Concrete Pavement.

The core purpose of Pervious Concrete Pavement is to have a considerable rate of infiltration with regard to the average rainfall intensity in the areas in which they will be installed. A mix design that would enable the achievement of a Pervious Concrete Pavement with a compressive strength ratio above 16 Mpa after 28 curing days can be adopted. Since the strength of Pervious Concrete Pavement is largely affected by its porosity which is even the main characteristic feature that is being looked for, two singled sized aggregates will be used and these will be 15mm and 17mm aggregates so that the porosity of Pervious Concrete Pavement will be achieved at an estimated value of 13mm/s through a 0.5 x 0.5 square meter area with a 0.15m thickness in an hour. For the Pervious Concrete Pavement to be more porous, 75% of 17mm aggregates and 25% of 15mm aggregates will be used in the mix. The binder content that will be used is Ordinary Portland cement and the mix ratio will be 1:6, 1 for the cement binder content and 6 for the coarse aggregate. The materials as well as their amounts are listed in the table below.

Table 1: Mix design ratios of Pervious Concrete Pavement.

Material	**Amount in Mix**
17 mm Aggregates (75%)	63.36kg
15 mm Aggregates (25%)	21.12kg
Cement Binder Content	12.67kg
Water Cement Ratio	0.45

3.2 Permeable Interlocking Concrete Pavement.

For making the Permeable Interlocking Concrete Pavements, coarse aggregates, fine aggregates and Ordinary Portland Cement will be required. The mix that will be adopted for these 3 materials is 1:1.5:3, 1 for cement, 1.5 for the fine aggregate and 3 for the coarse aggregate. This kind of a mix will be adopted because a compressive strength of above 20Mpa will have to be achieved for the Permeable Interlocking Concrete Pavements. Also, the pavements will be made such that they will be able to interlock in all of their sides to the other adjacent pavements. This will largely be determined by their shapes. The thickness for the Permeable Interlocking Concrete Pavements will be 100mm and calculations for a mix design for a 0.5 x 0.5 m^2 size of pavement were carried out and the amount of materials needed are tabulated below.

Table 2: Mix design ratios of Permeable Interlocking Concrete Pavement.

Material	Amount in Mix
Cement	16.13kg
Fine aggregates	23.52kg
Coarse aggregates	53.76kg
Water Cement Ratio	0.45

3.3 Concrete Grid Pavers (CGP) – Terracrete Blocks.

The concrete grid pavers will be made in form of terracrete blocks which will be uniquely designed to meet both the hydrological and structural design required from permeable pavers. The blocks will be made in dimensions of 100mm thickness, 250mm breadth and 250mm length (150 x 250 x 250 mm). For these Concrete Grid Pavers, a concrete mixture that will need to attain a compressive strength above 20Mpa will be required to be made and to this effect, still a mix ratio of 1:1.5:3 will be used. Calculations of the mix design for the materials needed for one terracrete block were carried out and the amount of the materials required are tabulated below. An example of a terracrete block is as well shown below.

Table 3: Mix design ratios of a 0.1x0.25x0.25m Concrete Grid Paver – Terracrete Block.

Material	Amount in Mix
Cement	2.52kg
Fine aggregates	3.68kg
Coarse aggregates	8.40kg
Water Cement Ratio	0.45

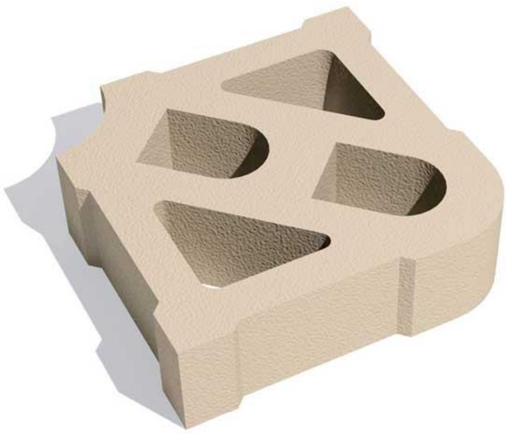

Fig. 1: Terracrete Block

3.4 Porous Asphalt Pavement.

The Porous Asphalt will be designed with an open graded mixture which will allow voids of about more than 18 %. This is because a Porous Asphalt Pavement having voids of more than 18%, will definitely have a higher infiltration rate which is a key characteristic for a pervious pavement. Therefore, all the three materials which include bitumen, coarse aggregate (all materials retained on the 4.75mm sieve) and a filler (typically a fine aggregate material in small proportion i.e. material passing the 4.75mm sieve) will be mixed in a way that will enable the achievement of a void percentage of more than 18%. The bitumen that will be used in the mixture will be Polymer modified bitumen A-P1 with a penetration grade of 35/50, 50/70 or 70/100 (the choice between the 3 will depend on their availability). Quarry dust will be used as a filler and coarse aggregates of different sizes per gradation will be used though in this mix, 2 to 3 sizes of aggregates will be omitted in order to enable the achievement of the required percentage of voids in the Porous Asphalt Mixture. The proportions of the materials to be used is as Tabulated below;

Table 4: Mix design ratios of Porous Asphalt Pavement

	Sieve Size (mm)	37.5mm Max
	37.5	100
	26.5	84 – 94
	19.0	71 – 84
	4.75	36 – 53
	2.36	25 – 42
	1.18	18 – 33
Active Filler (Hydrated Lime)	Aggregate	95.0%
	Bitumen (A-P1 35/50, 50/70 or 70/100)	4.0%
		1.0%

3.5 Pervious Waste Plastic Pavements.

To make pervious waste plastic pavements, polyethylene terephthalate (PET) waste will be mixed with coarse aggregates. For these pavements no filer or fine aggregates in whatsoever state will be used. Only aggregates sizes ranging from 4.75 mm and going up will be used. The Polyethylene Terephthalate which is the thermoplastic used for food and beverage packaging i.e. such as plastic bottles will be used. These will be cut in small chips and the chips will be added to the preheated aggregates at 270 degrees Celsius. The chips will be added with a 7.5% mass ratio. Square blocks of 0.15 x 0.5 x 0.5 m will be made. The composition of both the aggregates and the Polyethylene Terephthalate in the mix are shown in the table below and the mix ratio will be 1:3.

Table 5: Mix design ratios of Pervious Waste Plastic Pavement

Material	Amount in Mix
Polyethylene Terephthalate (PET)	7.5%
Coarse Aggregates	92.5%

4 Conclusion

Allowing runoff to pass through the permeable pavement minimises runoff volume and this would reduce urban flooding and contribute to improving water quality, which is in line with sustainable engineering. The development of different types of pervious pavements to provide a solution for mitigating urban floods will also create a pollution management system. In addition, this project is also aimed at developing a new pervious pavement system using waste materials, which would as well reduce urban flooding and contribute to pollution management since the waste materials will no longer be exposed to the ground but rather be used for the development of the permeable pavements.

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The energy transition and demand for metals: Opportunities for Zambia

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Abstract

As the effects of global climate change become increasingly adverse, the global community is coming together to combat climate change by adopting clean energy technologies that do not emit greenhouse gases. The transition to clean energy technologies, particularly in the transport and energy sectors, will result in increased demand for the minerals used to develop them. The projected surge in demand for these mineral resources presents huge economic benefits to resource-rich countries hosting them. Zambia, which is already a source of some of these minerals, could also potentially host other clean technology minerals such as lithium and rare earth elements. However, it is important that the country adopts legislation and policies that will ensure exploration, extraction and processing of these mineral resources has baseline social, environmental and climate footprint throughout the value chain.

Keywords: Energy transition, clean energy technology, lithium, rare earth elements

1. Background

As the world faces an unprecedented climate crisis, the global agenda to decarbonise the energy and transport sectors has gained momentum (Banks *et al.*, 2019). The Paris Agreement, which has so far been ratified by 192 parties that include Zambia, endeavours to shift the world to a low-carbon economy via clean energy technologies. At the last UN Climate Change Conference of the Parties (COP26), the parties agreed to phasing down use of fossil energy and attaining net zero emissions by the middle of this century (COP26, 2021). These global commitments are accelerating the adoption of clean technologies in the transport and energy sectors (Church and Crawford, 2020). Table 1 shows key clean energy technologies and minerals that are required to build them.

Table 1: Clean energy technologies and minerals required to build them

Clean energy technology	Minerals required
Solar Power	Bauxite & Alumina, Cadmium, Copper, Gallium, Germanium, Indium, Iron, Lead, Nickel, Selenium, Silicon, Silver, Tellurium, Tin, Zinc
Wind Power	Bauxite & Alumina, Chromium, Cobalt (Co), Copper (Cu), Iron (Fe), Lead (Pb), Manganese (Mn), Molybdenum (Mo), Rare Earth Elements (REE), Zinc (Zn)
Electric vehicles and energy batteries	Bauxite & Alumina, Cobalt, Copper, Graphite, Iron, Lead, Lithium (Li), Manganese, Nickel (Ni), REE, Silicon (Si), Titanium (Ti)

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Because clean energy technologies consume more metallic minerals, and in addition new metals that have not been used on a large scale so far such as REE and Li, this will lead to rise in demand for these resources as the technologies become mainstream (Svemin, 2021). Figure 1 shows mineral consumptions for selected transport and power generation technologies. The World Bank estimates that demand for these minerals could rise by almost 500% by 2050, and that more than 3 billion tonnes of these materials will need to be extracted to keep pace with demand (Fawthrop, 2020).

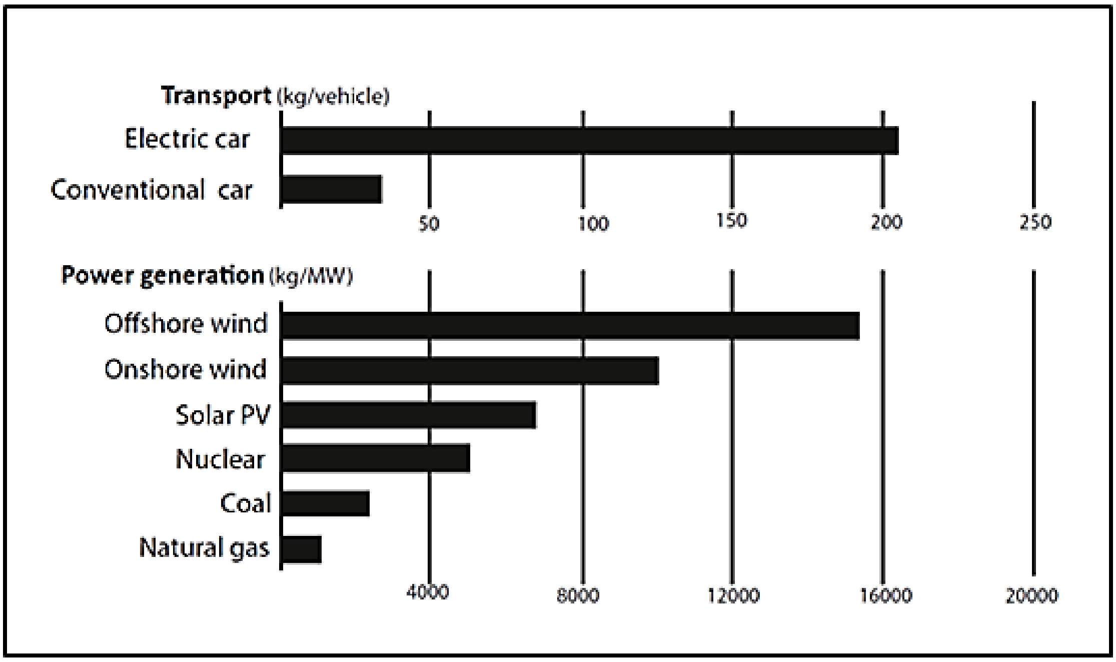

Figure 1: Mineral consumption for selected transport and power generation technologies (Modified from IEA, 2020).

State and private players are now investing heavily in clean energy technologies. In 2020, the Chinese government increased its budget for renewable energy subsidies to $13 billion (Bloomberg News, 2020). The United States of America (USA) has committed to creating at least 10 million clean energy jobs and attaining a carbon free energy sector in the USA by 2035 (Lybrand, 2021). Moreover, in the European Union's (EU) long-term budget for 2021–2027, at least 30% of the expenditure is earmarked for climate-related projects (EU, 2022). In the private sector, car manufacturers like Volvo, BMW, Volkswagen, Daimler and Toyota have taken strides to electrify all their fleets by 2050 (Church and Crawford, 2020; Overland, 2021). Figures 2 illustrates the growth trajectories of clean energy technologies in the energy and transport sectors.

The World Bank suggests that the shift to clean energy technologies offers economic benefits to resource rich countries like Zambia, (Church and Crawford, 2020). This contribution highlights the potential that Zambian has as a reliable and sustainable source of some of these clean technology minerals listed in Table 1 but have not yet been exploited. An early realisation of the key role these minerals will play in the global economy could help the country build value chain around these metals and the clean technologies they underpin.

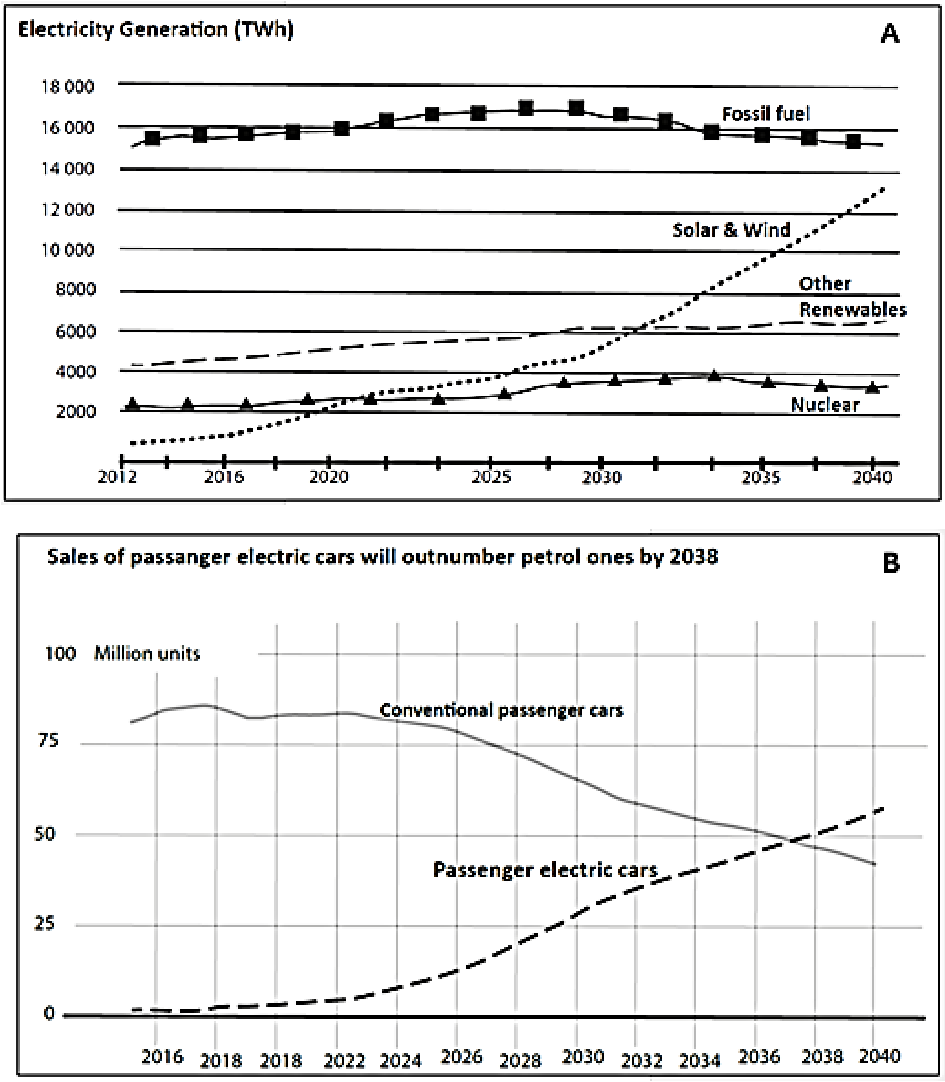

Figure 2: A) Solar and wind generated electricity set to overtake fossil electricity in the second half of this century. B) More passenger electric cars than conventional cars will be sold by 2038, (Bloomberg BusinessWeek, 2017; Bloomberg New Energy Finance, 2017)

2. Clean energy mineral resources in Zambia

The Zambian geological bedrock hosts some of the minerals considered critical to clean energy technologies presented in Table 1. Commodities such as copper, cobalt, lead, zinc, manganese and nickel are already actively exploited in different parts of the country (Figure 3). In view of this anticipated demand surge, there is need to review and improve our current understanding of ore deposit models to increase productions, and extend the lifespan of current mining operations. Increased metals demand also means that some mineralised areas that have been considered marginally economic to sub-economic could potentially represent profitably exploitable resources in a not so distant future. It is for this reason that this review is revisiting REE and lithium which have not yet been mined in the country although past studies are pointing to geological terranes amenable for their mineralisation (Mambwe and Mwape, 1991). The following is a synopsis of geological terranes in Zambia that could have potential for economic REE and Li mineralisation.

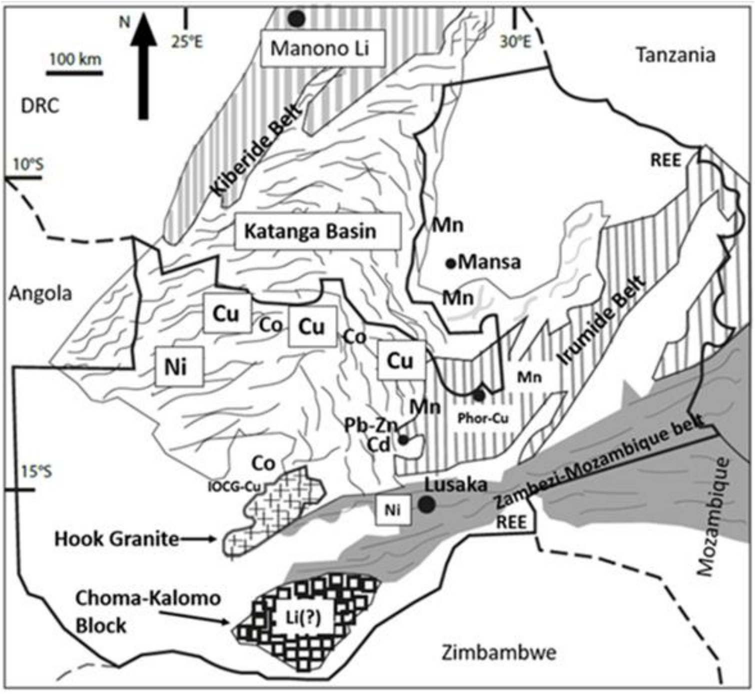

Figure 3: Simplified geological map of Zambia showing selected geological terranes and clean energy technology minerals that they host or could potentially host

2.1 Rare earth elements (REE) deposits

REE refer to a group of seventeen metallic elements of the periodic table from lanthanum (La) to lutetium (Lu) including yttrium (Y) and scandium (Sc) (Harmer and Nex, 2016). REE are used to make strong magnets such as neodymium-iron-boron magnets that constitute critical components in electric cars and wind turbines (Linnen *et al.*, 2014). Potential deposits for economic REE deposits in Zambia are the carbonatite rock deposits. These rocks constitute the majority of the world's REE resources and are presently the main sources for global REE minerals (Goodenough *et al*., 2018). The carbonatite deposits that have so far been identified in Zambia are:-

2.1.1 Nkombwa Hill carbonatite

The Nkombwa Hill carbonatite deposit is in Isoka District of Muchinga Province. It occurs as a roughly circular plug with a diameter of 1 km. It is intruded into biotite gneisses of the Irumide Belt at the northern edge of the Luangwa valley (Bailey, 1977). Preliminary investigations from Nkombwa carbonatite have report elevated REE grades of up to 23% total rare earth oxides predominantly hosted in monazite (Harmer and Nex, 2016; Mambwe and Mwape, 1991).

2.1.2 Rufunsa carbonatites

The Rufunsa carbonatites are in Luangwa District of Lusaka Province. The carbonatites comprise four separate hills that lie on a northwest trending arc that approximately parallels the lower reaches of the Rufunsa River, a tributary of the Luangwa River. These carbonatite bodies are the Kaluwe, Nacomba, Mwambuto and Chasweta hills. The Rufunsa carbonatites were intruded into gneisses and granites of the Basement Complex before piercing through the Karoo sedimentary rocks. Anomalous radioactivity associated with REE mineralisation at Rufunsa carbonatites has been reported (Mambwe and Mwape, 1991).

2.1.3 The Kesya and Mkwisi carbonatites

These two carbonatite bodies are located within the vicinity of each other about 100 km south-east of the city of Lusaka. The Kesya and Mkwisi carbonatites are hosted within the Basement Complex gneisses and metasedimentary rocks of the Zambezi Mobile Belt respectively. At Kesya and Mkwisi, REE mineralisation of up to 4% of the host rocks and mainly hosted in monazite and xenotime have been reported (Mambwe and Mwape, 1991).

Majority of the carbonatite deposits in Zambia are in the south-eastern parts of the country in the vicinity of the Zambezi and Luangwa rift systems. Figure 4 shows the locations of the carbonatite centres in Zambia and gives simplified geology of the deposits.

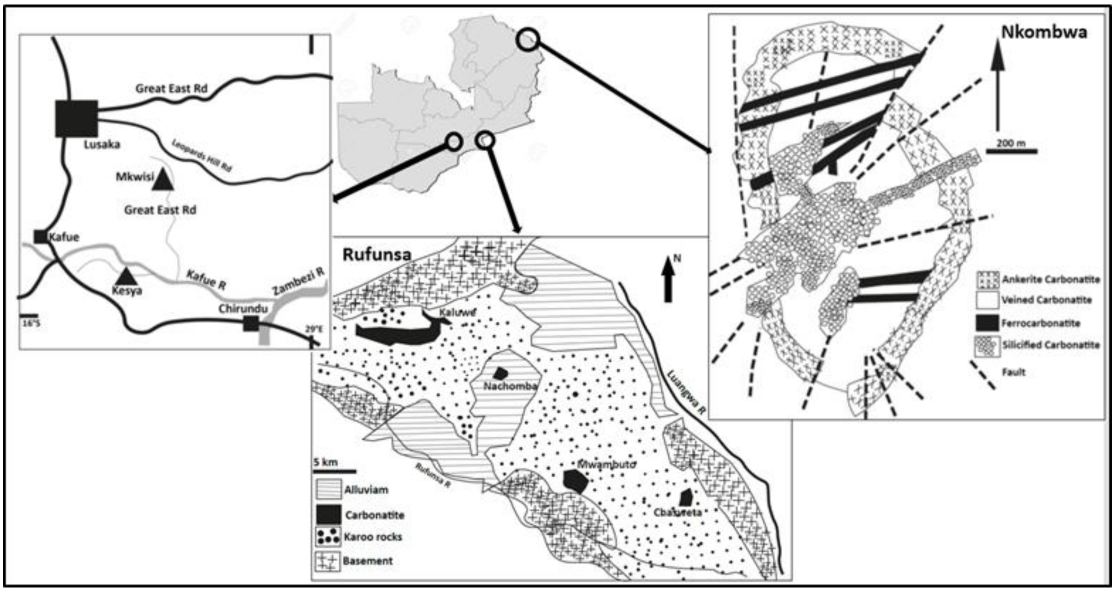

Figure 4: The locations of the carbonatite deposits in Zambia including simplified geological maps of the Nkombwa and Rufunsa carbonatites, (Modified from Bailey, 1960 and Zambezi, 1995)

2.7 Lithium

Lithium is one of the crucial metals essential for the energy transition. It is used to produce lithium-ion batteries (LIBs) used to power electric cars, as well as to store utility-scale electric energy (Graham *et al*., 2021). As the global demand for electric cars rises and the supply of lithium tightens, the price for this mineral will keep rising and the world is set to look for more sources of the commodity (Holman and Ribeiro, 2021). In Africa, Lithium deposits are predominantly hosted in Lithium-Cesium-Tantalum (LCT) pegmatites rocks (Nex *et al*., 2021).

The LCT pegmatites account for a quarter of the world's lithium production (Dwight *et al*., 2017). The Mesoproterozoic Kiberide Mobile Belt which extends from southern DRC (Figure 3) to southwest Uganda contains numerous deposits of lithium, tin, tungsten, niobium and tantalum (Dewaele *et al* 2011; Pokl *et al* 2013). The Kiberide Belt hosts the world's largest pegmatite lithium deposit, the Manono deposit found in the DRC (Roker, 2018). In Zambia, a Mesoproterozoic geological terrane known as the Choma-Kalomo Block in the Southern Province of Zambia is thought to belong to the Kiberide Belt (Bulambo *et al*., 2004). Like the Kiberide Belt, The Choma-Kalomo Block has LCT pegmatites that contain tin, tantalum and potentially also, economic lithium mineralisation (Lungu, 2016; Nex *et al* 2021). In other parts of Africa today, LCT pegmatites like those of the Choma-Kalomo Block are the main focus for lithium exploration (Nex *et al*., 2021).

3. Discussion

The energy transition offers Zambia a real economic opportunity to benefit from the surging demand for clean technology minerals. For minerals that the country is already exploiting, there is need for more exploration to extend the lives of current operations that could be nearing their end and to discover new reserves. The energy transition is also driving demand for metals that have never been exploited in Zambia before. For Zambia to rump up production at current operations and identify new deposits, there is need to scale-up our understanding of known deposits and carry out more explorations so that the country can start extracting strategic metals that it is not currently producing. Electric vehicles and storage batteries are technologies that require some metals that have previously only been used on a small scale such as lithium and REE. Neither of these metals has been exploited before in Zambia but potential for their mineralisation within the Zambian bedrock has been demonstrated. The Choma-Kalomo Block with its striking similarity in age and geology to the Kiberide Mobile Belt makes it a likely candidate for lithium deposits in Zambia. The Zambian carbonatites deposits offer prospects of easily minable economic REE. It is very likely that in previous explorations, perhaps less attention was paid to these commodities due to the then prevailing market conditions. However, with the energy transition and the critical role that the metals play, it is essential for the country to invest in targeted exploring for these metals.

Although demand for clean energy minerals provides economic opportunities for Zambia, significant challenges could arise if the climate-driven clean energy transition is not managed responsibly and sustainably (World Bank, 2021). It is therefore important for the country to build legislation and polices that will guarantee that the exploration, extraction and processing of these minerals will have minimal social, environmental and climate footprint throughout the value addition chain. Furthermore, as the world becomes ever sensitive to matters of environmental protection, producer countries will also need to demonstrate environmental stewardship and respect of human rights in the supply chain if they are to attract meaningful investments into the sector (Dominish *et al*., 2019).

4. Conclusion

As the world transitions to a green economy, the demand for minerals used to develop and deploy clean energy technologies is set to rise. The Zambian bedrock is host to huge resources of clean energy minerals some of which are currently exploited or could potentially be mined in a not so distant future. The energy transition offers significant economic benefits to Zambia. To prepare adequately for this transition, the country needs to come up with a robust legislative framework that will ensure investments in sourcing clean energy minerals has minimum climate footprint, high environmental standards, and quality social circumstances.

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Production of green charcoal by the use of organic solid waste

Mwango Mukayi[1]

Abstract

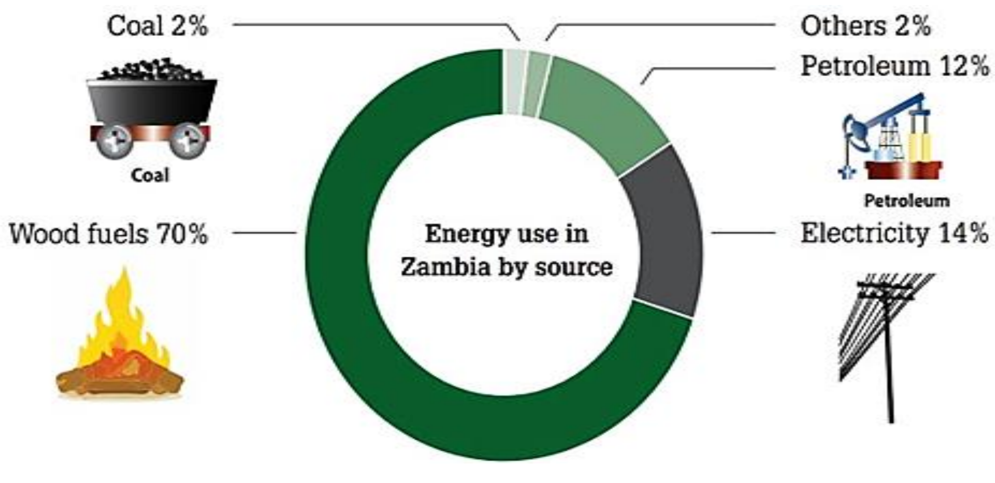
According to the Bioenergy and Food Security Assessment of 2020 by the Food and Agricultural Organization. 77% of the population uses Traditional Biomass as a primary source of energy for cooking [FAO, 2020]. This contributes to the loss of between 166,000 to 300,000hectares of forest every year [FAO, 2020]. And the demand is going to rise due to population increase and the increase in electricity tariffs. This is not sustainable therefore as a nation we need to find an alternative to traditional biomass energy. After almost two years of research we have come up with just such a solution, Green Charcoal. This can be produced from organic solid waste. This is also called Solid Recovered Fuels (SRF). SRFs are an engineered blend of non -recycled combustible waste condensed into solid fuel pellets or briquettes.

Keywords: Charcoal, Biomass, Energy, Organic, Briquettes

1. Introduction

Zambia still has limited access to modern energy especially in rural, the country is still striving to increase access to energy and to make the energy supply more sustainable. To date the country relies on the use of traditional biomass which accounts for about 77% of primary energy use.

Fig 1: Energy Use in Zambia (Ministry of Mines Energy and Water Development 2013)



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As can be seen from fig.1 [Ministry of Mines, 2013], it is not sustainable to continue at this rate we urgently need to find a more sustainable source of energy that is acceptable to our people bur at the same time that is environmentally friendly

1.1 Green Charcoal

In this context when we talk about Green Charcoal we are talking about charcoal that is not tree based. In this research it was realised that we can use organic waste to make charcoal briquettes that has a high calorific value and burn efficiently and smokeless.

These include Kitchen waste, forest waste, farm waste even human waste. In one experiment food left overs, Figure 2, were used to make charcoal.

Fig. 2: Food Left Overs

These food leftovers were carbonized using pyrolysis. This is the thermochemical treatment of a substance in the absence of air so it does not result in oxidation of the substance but in organic substances the result is what is called bio-char. This is a black substance that has a high calorific value and is rich in carbon. Figure 3 shows the carbonized food left overs.

Fig.3: Carbonized food waste

In this experiment 6 kg of food waste was used, this gave 2.3 kg of char. Therefore by weight we have a ratio of about 3:1, that is, 3 parts of waste gives 1 part char.

The nature of char is that it cannot hold together so the next thing that was done is to grind the char into fine powder as shown in Figure 4

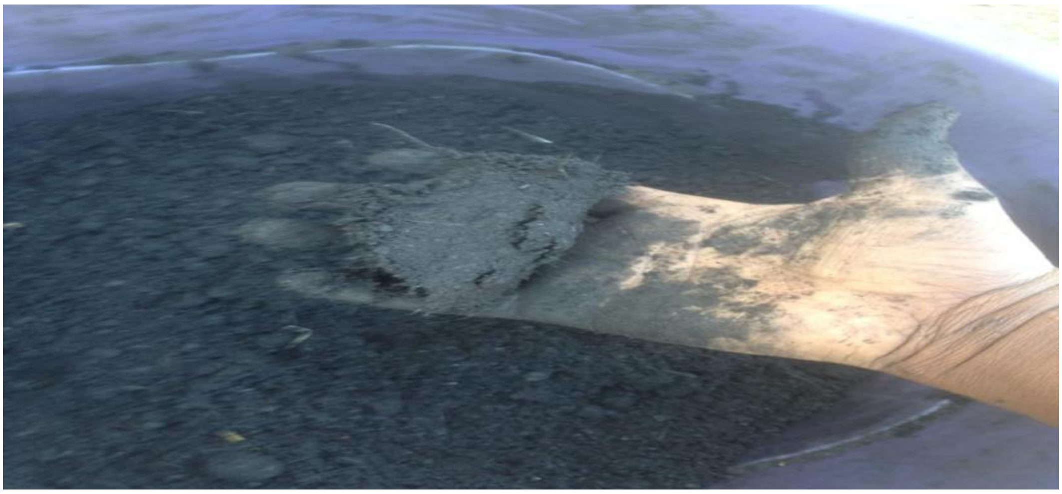

Fig. 4: Char after Grinding

For the char to bond together a bonding agent is added. After that the char and the bonding agent is briquetted. The result is what is shown Figure 5.

Fig.5: Charcoal Briquettes

Is this a sustainable solution? Taking Kitwe as an example, according to Zambia Environmental Authority report, Kitwe generates 15,140 tons per year [ZEMA, 2019] of which more than 50% is organic as can be seen from the chart in Figure 6 [Mwanza and Mbohwa, 2018]. That means 1,261.67 tons of waste is generated every month. That gives us 630.83 tons of organic waste a month. This is capable of producing 189.2 tons of charcoal briquettes a month.

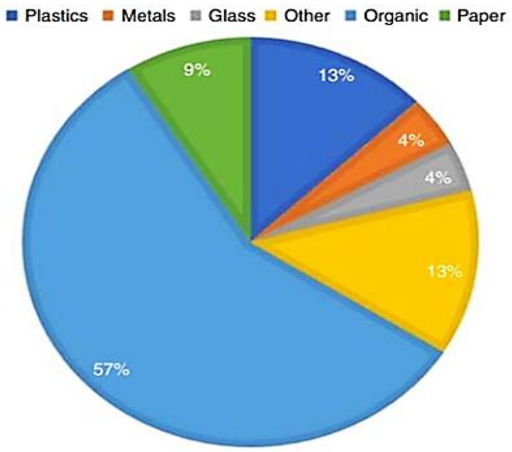

Fig 6: Composition of Solid Waste (Mwanza and Mbohwa 2018)

Care must be taken to notice that in this estimation only Municipal Solid waste (MSW) has taken into account, disregarding other forms of organic waste like Forest waste, Farm Waste, human waste and saw dust if all these sources of waste is taken into consideration we have a vast reserve of Biomass that can sustain the nation and beyond.

2. Solid Waste Processing and Briquetting

Considering the fact that solid waste in Zambia is not segregated at the source [ILO, 2001] this means that it has to be segregated at the point of processing. The commercial green charcoal production plant should include six stages.

These are segregation, drying, carbonization, grinding, blending and briquetting. Below is the concept of the plant that can be used to produce green charcoal. The flow chart in Figure 7 illustrates the stages of the production process.

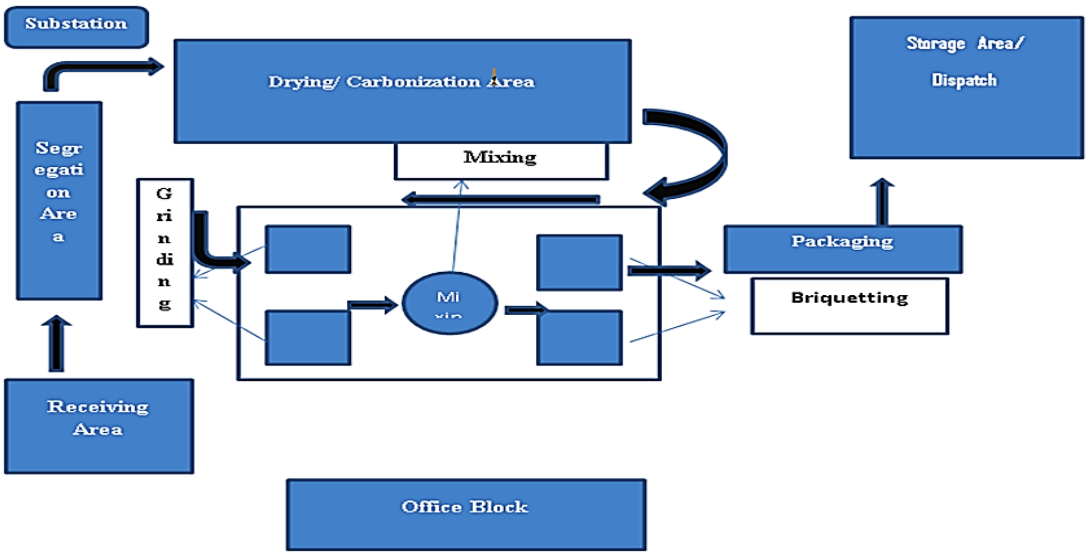

Fig.7: Green Charcoal Plant Concept

The first stage after the waste is received is Segregation. As can be seen from Fig.6, 57% of the waste produced is organic [Mwanza and Mbohwa, 2018] so segregation is important to separate the organic waste from the rest as this is what is needed for processing. The second stage is drying. Before the material is brought to the carbonization stage we need to ensure that the moisture content of the material is reduced to up to less than 15% this will mean we will expose the material to the temperature of up to 100º Celsius. This is important to ensure that the carbonization can happen within 30 Minutes. When the moisture content is reduced to the desired level then we move the material to the third stage the Carbonization stage. Pyrolysis or carbonization is defined as the irreversible thermo-chemical reaction that is started by re-heating in the absence of air to start it and to trigger endothermic and exothermic reactions. The biomass produces, as a product of the pyrolysis process under normal conditions, a mixture of gas, liquid and charcoal. Using the pyrolysis process will help improve the energy content of the biomass. This process has two variants Fast and Slow pyrolysis. Since our interest in this project is the production of solid fuel we are going to use slow pyrolysis. In this process we will use between 380 - 500 degree Celsius and the process will last between 5 – 30 Minutes. We will use solid fuel for this purpose. Table 1 summarises the evolution of carbon content and calorific value as a function of temperature during carbonisation, after the study carried out by BRIANE and DOAT [Briane and Doat, 1985]. We are using the reactor method of carbonization. The reason is that we will want to carbonize even the light materials like vegetative materials of weak granulomere and legumes. Further the charcoal yield is about 35% by weight and the energy content of 4,780 kCal/m³ is very good for our purposes. The reactor method also allows us to recover pyrolytic gases which we further inject in the heat source to sustain the pyrolysis process.

Table 1: Carbonization Stages (Source: Briane and Doat, 1985)

Carbonization Steps	**Water Loss**	**Release of Oxygen Gas**	**Start of Release of Hydro-carbons**	**Hydrocarbon Phase Cm Hn**	**Dissociation**
Temperature, ºC	150 - 200	200 - 280	280 - 380	380 - 500	500 – 700
Carbon Content %	50 - 60	60 -70	70 - 78	78 -85	85 - 90
Calorific Value(kCal/m³)	1,100	1,210	3,820	4,780	3,630

The fourth stage is the grinding stage. This is the reduction on the particle size of the carbonized materials. This is important to make sure the material will require not a high amount of power to compress.

The fifth stage is the blending stage. We have different materials as was seen from the different kinds of waste that have different calorific values. As such we want to have a mixture of these materials that will give us high energy content. Something that is higher than 18 MJ/kg. At this stage we add the predetermined ratios and then we mix them thoroughly to have a homogeneous mixture. At the same time we also include the blending agent. Further we also add another agent that helps to make sure that the briquettes that we make have room for oxygen to flow.

This is the final stage of the process. At this stage we form the mixture into briquettes or pellets. This is done under high pressure conditions so that we can end up with a product that is fully compacted. This is necessary for it last long on the brazier whilst giving high energy content. In this case we are going to make a 32 mm diameter by 5mm length briquettes. These briquettes can either be sun dried or using artificial means. In this case we will use artificial means so that just from briquetting the fuel is dry and ready to use. We use the compression technique. The briquettes are compressed with the force of up to 15 tons/cm². Due to the high compression and regular shape of the resulting briquettes with a high energy content, they last long on the brazier.

We can see that these briquettes have an upwards of 30 MJ/kg. Modern fuels such as LPG have the highest energy content per kilogram of fuel at approximately 45 MJ/kg [Chagunda, 2017]. In contrast, crop residues and dung have energy densities of about 14 MJ/kg of fuel [Chagunda, 2017]. The efficiency of a fuel is measured by the amount of energy used for cooking compared with that which escapes from the stove without actually heating the food. The efficiency of cooking with LPG is estimated to be approximately 60% compared with only 12% for agricultural residues burnt in traditional stoves. From the foregoing it can be seen that it is very important that we improve the efficiency of our traditional stove (*Mbabula*). In view of that we have developed an Energy Saving Mbabula (ESM), Figure 8, which improves the efficiency of the brazier by more than 60%.

Fig.8: The Energy Saving Mbabula

2.2 Comparative Advantage of Using Green Charcoal and the ESM

If we put the ESM side by side with the traditional Zambian brazier we can see a very big difference in the amount of heat that is lost to the surrounding. Let's take the ESM-17 which has a diameter of 17 cm and the charcoal chamber is 10 cm deep. We want to compare it with the ordinary brazier of equal dimensions. You will see that the top and bottom of the brazier is 453.96 mm² whilst the side is 534 cm². So the sides take up 54% of the total surface area. Also note that the top and bottom lose heat by radiation but the side heat is lost by conduction. The rate of heat transfer per unit area is given by Fourier's law.

$$q = -k \cdot \partial T / \partial x \qquad (1)$$

Where q is the heat rate per unit area, k is the thermal conductivity.

From the equation you can see that the rate of heat flow is directly proportional to the thermal conductivity of the material. In this case they are both made of mild steel. The difference is that the ESM has the space between the outer plate and the charcoal chamber filled with asbestos. Steel has thermal conductivity of 45 W/(mK) and that of asbestos is 0.08 W/(mK). In effect the ESM traps the heat inside the chamber. It reduces the heat loss by the factor of 562.5 this increases the intensity of heat applied to cooking surface increasing the efficiency of charcoal utilization.

3. Conclusion

We have a duty as a people to protect our environment; cardinal among these is ensuring the protection of our precious trees. But we also have a duty to provide energy for our people but we have to do it in a sustainable manner. It is against this back ground that the current trajectory that we are taking is not sustainable we cannot continue to lose our forests at the current rate. This is why the use of green charcoal is the best course of action. It will not cause a disruption in the lives of our people but it will save our precious trees. Our ancestors were brilliant they gave us charcoal but the time has come for us to move on by providing our people with a more sustainable source of energy. Green charcoal is the answer.

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A relation between solid waste mismanagement and climate change and energy generation from solid waste.

Chita Bwalya[1]

Abstract

Zambia is characterized by the effects of climate change such as unpredictable rainfall patterns, droughts, floods and rising temperatures. Staggering temperature rises have been predicted to increase between 1.9 and 2.3 degrees Celsius and rainfall is projected to decline by 3 and 0.6% by 2050 and 2100. Emission of greenhouse gasses by decaying solid waste in landfills contributes to the intensity of these factors. These impacts will likely affect the net agricultural production of Zambia which will affect the food basket and economy of the nation, food insecurity will result as well as a negative impact in energy supply. This article summarizes solid waste, and how it contributes to climate change as well as the impacts of solid waste on Zambia. It further discusses the methods that Zambia can employ in order to adapt itself to these impacts as outlined in the National Adaptation Planning for Climate Resilience (NAP4CR) project of 2021. Additionally, this article also presents the idea of generating energy from waste as a possible solution in the management of solid waste. The method for primary data collection in this article involved mostly survey of previous research done on the topic.

Zambia is producing tonnes of solid wastes annually that recycling by mechanical means alone is not feasible because the procedures such as collection and sorting employed in mechanical recycling are too slow to keep up with the rate of production of solid waste. Addressing this issue requires innovate solutions such as turning solid waste into energy and doing so in a decentralized manner, targeting areas of significant waste production such as homes, schools, hospitals and markets.

Keywords: climate, energy, sustainable, economy, waste.

1. Introduction

Climate change which is not only a change in the average weather patterns and temperatures but also an increase in climate variability, is due to an increased concentration of greenhouse gasses in the earth's atmosphere (Couroche Kalantary, 2010). These greenhouse gases, a fraction - (13%) according to the U.S. Energy Information Administration - of which comes from solid waste causes significant changes in the earth's atmosphere which result in catastrophic weather and temperature conditions that lead to disastrous natural devastations such floods, droughts and wild fires (Phillipe Rekacewicz, 2005).The effects of these emissions are clearly seen now in many developing countries including Zambia which in its capital city of Lusaka alone generates about one million tonnes of

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waste annually as of 2017 (Luke Muller et al. 2017). Due to, but not limited to this generation in waste, Lusaka is hit by devastating floods (Nchito 2007). Other than that, an estimated 2.3 million people in Zambia are on the brink of starvation, threatened by severe drought caused by dwindling rainfall (Mwenda, 2019).

There hasn't been a time like this in history in which millions of tons of solid waste is being generated and improperly managed at the expense of life. UN-Habitat (2010) highlighted that Zambia's waste generation as of 2010 were approximately 0.52kg per person daily and as of 2008 according to the Lusaka City Council (LCC), Lusaka generated about 1000 tonnes of solid waste daily which has doubled to 2700 tonnes per day in just 10 years (Jari Kangasmaki, 2020). Around the world, population and economic growth are responsible for changing consumption patterns and generating huge amounts of waste (Luke Muller et al. 2017) and Zambia is not an exception to this with its rapid uncontrolled urbanization. In its major cities such as Lusaka, Kitwe and Solwezi, Zambia is seeing about 39% of Zambia's population residing in urban areas according to the 2010 Census.

Despite the foregoing evidence on the impacts of climate change in some parts of Zambia, there remains much to be explored in understanding the greater significance and impact that solid waste is having on Zambia as a whole and how imperative and urgent it is that viable and final solutions be implemented immediately.

This article summarizes the many ways in which solid waste generation and inadequate management negatively affects the country in terms of the impacts of climate as it correlates to solid waste. The impacts include among others decrease in agricultural productivity, a significant increase in the deaths of wild animals, flooding and droughts in most parts of the country all which will drastically endanger our economy (Kalantary, 2010). The paper further introduces ways in which Zambia currently manages solid waste and present an engineered solution in terms of a decentralized waste-to-energy strategy that will bolster the green economy. While this study may be similar to other studies that have assessed waste to energy (e.g., Kombe 2019; Nyirenda 2020), this paper adds to these studies by introducing a decentralized approach in the waste to energy technologies in Zambia.

2. Overview of the impact of solid waste mismanagement in Zambia in relation to climate change

Zambia as a developing country has many issues pertaining to management of waste. Even though there have been deliberate laws set up by the government in the management of waste, for example in The Solid Waste Regulation and Management Act of 2018, a person who disposes or causes or permits to be disposed any solid waste contrary to subsection (1) of the act commits an offence punishable by law. Yet still, the country is facing challenges in management of waste because of the indiscriminate illegal dumping and littering. As earlier established, greenhouse gases from human activities such as but not limited to generation of solid waste, are the most significant driver of observed climate change since the mid-20th century according to the Intergovernmental Panel on Climate Change (IPCC) of 2013.This has brought about immeasurable impacts to the functioning of the country including; agricultural productivity, immature death of wild life, flooding, droughts, energy supply and endangerment of the economy (Kalantary, 2010).

Climate change impacts agriculture through increased frequencies of extreme climatic events such as droughts that allow no crops to grow at all or floods that destroy grown plants directly affecting agricultural production (Jain, 2007; Thurlow et al. 2012). According to the World bank the Zambian agricultural sector contributes 6% to national Gross Domestic Product (GDP) (World Bank, 2019). During the last ten years, Zambia has been experiencing a small but significant fall in the number of agricultural products it exports resulting in a reduced contribution of agriculture to GDP in the country (Chisanga et al. 2017; Mulenga et al. 2019). This mostly owes to the fact that drastic changes in weather are limiting the productivity of the famers. This will mean a decrease in the national food basket, and if this were allowed to continue may lead to a gradually falling agricultural GDP that will further shrink the economy.

In addition to this, increased temperatures and lack of food and water due to climatic changes have a negative effect on the population of wildlife. Quality of water resources as well as air quality also contribute to the decreasing number of wildlife. For example, wild animals have started migrating, suffering from lack of food due to increased droughts which cause soil degradation and fertility loss of their habitats (Kalantary, 2010). The decrease in wildlife might impact our tourism industry and this would impact the economy negatively given the fact Zambia depends partly on the tourism sector's game parks and game reserves.

According to the Energy Regulation Board (ERB) of 2015, Zambia experienced an undersupply of about 560 megawatts in its hydro electric energy supply owing to the low levels of water in the Kariba dam. The demand of electrical energy in the country is growing at a fast pace (ZDA, 2014), an average of about 3% of the total installed Electricity Generation Capacity of Zambia of 2,347MW (ERB, 2015). About 96% of this electric energy is derived from hydropower, but it goes without saying that Zambia's dependence on hydropower, which is the major source of electrical energy supply in Zambia, should be reevaluated.

3. Some adaptation methods for solid waste management

Zambia has made strides in ensuring that to a certain degree and competing with its growing population and industrialization, the country facilitates the reduction and mitigation of mismanagement of solid waste. An example is the engineered landfill such as the Chunga landfill in the country's largest city of Lusaka.

Fig. 4.1.1: Chunga landfill in 2007

Fig. 4.1.2: Chunga landfill in 2019

Fig 1: Chunga landfill in Lusaka, Zambia (Mwanza et.al, 2017)

Other than that, the Environmental Management Act (EMA) No. 12 of 2011 provides for requirements for handling waste such licensing or permitting process for collection, transportation, treatment and disposal of waste hence promoting the opening of recycling companies by private citizens. The Ministry of Water Development, Sanitation and Environmental Protection through the Zambia Environmental Management Agency (ZEMA) in 2018 issued a ban on plastic bags that did not conform to the National Standard (ZS719) on Plastic Carrier and Flat Bags developed by the Zambia Bureau of Standards, hence promoting the use of biodegradable plastics. Though effective, these solutions alone are not sufficient and may require additional well engineered ways that meet the green economy standards that Zambia is striving for.

Owing to this, one way we can properly dispose of waste is by using it to generate energy. Waste to Energy (WtE) technologies utilize solid waste to create electric energy, heat energy and other forms of energy such as combustible fuel commodities such as methane through various complex conversion methods (Lazarevic et.al, 2010).

4. Waste to energy technologies

Waste to energy and its associated technologies is the process of converting traditionally landfilled solid wastes into energy. The simple definition of waste to energy concept can also be said of as using different wastes for energy production as alternative energy sources instead of conventional sources (S.T. El-Sheltawy et. al, 2016). The waste to energy concept provides economic and environmental benefits while introducing a renewable resource. utilization of this concept can achieve environmental sustainability and compensate shortage of other energy sources while solving the fossil fuel shortage problem and decrease the environmental impacts associated with waste accumulation (S.T. El-Sheltawy et al, 2016). Waste to energy (WtE) plants are designed to reduce the emission of air pollutants and to destroy pollutants already present in waste

According to the United Nations Environmental Programme (UNEP) of 2017, Ethiopia has become the very first country in Africa to own a waste to energy technology plant. Among the about five waste to energy technologies including thermal technologies, direct combustion (mass burn), conventional gasification and plasma arc gasification, the plant utilizes pyrolysis, which is the thermo-chemical decomposition of organic material at elevated temperatures in a vacuum (Nyirenda, 2019) and thermal technologies that involve combustion. This plant has the ability to collect and harvest energy from about 1.4 million kilograms of waste daily (Alemu, 2019). The facility produces about one eighth of the city's power supply (25MW). The process of turning waste into energy in the Reppie WtE or incineration plant in Ethiopia includes firstly collection of solid waste, then the waste is sorted into that which can be combusted with ease and with less harmful emissions. The combusted solid waste is then used to boil water to certain significant temperature which then – the water - turns into steam that drives the turbines setup on the rotor shaft of a generator. The generator in turn converts the mechanical energy of the rotor into renewable sustainable electrical energy (UNEP, 2017). To even further increase sustainability, the emissions from the combustion is controlled and is done according to the Environmental Impact Assessment (EIA/EA) regulations. A world class Flue Gas Treatment (FGT) has also been setup to consistently monitor and reduce emission levels (Massreshaw, 2018). Other than that, the residual ashes collected from the combustion process are recycled and are later used a raw material in the manufacture of bricks or for road construction (Alemu, 2019). After only two years the country has seen a drastic reduction in not only the amount of solid waste on its largest dumpsite in its capital city of Addis Ababa, but also a decrease on its dependence on the national electricity grid.

5. The green economy project: waste to energy in zambia

Clean green energy as well as sustainability has for some time been of concern in Zambia. The ushering of the new 'new dawn' government in 2021, has since seen the introduction of such ministries as the ministry of green economy and environment. This ministry is expected to, among other policy issues, formulate legislation/regulations on carbon and environmental pricing such as carbon tax, carbon price, carbon fee and carbon dividend etc. (Nkula Kaoma, 2021).

Fig 2: Reppie waste to energy plant in Addis Ababa, Ethiopia (Monkbot et.al, 2018)

As has been established, a developing country like Zambia needs a viable way in which it can properly manage its solid waste to keep up with population increases per annum. As part of the solution, developing a green economy which according to UNEP is defined as an economy that results in improved human wellbeing and social equity, while reducing, to a significant degree, environmental risks and ecological scarcities, will be in the best interests of the economy. This green economy project can involve such ventures as recycling projects, organic agriculture, forest management, decentralized solar energy and many other green economy initiatives. One of the focus areas of this project can be to tap into areas where most solid waste is generated individually and then producing energy from this waste. Solid waste is an abundant resource. A case study done by (Kombe,2019) where assessment of the four major cities of Zambia (Lusaka, Kitwe, Livingstone and Ndola), was made to quantify the available municipal solid waste and determine its potential towards energy generation, showed that the energy potential increases as the years progress and this is attributed to the increase in amounts of municipal solid waste. The study further revealed that the four major cities have the potential to generate electricity from the annual municipal solid waste collected.

The part of the green economy project being presented in this paper focuses on generating energy from waste but the challenge lies in the collection, transportation and sorting of the waste hence the need for a decentralized approach. This implies placing permanent enhanced waste to energy plants right at the premises of the existing structures such as clinics, hospitals, schools and markets in most of the fast-developing urban areas of the country such as Kitwe district.

These WtE facilities can be enhanced in such a way as to be able to be accommodated in public areas. This means coming up with technologies that suppress the fumes during combustion of waste, also innovating noise and odor pollution cancelling devices that could hinder production or service provision in the selected area. Additionally, in homes, schools and hospitals, by redirecting a portion of greywater, which is any domestic wastewater produced from bathrooms, sinks, can be utilized in the processes of WtE production in turning turbines. And as has been noted, electrical energy is the most common form of energy generated from WtE facilities but by enhancing the WtE facility it may be possible to create a two in one sort of facility that utilizes both incineration and gasification which is the extracting of gases such as methane from the organic waste without burning, that is excluded from the incineration process.

A study of Kitwe district's largest market which is the second largest market in the country shows just how significant this project will be.

Chisokone market is approximately 1.2km^2 and is located in the central business town of Kitwe. According to the Association of Vendors and Marketeers (AVEMA) of 2019 an approximate number of about 10,000 people conduct their business in the market every day and as a result waste is generated every day.

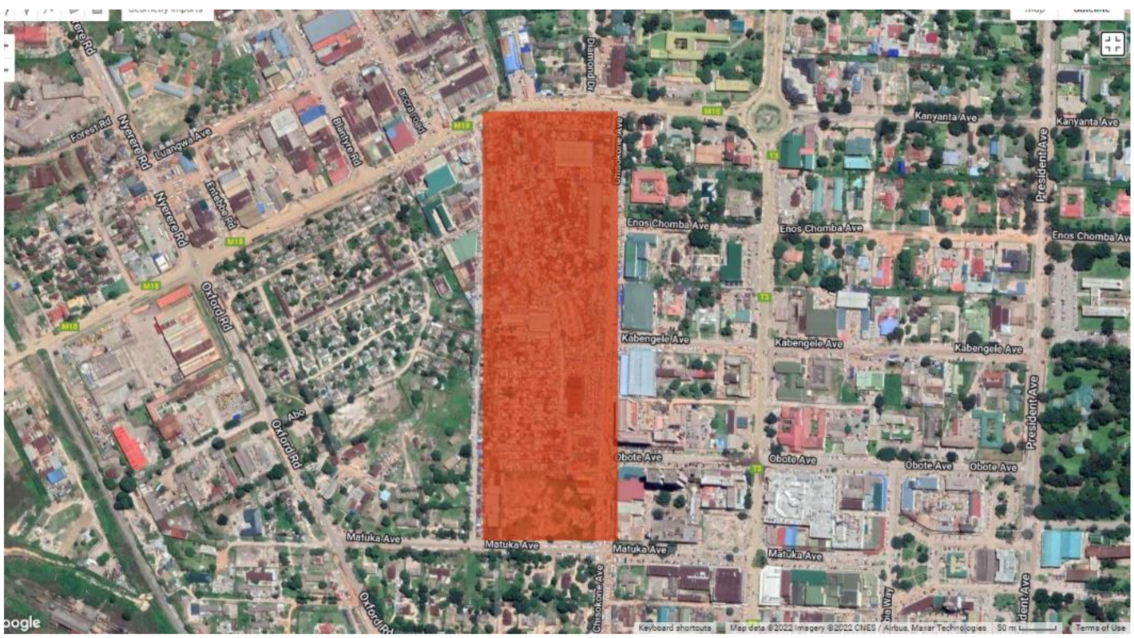

Fig 3: A Satellite image of Chisokone market in Kitwe, Zambia (Google Earth Engine)

The Kitwe City Council (KCC) oversee the collection, transportation, treatment and general management of solid waste that is generated in the market (Chungu, 2019). Because of the rate at which the city is growing the KCC are overwhelmed by the amount of solid waste being generated not only in the market but also in the town as a whole. A conceptual model of how the decentralized waste to energy was generated. Because the market is divided into three sections according to the Association of Vendors and Marketeers of Chisokone market, it makes it easier to identify areas that generate the most waste. The B section of the market is the largest and hence will require at least two small enhanced WtE facilities as shown in the conceptualized model below. The model focuses on the collection perimeters as well as focusing not only inside the market but as well as the surrounding perimeter of the town center. Three facilities are provided within the market and an additional facility close to the existing dumpsite. The facilities will be at least within a $0.5km^2$ radius of each other. This will place them at a location closer to waste generation sources.

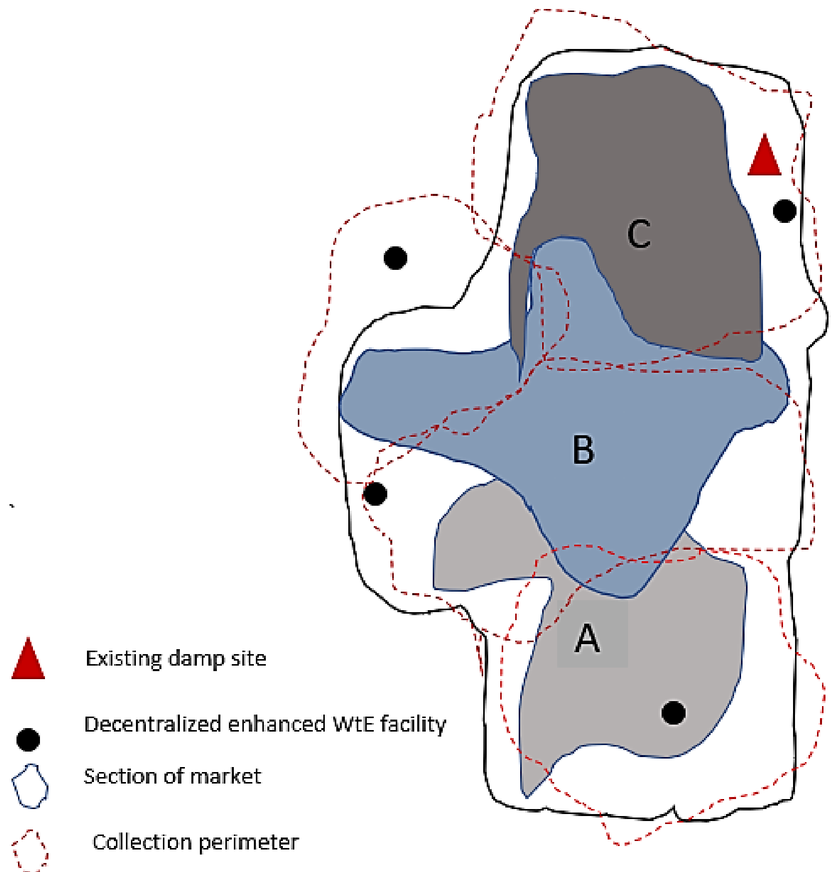

Fig 4: A conceptual mode of decentralized waste to energy facilities.

The goal of a decentralized waste to energy is to reduce the waste logistics by at least 50% due to transportation distances as well as diminish the electricity transmission losses by at least 10% (WIOMA). Other than that, an estimated reduction in the market's dependence on the national electricity grid is also estimated. While the benefits of these decentralized WtE energy facilities are many including the obvious reduction in solid waste, reduction in air pollution and energy generation, it also brings to the fore some concerns that might hinder the project. As a social problem, the willingness of marketeers in leave their trading spaces for these facilities should be put into consideration. Also, the amount of waste needed to produce sufficient energy for consumption may in later years not be enough to generate the needed amounts of energy.

The incineration method of turning waste into energy would be the most efficient in this case as it is better for waste management as it burns up to 90% of total waste in a chosen area, it will also reduce dependence on accumulating dumpsites and land fills as 90-95% of the landfill is vacated after incineration, it will also save on transportation of waste as incineration plants can be in proximity to towns (Kombe, 2019).The feasibility of waste to energy plants in Zambia was recommended with few adjustments (Nyirenda). Hence, the hypothetical approach to an enhanced WtE plant/facility can also be considered.

6. Conclusion

Zambia is one of the most affected countries by mismanagement of solid waste. It is therefore also one of the worst hit countries by climate change which is to a degree a by-product of solid waste mismanagement. Despite the policies and waste management strategies being implemented, they are still not enough to combat this colossal issue. With ideas such as the waste to energy technologies being enhanced with the needs of the country as a priority, Zambia is sure to create a sustainable clean green economy.

Therefore, further research on the enhanced version of the proposed waste to energy facility need to be actualized so as to assess whether implementation is a possibility.

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Ban of Fossil-fuel propelled automobiles versus Evolution of Electric Motor Vehicles (EMVs), how ready are we?

Andrew Munde[1]

Abstract

The universal realization that Climate Change is real and its effects primarily Global warming, has negatively affected the entire globe, prompting various nations to devise pragmatic mechanisms in which such effects can be curtailed. Several intervention measures across various disciplines are being implemented world over to stem these adverse effects of Climate change. As a key mitigation measure, one of the most ambitious programs that many nations have committed themselves is to cease the manufacture of fossil-fuel propelled automobiles between 2030 to 2050 and replace them with environmentally friendly Electric Motor Vehicles (EMVs). This paper was therefore drawn to assess whether our nation of Zambia is prepared for this drastic change and what ought to be done to timely position the country for this technological shift in the Automobile industry.

Keywords: Climate, Change, Greenhouse, Electric and Vehicles.

1. Introduction

Fossil fuel is a general term for buried combustible geologic deposits of organic materials, formed from decayed plants and animals that have been converted to crude oil, coal, natural gas, or heavy oils by exposure to heat and pressure in the earth's crust over hundreds of millions of years. Fossil fuels are commonly used in the Transportation Sector worldwide, with the main ones being Gasoline or Petrol and Diesel. The distribution by sector in terms of the use of Fossil fuels on average across the globe is herein indicated (ResearchGate, 2021).

The burning of fossil fuels in automobiles and in many other processes is the largest source of emissions of carbon dioxide, which is one of the greenhouse gases that allows radiative forcing and contributes to global warming (Science Daily; 2021).

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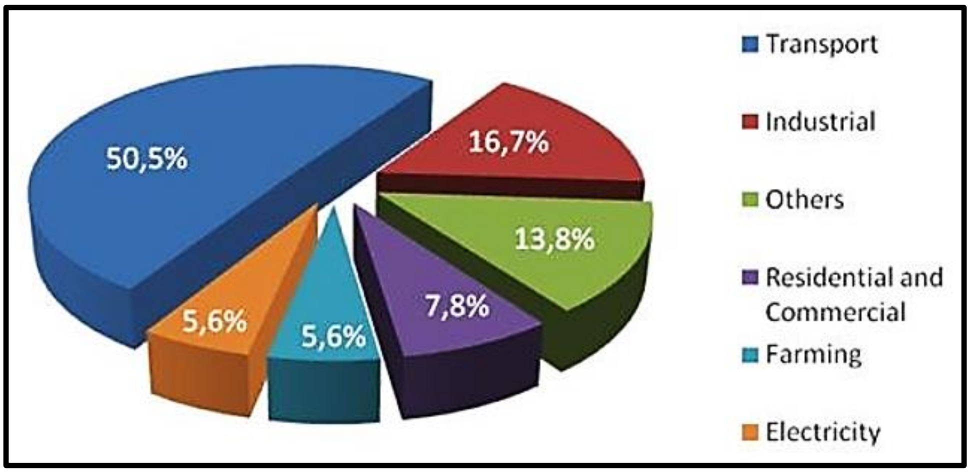

Figure 1: Global Consumption of Fossil Fuels by Sector (Sou5ce: https://www.researchgate.net/figure/Fossil-fuel-Consumption-by-Sector)

2. Climate Change Effects

The negative effects of Climate Change include but not limited to:

- High Earth surface temperatures
- Droughts and Floods
- Melting of snow in the Arctic and Antarctica Circles
- Tsunamis or Tornadoes especially in Coastal areas

A number of measures both scientifically proven and some still under research are being implemented world over to stem these adverse effects of Climate change such as;

Commitment to stop deforestation which leads to droughts and elevated temperatures

Use or deployment of renewable and sustainable energy solutions especially in Power development projects

Re-engineering of industrial processes to stem the emission of Green House Gases (GHG) which lead to depletion of the Ozone layer

As can be seen from the chart, if the mode of transportation can be transformed appreciably from propulsion by Fossil fuels to other cleaner energies such as Electrically powered automobiles, the corresponding risk to negative effects of climate change and particularly global warming would be significantly decreased.

3. General Overview of Electric Motor Vehicles, EMVs

In the face of ever-increasing earth surface temperatures through Global warming occasioned by the depletion of the Ozone layer from Green House Gas emissions largely attributed to use of fossil fuels, the evolution of Electric Motor Vehicles is clearly revolutionary in two major aspects; guaranteeing a resilient global environment and also sustainable transport sector.

Electric vehicles (EVs) are a promising technology for achieving a sustainable transport sector in the future, due to their very low to zero carbon emissions, low noise, high efficiency, and flexibility in grid operation and integration.

3.1 EMV Models

Different types of electric-drive vehicles are now available on the market. These include battery electric vehicles, plug-in hybrid electric vehicles, hybrid electric vehicles and fuel cell electric vehicles. Electrifying transportation not only facilitates a clean energy transition, but also enables the diversification of transportation's sector fuel mix and addresses energy security concerns. In addition, this can be also seen as a viable solution in the alleviation of issues associated with climate change. Furthermore, charging standards and mechanisms as well as relative impacts to the grid from charging vehicles are matters that require serious attention in various nations.

3.2 Advantages of EMVs

Electric Motor Vehicles offer several advantages compared to gasoline or diesel vehicles:

- ✓ Zero exhaust emissions—EMVs do not produce any exhaust emissions during operation.
- ✓ Reduced noise pollution—As EVs generate no propulsion noise, these vehicles are very quiet at low speeds (usually below 30 km/h).
- ✓ Increased independence from fossil fuels—A variety of resources can produce electricity, including renewable sources (solar, wind, geothermal heat, water).
- ✓ Reduced GHG emissions—EMVs can help mitigate the effects of climate change. This potential is highest if the electricity comes from Renewable sources.

3.3 Primary Components of an Electric Car

An Electrically powered car comprises three main components: Electric Engine, Motor Controller and Battery.

Battery

The battery of an electric car can be charged through the use of grid power which can be rectified to match Battery requirements. The following battery technologies are the most common on the market;

- **Lithium-Ion Batteries:** This battery technology gives extra performance and range. However, it also carries the highest price tag. Lithium-ion batteries are lighter than Lead acid and Nickel metal.

- **Lead Acid Batteries:** This battery technology is the most popular. It is also the cheapest among the battery technologies. What's good about it is that it is 97% recyclable.

- **Nickel Metal Hydride Batteries:** This battery technology provides higher output and better performance, but it costs much more than lead-acid batteries.

Motor Controller

The motor controller of an electric car administers its complete operation and the distribution of its power at any given moment. It helps monitor and regulates all key performance indications such as the vehicle's operator, motor, battery, and accelerator pedal. It has a microprocessor which can limit or redirect current. It basically lies at the centre of controlling the mechanical performance of the car.

Electric Engine

Unlike a gasoline engine with lots of moving parts, an electric engine or motor only has one moving part. This makes it a very reliable source of motive power. Choosing an electric engine depends on your car's system voltage. They can be structured to use either AC or DC current. AC motors are less expensive and lighter compared to DC engines. They are also more common, and they tend to suffer from less mechanical wear and tear. However, AC technology requires a more refined or sophisticated motor controller (didyouknowcars.com).

3.4 Electrical Motor Vehicle Commitments

As a contribution towards reduction of Green House Gas Emissions, many countries have committed to progressively phase-out the use of Fossil-fuel motor vehicles to Electric Automobiles.

To appreciate the current fossil-fuel usage distribution across the globe, the following mapping, Figure 2, illustrates consumption (ourworldindata.org).

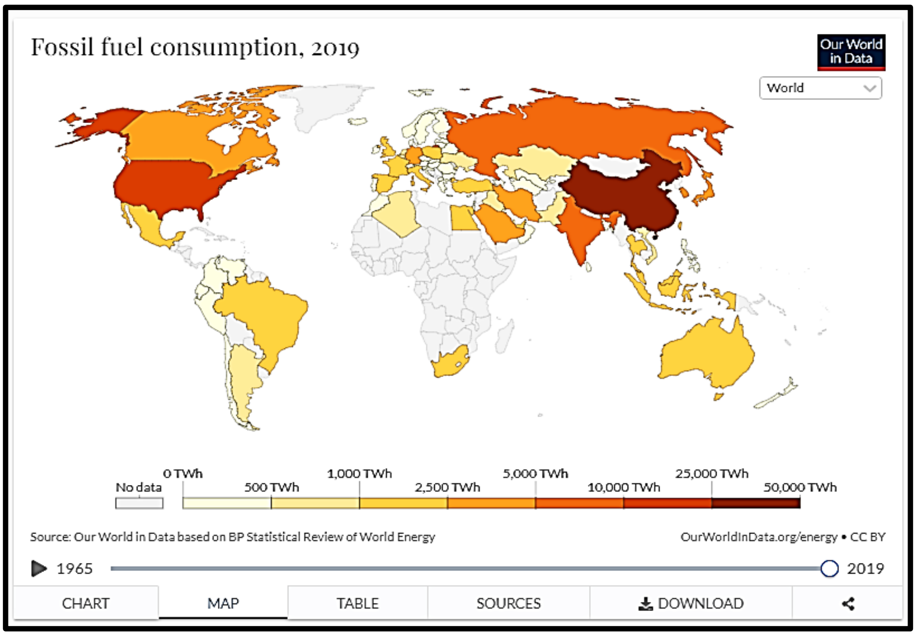

Figure 2: Fossil Fuel Consumption 2019 by Country (Source: https://ourworldindata.org/fossil-fuels)

Various pronouncements made by a number of countries towards combatting global warming through revolutionizing their transport sector to Electric cars is outlined in the various commitments below.

3.4.1 Countries' Commitment towards Migration to EMVs

Britain will ban the sale of new petrol and diesel cars and vans from 2030, five years earlier than previously planned, as part of what Prime Minister Boris Johnson is casting as a "green revolution" to cut emissions to net zero by 2050.

Britain, in 2019, became the first G7 country to set in law a net zero emission target by 2050, which will require wholesale changes in the way Britons travel, use energy and eat (reuters.com).

Other countries or regions that have pitched the idea of banning fossil-fuel based vehicles include:

United States:

California will ban the sale of new gasoline-powered passenger cars and trucks starting in 2035, Governor Gavin Newsom said in September 2020. (*Ibid*.)

Canada:

The Canadian province of Quebec said it would ban the sale of new gasoline-powered passenger cars from 2035. (*Ibid*.)

European Union:

EU environment ministers struck a deal on October 23, 2020 to make the bloc's 2050 net zero emissions target legally binding but left a decision on a 2030 emissions-cutting target for leaders to discuss in December. (*Ibid*.)

Germany:

German cities started to introduce bans on older diesel vehicles that emit higher amounts of pollutants than from late 2018. (*Ibid*.)

Norway:

Norway, which relies heavily on oil and gas revenues, aims to become the world's first country to end the sale of fossil fuel-powered cars, setting a 2025 deadline. Fully electric vehicles now make up about 60% of monthly sales in Norway. (*Ibid*.)

China:

In 2017 China begun studying when to ban the production and sale of cars using traditional fuels but did not specify when it might be introduced.

Sales of new energy vehicles (NEV) will make up 50% of overall new car sales in China, the world's biggest auto market, by 2035, an industry official said last month. (*Ibid*.)

India:

In 2019, India's central think-tank asked scooter and motorbike manufacturers to draw up a plan to switch to electric vehicles. The think-tank also recommended that only electric models of scooters and motorbikes with engine capacity of more than 150cc must be sold from 2025 (news.trust.org).

4. Aspects for Consideration

The following factors will have to be considered for Zambia to equally follow suit and move towards replacing its fossil-fuel automobiles wholly with electric motor vehicles:

Establishment of EMV Manufacturing or assembly plants in the Copperbelt or North-western Regions of Zambia where there's concentration of the requisite raw materials.

Government of the Republic of Zambia to sign Memoranda of Understanding with various local Mining firms to retain at least 10% of Copper and Cobalt Output for manufacture of electric engines, motors, batteries and various Electronic Components

Establish Car charging ports at various spots in the country in conjunction with electrical utilities such as ZESCO and municipalities for recharging of the EMVs

Increase awareness on the advantages of EMVs to improve local and Regional demand

Remove any present taxes for import or export of EMVs

5. Conclusion

Zambia remains committed to tackle the effects of Climate Change especially through demonstrable legal framework where the Ministry of Green Economy and Environment has been established.

However, what must follow now are concrete steps to actualise the goal of attaining a truly green environment through among others curbing Green House Gas Emissions. The Transport Sector presents such good opportunity in which the country must be resolute in phasing out its fossil-fuel automobiles which constitute almost 99% of the entire national fleet and migrate towards the environmentally friendly Electric Motor Vehicles.

To operationalise this goal, the country needs to set up supportive industries for manufacture, assembly and sale of these EMVs coupled with relaxed tax incentives to propel demand both locally and regionally.

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Evaluation of engineering profession regulation in Kenya, Tanzania, and Zambia in a fast-changing world

Martin Aluga[1], Chewe Kambole [2]

Abstract

The world in the 21st century is undergoing fast transformation due to various factors that include: the emergency, spread, and prevalence of coronavirus disease 2019 (COVID-19) pandemic, rapid urbanization, technological advances, political and social factors, high population growth, negative environmental impacts, climate change due to global warming and frequent occurrence of natural disasters such as cyclones, earthquakes, and wildfires of different forms and magnitudes. These factors are fast shaping the infrastructure development such as transport facilities, housing, water and sanitation facilities, energy, environmental engineering, agricultural, and manufacturing industries where the engineering personnel offer immense services. Additionally, engineering personnel are required to harness natural resources to provide much-needed development. Having adequate numbers of engineers necessary for the economy to grow and prosper is vital for any country. This article describes and compares professional engineering regulation, certification, and statistics of engineering personnel in Kenya, Tanzania, and Zambia alongside engineering profession promotion at the World Federation of Engineering Organisation (WFEO). The study also discusses the existing international agreements that govern the recognition of engineering educational qualifications and professional competence to facilitate global mobility in the fast-changing world. The research employed both qualitative and quantitative methods of data collection. It emerges that Kenya, Tanzania, and Zambia are not signatories to the global accords, which enhances mobility for engineering personnel and standardization of engineering curriculum.

Keywords: Climate Change, COVID-19, Engineering, Regulation, WFEO

1. Introduction

Natural disasters are being felt across the globe such as 2021 North American Wildfire Season, Rohingya Refugee Crisis of October 19, 2021, Atlantic Hurricane Season of October 5, 2021, Afghanistan Humanitarian Crisis of September 24, 2021, Venezuelan Humanitarian and Refugee Crisis of September 20, 2021, Haiti Earthquake and Tropical Storm Grace of September 20, 2021, Ethiopia Tigray Crisis of September 15, 2021, Yemen Humanitarian Crisis of August 31, 2021, International Wildfires, Flooding and Typhoons in China of July 17, 2021, Western European Flooding of July 14, 2021, North Indian Ocean Cyclone Season of May 17, 2021, Cyclone Seroja of May 4, 2021, La Soufrière Volcano Eruption of April 8, 2021, Australian Flooding of March 23, 2021, and Sulawesi Earthquake (Indonesia) of January 15, 2021 (CDP, 2021). Currently, the world is fighting the COVID-19 pandemic which has resulted in a drastic change in the way things

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used to be done (Aluga, 2020). Climate change effects are being felt globally, the Fourth Industrial Revolution (FIR) is here and the engineering regulators are faced with new technologies and new disciplines, therefore, there is a need to further the discussion about the form of engineering regulation. (Dalenogare, Guilherme, Néstor, & Alejandro, 2018).

These factors are fast-shaping the infrastructure development related to transport, housing, water and sanitation facilities, energy, environmental engineering, agriculture, and manufacturing industries where the engineering personnel offers their services. Engineering personnel (engineers, technologists, and technicians) are harnessing natural resources to provide much-needed development.

Having adequate?? numbers of engineers necessary for the economy to grow and prosper is vital for each country, especially in developing countries like Kenya, Tanzania, and Zambia. Therefore, this article looks at professional engineering regulation, certification, and statistics of engineering personnel in Kenya, Tanzania, and Zambia alongside engineering profession promotion at the World Federation of Engineering Organisation (WFEO). The study also discusses the existing international agreements that govern the recognition of engineering educational qualifications and professional competence to facilitate global mobility in the fast-changing world.

2. Data collection

The research employed both qualitative and quantitative methods of data collection. Qualitative data involved observations, communication from key engineering experts, and interviews of relevant experts. The quantitative data were obtained from secondary reliable published sources, websites, and data directly obtained from the registrars of engineering professional bodies.

3. Global Promotion of Engineering Professionalism

3.1 World Federation of Engineering Organisation (WFEO)

The engineering profession is not regulated at the international level. However, there are international non-government umbrella organisations that promote the engineering profession. The World Federation of Engineering Organisation (WFEO) is one such an organisation. WFEO cooperates with national and other international professional institutions in developing and applying engineering to constructively resolve international and national issues for the benefit of humanity. Kenya, Tanzania, and Zambia are all members of the WFEO through the Federation of African Engineering Organisations (FAEO). One important organisation that the WFEO has established collaborations with is the International Engineering Alliance (IEA) (WFEO, 2021).

3.2 International Engineering Alliance (IEA)

The International Engineering Alliance (IEA) is an international non-profit organisation that works through accords and international agreements to which national organisations can subscribe to improve the quality of engineering education and practice (IEA, 2021).

3.2.1 IEA Accords

Currently, the IEA has three accords (Table 1) and four international agreements.

Table 1: The IEA accords **(IEA, 2021)**

Accord	Description	Member states	
		Full member	**Provisional**
Washington Accord	This accord is for international bodies that are accrediting engineering degree programs.	Australia, Chinese Taipei, Ireland, China, Hong Kong China, India, Japan, Korea, Malaysia, New Zealand, Singapore, South Africa, Sri Lanka, United Kingdom, United States, Costa Rica, Turkey, Peru, Pakistan, Russia	Indonesia, Philippines, Myanmar, Bangladesh, Mexico, Chile, Thailand
Sydney Accord	This accord is for international bodies that are responsible for accrediting engineering technology academic programmes.	Australia, Canada, Chinese Taipei, Ireland, Hong Kong China, Ireland, Korea, Malaysia, New Zealand, South Africa, United Kingdom, United States	Peru and Sri Lanka
Dublin Accord	This accord is for international bodies that are accrediting programmes for engineering technicians	Australia, Canada, Ireland, New Zealand, Korea, South Africa, United Kingdom, and Malaysia	

3.2.2 IEA Agreements

- The International Professional Engineers Agreement (IPEA) establishes the competency of professional engineers for independent practice.
- The APEC recognises competence standards for professional engineers within the APEC economies.
- The International Engineering Technologists Agreement (IETA) IETA, the members aim to facilitate cross-border practice by experienced practicing engineering technologists.
- The Agreement for International Engineering Technicians (AIET) establishes an international benchmark competence standard for individuals practicing as fully qualified engineering technicians.

Kenya, Tanzania, and Zambia are not signatories to any of the aforementioned agreements. Currently, the countries are at preliminary stages for joining the IEA.

4. Engineering Regulation in COMESA region

Regionally, the engineering profession is not regulated but each member state is regulated by a national statutory body or self-regulated by the Professional Engineering Institutes (PEIs). Kenya and Zambia are both members of the Common Market for Eastern and Southern Africa (COMESA) while Tanzania is not a member of COMESA. Each member state is regulated independently by the relevant statutory body. Both Kenya and Zambia have mandatory professional engineering regulations, enforceable by law. All other COMESA member states have some engineering regulation except the Republic of Burundi, Union of Comoros, Republic of Djibouti, State of Eritrea, Republic of Seychelles, and the Federal Republic of Somalia who are at preliminary stages to establish a regulatory framework (COMESA, 2021).

5. Regulation in Kenya

5.1 Statutory bodies and their functions.

Engineering profession regulation in Kenya has evolved. From 1969 to 2011, the Kenyan Engineers Registration Board (ERB) was the statutory body responsible to register engineers (GoK, Engineers Registration Act, CAP 530, 1969). In this period, engineers, technologists, and technicians were regulated under this ERB. In 2011, the Engineers Registration Act (CAP 530) was repealed and replaced with Engineers Act No. 43 of 2011, which established the Engineers Board of Kenya (EBK). The EBK regulates engineers only (GoK, Engineers Act No. 43 of 2011, 2011). This created a gap in the regulation of technologists and technicians. To close this gap, the Kenyan Government enacted the Kenya Engineering Technology Registration Act of 2016, which established the Kenya Engineering Technology Registration Board (KETRB), which regulates the technologists and technicians (GoK, Kenya Engineering Technology Act, 2016). The main functions of EBK include but are not limited to training, registration, and professional development of engineers. The KETRB has similar functions to those of EBK that apply to technologists, technicians, and students. Other engineering professional bodies in Kenya include the Institution of Engineers of Kenya (IEK) (IEK, 2021) and the Institution of Engineering Technologists and Technicians (IET). For one to be registered as a professional engineer by EBK, he/she must be a corporate member of IEK while, for one to register as a technologist or technician by KETRB, he/she must be a member of IET.

5.2 Regulated Membership Classes

The membership classes and statistics of members for EBK and KETRB are shown in Table 2. They range from consulting firms to technicians under the two statutory bodies.

Table 2: Engineering classes and statistics in Kenya as of March 2022 (EBK, 2022).

Engineers Board of Kenya		**Kenya Engineering Technologists Registration Board**	
Category	**Number**	**Category**	**Number**
Accredited checkers	-	Engineering Technology Consulting Firm	-
Consulting Engineering firms	**150**	Consulting Engineering Technologists	**12**
Consulting Engineers	**480**	Professional Engineering Technologist;	**725**
Professional	**2,336**	Candidate Engineering Technologist	**233**
Temporary	**208**	Certified Engineering Technician;	**166**
Graduate	**18,929**	Candidate Engineering Technician;	**62**

Amongst the consulting engineers, 88% are civil engineers, 8% are mechanical, 3% agricultural. Similarly, 82% of the consulting engineering firms are in the field of civil engineering. Of the total number, 11% of the registered engineering personnel are professional and temporarily registered engineers. Most (81%) of the registered engineering personnel are graduate engineers. For the technologists and technicians, 61% of the total are registered professional engineering technologists, followed by registered candidate engineering technologists. The registered consulting engineering technologists are the minority at 1%.

6. Engineering Regulation in Tanzania

6.1 EIZ and Its Functions

In Tanzania, engineering is regulated under one body of the Engineers Registration Board (ERB). The ERB is a statutory body established by an Act of Parliament (URoT, Engineers Registration Act No. 15 of 1997, 1997). Members of the Institution of Engineers of Tanzania (IET) (IET, 2021), with relevant academic knowledge of, and practical experience in engineering are also registered by ERB.

6.2 Regulated Membership Classes

The membership classes for ERB, as of December 2021, are shown in Table 3. They range from engineering firms to technicians.

Table 3: Engineering classes and statistics in Tanzania as of December 2021 (ERB, Engineers Registration Board, 2022)

No.	Category	Number
1.	Local Engineering Consulting Firm;	**273**
2.	Foreign Engineering Consulting Firm	**122**
3.	Temporary Consulting Engineers	**147**
4.	Consulting Engineers	**482**
5.	Temporary Professional Engineers	**2,622**
6.	Professional Engineers	**7,678**
7.	Incorporated Engineers	**492**
8.	Graduate Engineers	**20,838**
9.	Graduate Incorporated Engineers	**724**
10.	Technician Level I	**286**
11.	Technician Level II	**248**

The ERB rules that guide its operations include the engineer's registration (professional practice, conduct, oath, and ethics) rules of 2014. These rules apply only to consulting engineers, professional engineers, and engineering consulting firms. The rules ensure that practicing engineers abide by the regulations, truthfully execute works, consecrate their lives to the service of humanity and speak out against evil and unjust practices (URoT, The Engineers Registration (Professional Practice, Conduct, Oath and Ethics) Rules, 2014, 2014). In terms of membership, the current Tanzanian ERB statistics show that majority of its members are graduate engineers at 63% while only 23% are professional engineers. Since 2002, the membership of ERB was increasing steadily but dropped drastically from 2019. The increase in membership from 2002 to 2019 is attributed to Tanzania implementing the Structured Engineers Apprenticeship Programme (SEAP). The ERB has three forms of financing SEAP; SEAP Training using funds administered by the Board (including Government subvention); SEAP Training financed directly by employers of the engineers and self-initiated Professional Training (ERB, The Structured Engineers Apprenticeship Programme (SEAP), 2003). The drastic fall in membership from 2019 can be attributed to Coronavirus Disease 2019 (COVID-19), which began in Wuhan, China in 2019. The occurrence of the pandemic restricted the movement of people and closure of some operations including travel bans. Some government offices also closed in a bid to curb the spread of the pandemic (Aluga, 2020). Currently, there is an increase in membership from 2021. This can be attributed to the ease of the COVID-19 regulations, especially on travel (IET, 2021).

7. Engineering Regulation in Zambia

7.1 EIZ and Its Functions

In Zambia, engineering is regulated under the Engineering Institution of Zambia (EIZ) re-established under the EIZ Act No. 17 of 2010 to promote and regulate the engineering profession in the country (EIZ, 2021). The EIZ has the mandate to, among other functions, register engineering professionals, engineering organisations, and engineering units and regulate their professional conduct; as listed in the EIZ Act No. 17 of 2010, section 4 (GoZ, 2010).

7.2 Regulated Membership Classes

The classes at EIZ include Engineering Organisation, Engineering Unit, Fellow, Professional Engineers, Incorporated Engineers, Associate Engineers, Graduate Engineers, Student Engineers, Professional Technologists, Full Technologist, Trainee Technologist, Student Technologist, Certified Technician, Full Technician, Trainee Technician, Student Technician, Master Craftsperson, Full Craftsperson, Trainee Craftsperson, Student Craftsperson, and Skilled Persons. These can be grouped as engineering units, registered engineers, technologists, technicians, and craftspeople.

In Zambia, 41% of the registered engineering personnel belong to the category of registered engineers, followed by craftspersons at 33%, while the technologists and technicians are at 14% and 12 % respectively as displayed in Figure 1.

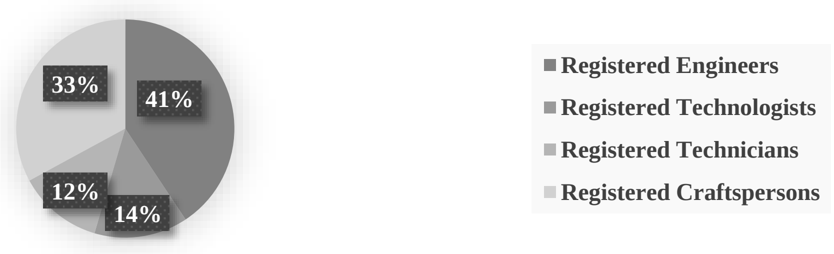

Figure 1: The engineering personnel in Zambia, 2021.

8. Comparison of Kenya, Tanzania, and Zambia

The total number of professional engineers in Kenya, Tanzania, and Zambia is approximately 13,660, of which 64% are in Tanzania. Zambia commands 21% while Kenya trails at 15% as displayed in Figure 2. Kenya has the highest population per professional engineer compared to both Tanzania and Zambia with a deficient of more than 7000 professional engineers to meet the UNESCO recommendations (WB, 2020).

Figure 2: The registered professional engineers in Kenya, Tanzania, and Zambia 2021.

9. Conclusion and Recommendation

9.1 Conclusion

Globalization, alongside challenges arising from population growth and climate change, calls for competent and responsible professional engineering practice. The facilitation of the professional mobility of the engineering profession, enabled by the recognition of qualifications, encourages dialogues and exchanges, promotes best practice, and accelerates innovation. The following are some of the observations made from the study of engineering profession regulation in Kenya, Tanzania, and Zambia in a fast-changing world:

- World Federation of Engineering Organisations (WFEO) under the auspicious of UNESCO enhances the engineering profession at the international level of which Kenya, Tanzania, and Zambia are members.
- All COMESA member states including Kenya and Zambia have mandatory engineering regulations except the Republic of Burundi, Union of Comoros, Republic of Djibouti, State of Eritrea, Republic of Seychelles, and the Federal Republic of Somalia.
- Engineering profession is regulated and enforceable by law in Kenya, Tanzania and Zambia.
- Kenya has two statutory bodies responsible for the regulation of the engineering profession while Tanzania and Zambia, all engineering personnel are regulated under one statutory body.
- The Structured Engineering Apprenticeship Programme (SEAP) implemented by Tanzania has enabled the training of more professional engineers than Kenya and Zambia combined.
- Kenya, Tanzania, and Zambia are not signatories to the IEA accords and agreements.

9.2 Recommendation

- Kenya through EBK together with relevant stakeholders such as the Commission of University Education, should take necessary steps in becoming a signatory to the Washington Accord alongside the International Professional Engineers Agreement (IPEA), and also a signatory to the Sydney Accord, Dublin Accord, alongside signing the International Engineering Technologists Agreement (IETA) and Agreement for International Engineering Technicians (AIET) to enhance mobility of professional engineers, technologists, and technicians in Kenya.
- Tanzania and Zambia through ERB and EIZ respectively in conjunction with relevant stakeholders, should take necessary steps to become a signatory to the Washington Accord, Sydney Accord, and Dublin Accord alongside signing the International

Professional Engineers Agreement (IPEA), International Engineering Technologists Agreement (IETA) and Agreement for International Engineering Technicians (AIET) to enhance mobility of engineers, technologists, and technicians in Tanzania and Zambia.

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Adaptable Engineering Professionals' Role in Sustainable Development of Zambia

Francis Mwale[1]

Abstract

Adaptable engineering professionals are those engineers who adjust or modify engineering input into situations to effect solutions to societal problems. With the emphasis on sustainable development becoming preeminent on a global scale, through Strategic Development Goals, adaptable engineers are required to ensure that engineering solutions provided foster sustainable development. This paper studies the enrolment and graduation trends of engineering crafts skilled persons at Kitwe Trades School from 2004 to 2019, to understand the availability of craft skills required for implementing sustainable engineering solutions. It also highlights a report on recent efforts by the Zambian government to strengthen Science and Technology in teaching institutions and re-crop graduates, technicians and crafts-skilled persons, in order to improve Zambia's competitiveness on the global market, fight poverty and enhance sustainable development. Proposed solutions to capacity building in engineering, leading to improved sustainability, include enhancing apprenticeship, coaching and mentorship activities, spearheaded by adaptable engineering professionals across the whole engineering spectrum. E-learning and the use of the internet for knowledge gathering and training are also recommended as a solution to continuing professional development and a stop-gap solution to dwindling availability of new engineering professionals. In manufacturing, synergies between Small and Medium Enterprises (SME's) are encouraged to help mitigate effects of limited financial resources among SME's, improve production and quality, and grow capacity through sharing of resources, through a case study of Dajomuka Electrical, a distribution box manufacturing company.

Keywords: sustainable development, Synergies, apprenticeship, coaching, mentorship.

1. Introduction

The Engineering Institution of Zambia recognized that engineering practice involves a spectrum of disciplines, from crafts persons, all the way to the professional engineer. Adaptable engineering professionals must, as such, also apply from crafts, all the way to professional engineering.

What though is adaptable engineering practice, or who is an adaptable engineering professional? On 15th July 2015, United Kingdom based Association of Consultancy and Engineering (ACE) excellence award winner Matt Browell-Hook (2015) quoted from the dictionary that 'to adapt is to "make suitable to requirements or conditions; adjust or modify fittingly". Just as in other areas of life, as engineers we modify our inputs to be

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able to affect the output. This can be very linear and prescribed to meet a known outcome or can be more flexible to see what the outcome will be (Browell-Hook, 2015).' "When you take an engineering approach to your career and look at your inputs you will be amazed at the number of consistent facts. Your ability to stand out and move forward will be defined by your ability to bring an input from another industry and introduce it to your new one; it's a straight forward as rearranging the equation but you must be willing to adapt." Mat attributed his winning the Engineering Professional award to his ability to adapt.

It can be concluded, from Matt's opinion quoted above, that adaptable engineering professionals are those engineers who will fit themselves to engineering requirements by making use of their inputs: training, experience, aptitude and attitude, to solve societal requirements now and in the future.

The sustainable development of Zambia, on the other hand, is tied to the United Nations Development Programme (UNDP) Sustainable Development Goals (SDGs). "The SDGs, also known as the Global Goals, were adopted by the United Nations in 2015 as a universal call to action to end poverty, protect the planet, and ensure that by 2030 all people enjoy peace and prosperity" (UNDP, 2015).

It follows that adaptable engineering professionals who will foster sustainable development in Zambia, will be those who apply training, experience, aptitude and attitude in a sustainable way. Engineering training, in particular, is indispensable to the acquisition of modern engineering methods of ensuring sustainable development.

This paper looks at trades training at Kitwe Trades School, as a case study. It addresses observed student recruitment and completion trends, challenges in current and future engineering training. It also gets an opinion from the Assistant Dean of the School of Engineering at the Copperbelt University, again on the aspects of challenges in and future of engineering training. It then highlights the views of a Zambian architect, trained at the Copperbelt University who has recently earned international recognition. Finally, a conclusion is provided, giving recommendations on how engineers may attain an adaptable engineering career leading to the sustainable development of Zambia.

2. Materials/Methods/Methodology

In order to achieve the set objective, a literature review was conducted for the case study of Kitwe Trades Training School, located in Kitwe District of Copperbelt Province. Collected student enrolment, performance and graduation data was reviewed and analysed by plotting graphs to observe trends.

One-on-one interviews were carried out with notable heads of engineering training institutions in Kitwe. A personal interview was also conducted with a Zambian architect, trained at the Copperbelt University who has recently earned international recognition. Another personal interview as was conducted with an engineering SME businessman who runs a sheet-metal workshop, Dajomuka Electrical, situated in Ndola, which was also used as a case study to explain the opportunity for synergies among SME's.

3. Discussion

3.1 Case Study of Kitwe Trades Training School

3.1.1 Introduction

Kitwe Trades School (KTS) is owned by Konkola Copper Mines (KCM). It derives its students from KCM, other organizations and individual entrants. KTS offers nine courses at craft level. These are: Automotive Electrical and Heavy Equipment Repair- under automotive trade; Electrical, Process Instrumentation, Refrigeration and Air conditioning – under Electrical trade; and Mechanical Fitting, Machining, Metal Fabrication and Rigging – under Mechanical trade. The objective of the case study was to understand challenges in training and the future of craft skills training at one of the established crafts training colleges on the Copperbelt of Zambia.

3.1.2 Trends observed in the Case Study of KTS

3.1.2.1 Decline in Enrolment in the period 2004 40 2019

A decline in enrolment in the period from 2004 to 2019 was observed as shown in Fig. 1 below. 2012 shows the highest enrolment figures. From 2013, enrolments generally declined. This could be explained, in part, by the uptake of Mopani copper mines craft students by the newly opened twenty million united states dollars' worth purpose-built training centre by Mopani copper mines in Mufulira. Generally, the enrolments trends reflected the dynamic demand for the respective craft skills specifically from the mines, but also from the growing numbers of contracting companies that mines opted to sub-contract to provide services to the mines. Particularly, there were no refrigeration nor air conditioning course entrants from 2004 to 2019.

3.1.2.2 Observed decline in sponsorship trends in engineering related crafts courses at KTS from 2004 to 2019

The general trend typified in Fig. 2 below is that self-sponsorship is the dominant mode of sponsorship from 2012. The current Principal of KTS explained that of the whole group of self-paying students in any given year, only 10% were able to pay their school fees promptly. The rest struggled through-out their course to fulfil their school fees.

3.1.2.3 Observed decline in number of students completing trades courses from 2015 to 2019

The general trend typified from Fig. 3 is that, correspondent with declining entrant numbers of students, is that of students completing crafts courses. The ratio of students sitting exams to those passing is satisfactory (at 83.4% overage for the period 2015 to 2018). Fig. 3 shows KTS trends in number of students attempting against those who passed crafts exams.

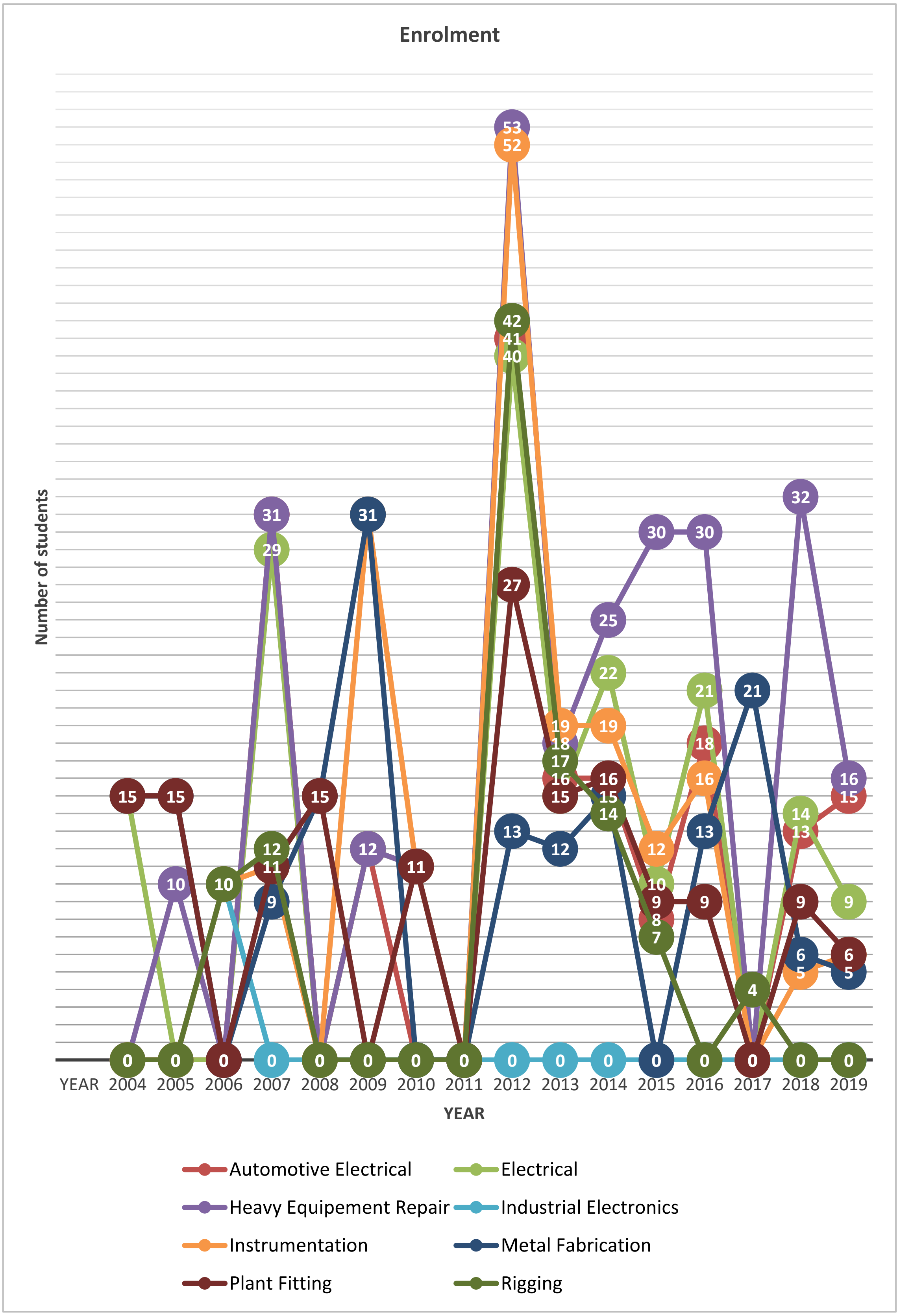

Fig. 1: KTS enrolment trends in engineering related crafts courses from 2004 to 2019

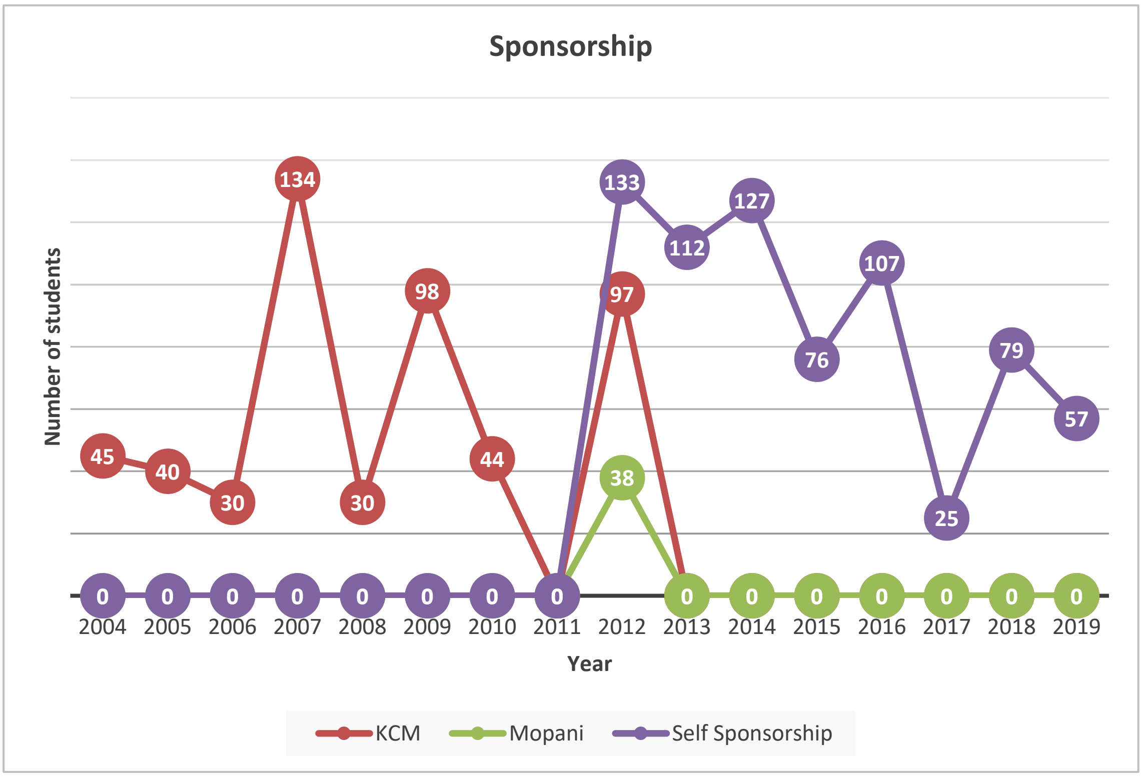

Fig. 2: Sponsorship of engineering related crafts courses from 2004 to 2019 at KTS

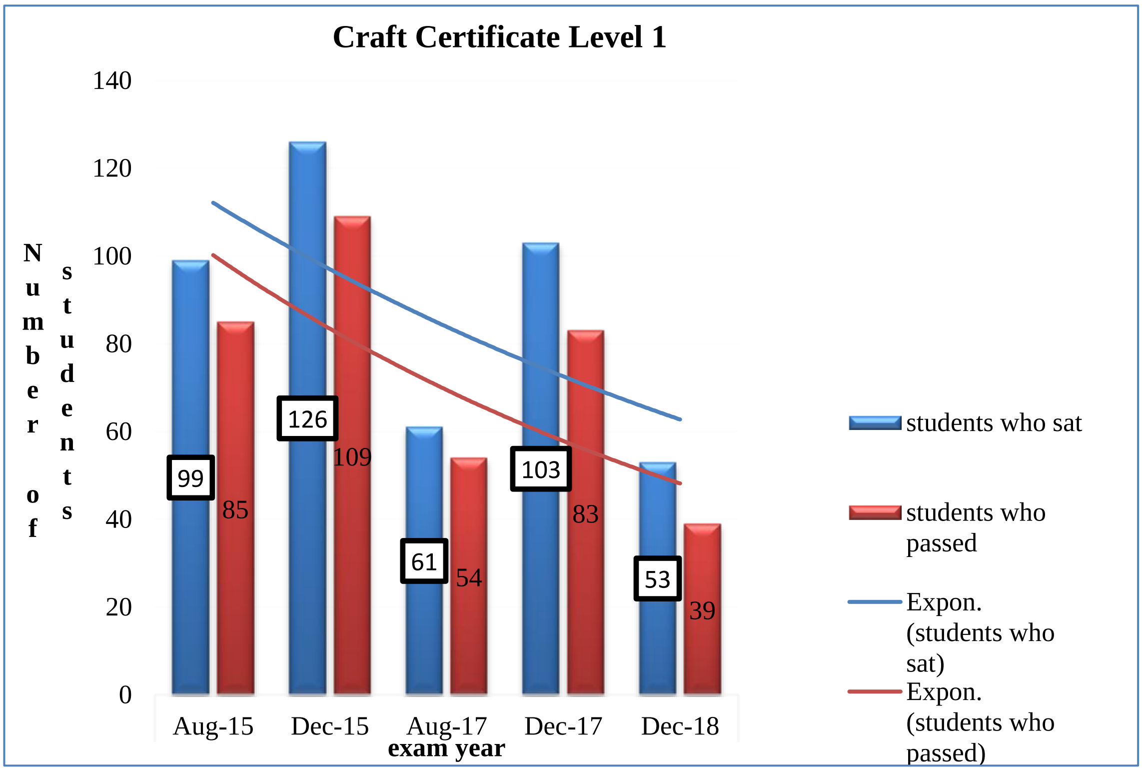

Fig. 3: KTS trends in number of Students attempting versus those who passed crafts exams

3.1.3 Implications of declining entrant, sponsorship and completion trends at Kitwe Trades School on Zambia's sustainable development in general

The decline in availability of newly trained crafts holders observed at Kitwe Trades School appears to correlate with observations made by the Zambian government. A programme to strengthen Science and Technology in teaching institutions and re-crop crafts skills, in particular, was initiated in 2014 called the Zambia-Support to Science and Technology Project (SSTEP) (Mwale, 2014). It was an initiative of the Government of the Republic Zambia (GRZ) in collaboration with The African Development Bank (AfDB), with keen focus on Higher Education (HE) and Trades Training Institutions (TTIs) development. The project's two main objectives were to contribute to human resources development to advance economic growth and reduce poverty in Zambia. The second objective was to contribute to increased access and improved quality and equity of science and technology in the target institutions.

The project was worth 39.28 million United States Dollars, commenced in 2015, in earnest, and the last disbursement was to be made in December 2018. It was intended to deliver 1,127 crafts graduates, among other science and technology human resource deliverables. The number of merit-based scholarships that were to be awarded by discipline and level under the SSTEP project are shown in Table 1 (Mwale, 2014).

Table 1: Number of merit-based scholarships that were to be awarded by discipline and level under the SSTEP project

Discipline	**Level**			
	Graduate	**Technologist**	**Technician**	**Craft**
Geology	40	4	2	40
Mining	112	84	56	175
Metallurgy	100	79	33	22
Engineering	86	82	195	890
Total	**344**	**249**	**286**	**1127**

One of the measurable impacts intended by the SSTEP project was to raise Zambia's global competitive index from 102 out of 144 countries (score 3.8) in 2013 to 93 out of 144 countries (score 0.8) by 2018. However, according to the World Economic forum, Zambia ranked 102 out of 140 countries in 2013. By 2018, Zambia was ranked 118 out of 140 countries according to Trading Economics (2014). A decline, and not an appreciation in global competitiveness, has been the aggregate outcome of the SSTEP project and other developmental efforts of Zambia in the last five years.

3.2 The Future of Engineering Training

3.2.1 Opinion of the Assistant Dean of the School of Engineering at Copperbelt University

The Assistant Dean in the School of Engineering bemoaned the wide gap between the theory and laboratory work in teaching of engineering subjects at Copperbelt University. He also felt that the ratio of lecturing hours to those spent in research and development was very high, resulting in limited development of syllabi to cater for new concepts in engineering training such as electric vehicles, artificial intelligence (AI) and Internet of Things (IoT). He viewed the need to attend international conferences as critical to the development of syllabuses that would address current and emerging engineering knowledge. He also wished that university education was seen as national capacity building and given more resources to reduce the gap between adaptable engineering professionals and academic graduates.

3.2.2 Opinion of the Principal of Kitwe Trades School

The principal of KTS bemoaned the shift from craft courses comprising three theory and one practical subject, which resulted in 70% practical activities and 30% theory, to the new Technical Education Vocational and Entrepreneurship Training (TEVET) programme which has introduced more theory subjects (fifteen [15] theory subjects in some courses) and one practical exam. Asked on how he was preparing crafts learners for the Fourth Industrial revolution, where AI, IoT and electric vehicles were the future, the principal advised that crafts courses could only be as strong as market demand for them. The current diminishing enrolments in engineering programmes at craft level suggested that industry demand for current subjects was dwindling. Introducing future looking course was difficult in the current environment.

3.2.3 International recognition

Mr. Kelly Kalumba is an imminent professional architect with over twenty years' notable experience working with Louis Karol Architects in South Africa, as Senior Partner, working and managing a large number of projects across most of African and European countries. He has a degree in architecture from Copperbelt University. His personal achievements include the South African Professional Services Awards top 3 finalists and the High Commissioners Award for recognition of outstanding performance and worldwide contribution to the architectural industry (APIS, 2019).

In response to questions on how an engineer could stay adaptable – adjustable/ complaint – in this day and age, the award-winning architect recommended attending Continuing Professional Development (CPD) activities as key to staying adaptable. He also stated that respect for professional boundaries and not transgressing other professionals' scope, as well as interacting with other professionals as important steps in the drive to being an adaptable engineer. Attending to workshops, seminars and conferences was his other recommendation to engineers intending to be adaptable.

With regard to training requirements for developing adaptable engineers, he bemoaned lack of sufficient interaction between engineers and other professionals, and understanding the stakeholders in a particular engineering requirement, as a hindrance to sustainable engineering practice. He recommended joint CPD's with other professionals and understanding the regulations, and respecting and keeping respective lanes in professional disciplines (i.e., Architects handling architectural works, Quantity Surveyors sticking to quantity surveying, Planners sticking to planning etc.). Further, he reiterated the need to understand the regulatory framework applicable to various professionals in the spectrum of engineering practice (EIZ and Association of Consulting Engineers of Zambia (ACEZ)).

Asked on how Zambian engineers could gain international recognition, the seasoned architect recommended outright performance as the only answer, adding that qualifications from Zambia were usually questioned up until the said individual proved themselves.

3.3 Proposed roles of adaptable engineering professionals in ensuring sustainable economic development of Zambia.

3.3.1 Consolidating apprenticeship, coaching and mentorship activities

In the wake of the dwindling global competitiveness of our country, the professional adaptable engineer faces a rare opportunity to use the negative situation to innovate positive outcomes. One area where his impact can be exerted is in enhancing apprenticeship, coaching and mentorship activities in existing industries. Corresponding capacity built in the additional skilled manpower will result in higher productivity, which translates into a better fight against poverty; also leading to improved regional and global competitiveness. Adaptable engineering professionals can innovate skills transfer programmes for industry entrants, to multiply the human capacity more affordably, as less financial resources are required for apprenticeship, coaching and mentorship programmes, compared with full time on-site trades training courses. This proposal does not suggest that onsite trades training programmes at trades training colleges can be eliminated. On the contrary, apprenticeship, coaching and mentorship programmes reinforce productivity of trained engineers, of whom crafts holders are usually the executing front. This initiative would act as a stop-gap solution to the shortage of financial resources to sponsor full-time crafts courses.

3.3.2 The use of the internet for knowledge gathering and on-line training – webinars

The internet remains an invaluable resource for knowledge gathering, information and training. Electronic learning (e-learning) is now possible anytime, anywhere through on-line seminars, also known as webinars, as well as virtual universities and colleges, such as the Quantic School of Business and Technology. Engineers can learn new strategies, skills (both hard and soft) on-line, thereby enhancing their adaptability as engineering professionals. These e-learning and online programmes would be part of CPD activities recommended by EIZ. The EIZ can develop home-grown e-lessons by engaging selected accomplished persons in the whole spectrum of engineering practice to create home-grown content for online learning. The Institution of Engineering and Technology (IET) has established an e-learning academy that is helping companies in the U.K. and abroad to uphold and enhance their engineers' skill sets. As these engineers are available to their companies during working hours, productivity is not compromised in these companies. The engineers then undertake the e-learning outside working hours. The flexibility of when to take the on-line courses allows the engineers to continue contributing to their country's economic growth during working hours.

E-learning could be adopted by EIZ professional engineers, to help reduce the overall cost of acquiring engineering training. In particular, e-learning could help increase the number of crafts skills holders as it is cheaper to deliver to individuals, than traditional on-site training.

3.3.3 Encouraging synergies among Small and Medium Enterprises (SMEs) - the case of Dajomuka Electrical

Dajomuka Electrical is an SME business in Ndola run by Davie for the last 25 years (see Fig. 4). Davie has a trade in panel beating. However, he previously worked for Electro Products, a company that manufactured electrical switch boards. When the company closed shop, Davie started Dajomuka Electrical. Using basic sheet metal skills, Dajomuka Electrical manufactures a wide range of electrical switch boxes, including meter boxes, distribution boxes (DBs), feeder panels, to mention a few (see fig. 5(a) and 5 (b)). Their policy for manufacturing is "show us a sample and we will make you the required electrical switchboard."

Dajomuka Electrical supplies its products to most hardware shops in Ndola. However, a closer look at their manufacturing equipment shows that their capacity to produce merchandise is limited by their existing infrastructure. Further, Dajomuka Electrical uses designs that Davie remembers from his days at Electro Products. Davie is not aware of standards that apply to the manufacturing of electrical switchboards. He uses ordinary oil paint on the electrical boxes he fabricates, instead of fire-retardant paint. He is not aware of Zambia Bureau of Standards (ZABS) and their role in enhancing national standards in the production of goods and services.

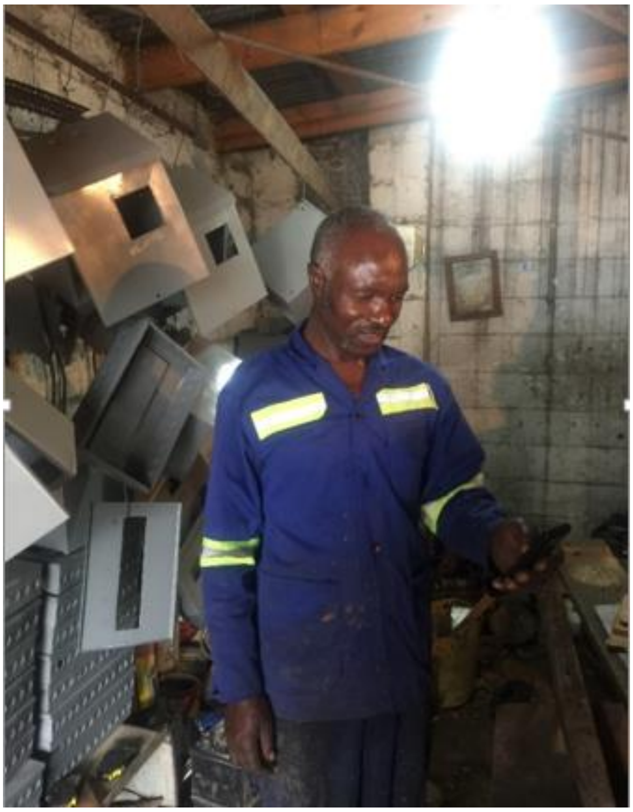

Fig. 4 : Davie in his store room at his sheet metal workshop

3.3.3.1 Enhancing Dajomuka Electrical's products to meet National – and by implication, International Standards

Dajomuka could enhance the quality and quantity of its products if they began to produce their products based on a recommended international standard or an adapted local ZABS standard. Making affordable training on modern sustainable production methods of electrical switchboards on a small scale available to Dajomuka Electrical would ensure that both its productivity and continuity is improved.

Further, changing from using the home-made bending machine to acquiring or using an electric bending machine could increase his productivity, several fold. Davie acknowledges that the use of an arc welding machine limits the final touch on the switch boards he produces. He believes that a spot-welding machine could improve his finesse.

Fig. 5(a): Tin smith folding parts of an electrical distribution box.

Fig. 5(b): Completed electrical distribution boxes

Davie currently nets a profit of 30% on his products. With basic improvements in his manufacturing infrastructure, he could increase productivity and profitability. Combining efforts with another SME that already has the equipment he requires, while he builds capacity to acquire his own modern infrastructure could solve his problem of limited output and quality, in the short-term, while enabling him to produce enough to meet his recurrent expenditure and save for his capital requirements. Such synergies could bridge the gap created by limited access to capital and liquidity in the current economy.

In some instances, Dajomuka electrical goes into an arrangement with some hardware stores where they supply him with inputs like sheet metal and paint. He then produces the distribution boxes and charges the hardware stores for his labour. This, in itself, is reminiscent of the advanced systems such as Keiretsu, practiced in Japan. Companies like Toyota have improved the system to outsource its inputs from the global market. This contrasts from the older Keiretsu system, which was based on local suppliers and a common bank - Katsuki Aoki and Thomas Taro Lennerfor – (2013)

4. Conclusion

1. Adaptable engineering professionals are those engineers who will adapt themselves to engineering requirements by making use of their inputs: training, experience, aptitude and attitude, to solve societal requirements now and in the future. A key input to engineering adaptability is availability and access to training that equips engineers with modern skill sets, required to solve modern-day engineering problems in a sustainable way.

2. From the Kitwe Trades School Case study, it was observed that there was a decline in the enrolment and graduation of crafts artisans in the period 2004 to 2019. E-learning could take up the training gap arising from dwindling college enrolments and graduations. Adaptable engineers could develop local e-learning modules providing a wide range of engineering subjects best adapted to the Zambian environment, yet compliant with world best practice. Resulting improved engineering capacity can lead to improved and sustainable productivity. Financial gains resulting from improved productivity can then fund more trades, technician and graduate engineering training, while also reducing poverty and minimizing environmental damage.

3. Other roles of adaptable engineering professionals in ensuring sustainable development include:

   - Implementing apprenticeship, coaching and mentorship activities. These activities are seen as adaptable avenues through which engineers can bridge skills gaps;
   - Using the internet for knowledge gathering and online training – webinars.
   - Encouraging synergies among Small and Medium Enterprises (SMEs).

4. The road to self-determination of any country involves several actors. Adaptable professional engineering has its critical role in contributing to the sustainable development of Zambia. Let it begin with each EIZ member at every level of engineering practice.

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The role of the engineer in developing smart city initiatives in Zambia

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Abstract

Many developed cities in the world today have embraced smart city initiatives through smart projects and services. Some cities in developing countries such as Kigali, Cape town and Nairobi have been reported to embrace smart city initiatives. Literature summarises the role of smart initiatives as making traditional city services more efficient through the use of digital platforms for the benefit of the city inhabitants and governance by local and central government institutions. The introduction of smart city projects and services eventually lead to the attainment of full smart city status, a situation that is not yet common particularly in cities of developing countries. The financial services sector including the banking industry is the only sector in Zambia that has attained significant progress in introducing smart services to its customers through digital platforms such as computers, smart phones and ordinary mobile phones. This study explored the roles that engineers can play towards the introduction and expansion of smart projects in the Zambian cities with initial focus on city transport system and services; water engineering and city security. Data for this study was obtained from official reports, observations and surveys from engineering experts. Results from the study indicate that some smart city services are already in use in Zambia but lack sustainability programs in the public sector. The full involvement of local network, computer, electronic, electrical, water and civil engineers in expanding smart projects and initiatives could lead to significant scores in the attainment of the smart city agenda. It is clear that involvement of these engineers in building smart city initiatives would lead to locally engineered; sustainable efficient public services; reduction of human error in service delivery and protection of revenue collected by local and central government authorities. Further, smart city initiatives promote virtual services and spaces which is one of the mitigation measures for counteracting COVID 19.

Keywords: Smarty city, services, opportunities, benefits, engineer, Zambia

1. Introduction

The term smart city can easily be mistaken for a city that is clean and orderly in terms of citizen dressing and surroundings, however, this is not so. A smart city is defined as a town, old or new, that utilises Information and Communication Technology (ICT) and innovation as a gateway to sustain economic, social and environmental aspects of the city (Anthopoulos, 2017). Further, the aim of the smart city is to address several challenges associated with people, economy, governance, mobility, environment and living (Anthopoulos, 2017). Ooms, (2020) states that smart cities use integrated ICTs to support citizens and organizations in dealing with the challenges of urbanization, safety, and sustainability. Dameri (2013) defines a smart city as a city that is driven by technology in order to improve logistics, mobility and environmental sustainability in the city. Shea and Burns (2020) describes a smart city as a municipality that uses

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(ICTs) to increase efficiency in day to day operations, share data with the public and improve both the quality of government services and welfare of citizens. The use of digital space, virtual platforms, remote transactions, sensors and unmanned services all amount to smart city services. It must be mentioned that smart projects and services do not necessarily qualify a city to be smart unless the entire city goes smart, however, delivery of smart city projects and services is part of the process of attaining smart city status.

2. Background

Smart city projects and services rely on stable and affordable internet in order reach out to users of smart city services. Smart city projects and services can be seen as unit blocks for building or developing a smart city. This section presents the ICT background and application to some sectors in Zambia leading up to the case build-up of this study. UNESCO (2009) defines Information and Communication Technology (ICT) as a wide set of technological tools and resources used to transmit, store, create, share or exchange data or information. These tools and resources include computers, tablets, smart phones, the internet of things (IoT), live and recorded broadcasting technology. Between 2010 and 2020, Zambia has experienced development of isolated smart projects and services in the following sectors:, Financial and banking sector, water sector, power sector, parts of the transportation sector, aviation, and public security. Further, mobile phone service providers and internet service providers have been at the centre of facilitating the majority of these services. From the observations made based on the ten years (2010 to 2020), the financial services sector could be ranked as the most developed in terms of smart initiatives and services to the general public in Zambia. While smart city projects and services have been identified in the listed sectors, many of them apart from the banking and financial services sector lack significant growth, expansion, visibility and sustainability (International Finance Cooperation, 2017). (IFC, (2020) report for Zambia states that in 2008, the Zambia National Commercial Bank (Zanaco) launched Zambia's first mobile banking service called xapit, which is still a popular service today. Today most banks have the mobile banking services on the smart phones, tablets and computers thereby reducing queues and carbon foot print through avoided vehicular trips to the banking halls for banking services and payment for services such as water and electricity. Banking services such as fund transfers, checking account balance and generating bank statements are among the benefits of smart initiatives presented by the banking sector. These bank synchronised services are facilitated by phone providers such as MTN, Airtel and Zamtel platforms for communication and financial transactions such as mobile money service. Further, this has resulted in potential areas such as smart parking fail to take off due to engineering, financial, capacity and management barriers. There are other localised and yet not fully developed smart initiatives in the education, tourism and hospitality sectors. These smart services still in their initial stages can be related to the smart city maturity cycle (Figure 1) that shows stages of smart city development which ranges from silo or localised services to advanced integrated systems powered and interlinked through ICT.

This paper focuses on the roles that engineers can play in Zambia in improving and expanding existing smart city initiatives and services. Further the paper explores the roles that engineers can play in introducing new smart city services not yet introduced despite having the conducive environment and resources. Engineering areas identified as platforms for enhancing improved and new smart city services include network design, computer software, computer hardware, electronic engineering, electrical engineering, water, transport, building services engineering and civil engineering.

3. Literature review

Ahvenniemi et al. (2017) states that smart cities and communities focus on the intersection between energy, transport and ICT. This statement is a common anchor of smart city services whose aim is to improve quality of life and governance through the use of ICT. According to Bibri and Krogstie, (2020); Nikitin et al. (2016); Pozdniakova, (2018.), despite being not smart cities, London and Barcelona are among the leaders in implementing data-based technologies and decisions using advanced technology and digitisation. The data-based decisions mainly include transport and security among others.

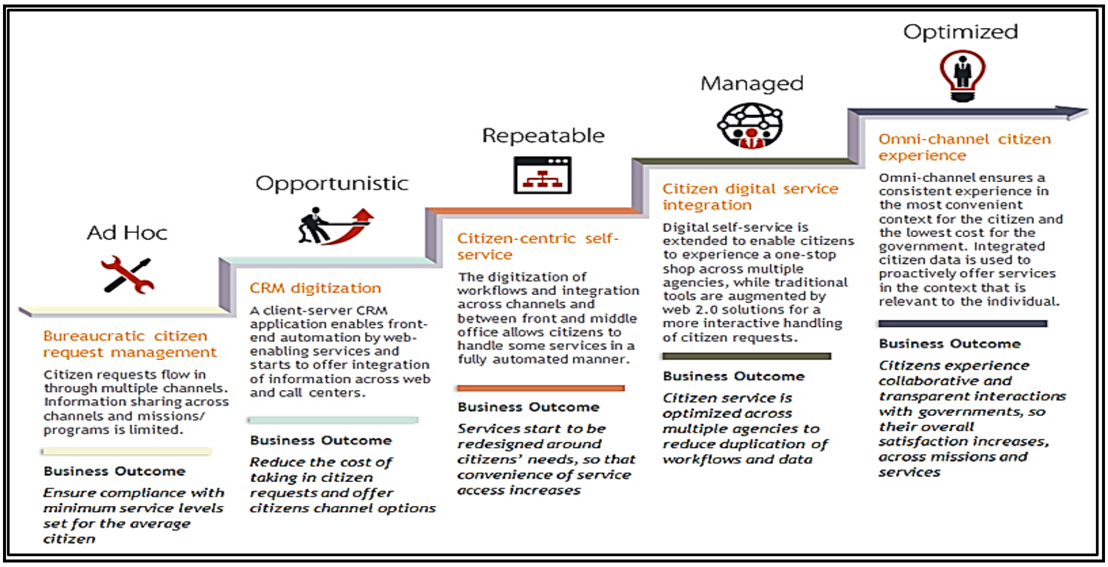

Figure 1: Stages of smart city development
Source: https://www.businesswire.com/news/home/20150416006210/en/3rd-Platform-Technologies-and-IoT-Will-Drive-Citizen-Engagement-According-to-New-IDC-MaturityScape

The European smart city website (http://www.smart-cities.eu) lists many European cities that have smart city projects that are active. Among the cities listed include Leicester in the United Kingdom, Rotterdam in the Netherlands and Stockholm in Sweden. The website reports that the main fields on focus in smart city initiatives include achieving a smart economy, smart governance, smart mobility, smart environment and smart living. These are further broken down as providing the following through smart digital platforms: political awareness; efficient and transparent administration; efficient local transport system; individual security and health conditions among others. Thomas (2005) states that as early as 2005, South Africa had started embracing smart services in readiness for the 2010 world cup. Thomas (2005) further states that South Africa provides smart services using smart cards in areas of electronic tolling payment, electronic licensing of vehicles, medical aid, access control to spaces, municipality services such as smart parking payment, smart payment for train and bus fares among others. Bwalya (2005) states that Durban, Cape Town, and Port Elizabeth are among cities that have embraced smart city projects. Burns (2021) states that in 2018, Kigali, the capital city of Rwanda was recognised as one of the top 50 smart city government rankings because of its ambitious master plan which includes a rapid rebuilding of the city, innovation hubs, new business districts and sweeping new developments. Evariste et al. (2020) discussed the internet of vehicles as a smart parking option and its associated analysis in the city of Kigali. Mhangara et al (2017) states that Cape town's smart city strategy spans as back as the year 2000. Today, Cape Town is reaping on its massive investment in information and communication technologies, which have made it Africa's premier international city. Mhangara et al (2017) adds Nairobi in Kenya and Dakar in Senegal to the list of smart cities. Okai et al. (2018) outlines the benefits of smart cities as better city planning and development; E-government services delivered to citizens, faster, and at a lower operating expense; improved productivity and service and Smart meters. With the given definitions and descriptions of smart cities, the role of engineering in the development of smart cities becomes critical because much of the smart infrastructure, initiatives and services involve the input of various engineering disciplines. From the civil engineering perspective, Cosgrave (2018) states that in order to be able to contribute to smart infrastructure and construction that provide social as well as technical requirements, engineers must be able to engage in critical debates that incorporate and value human experience. Further, Cosgrave (2018) states that interface of the social science understanding of the smart city and the technical interpretation must be well understood because smart infrastructure' serves social purposes, embrace complexity, understands financing of smart cities and embraces engineering education. While the funding for smart city projects cannot be left out in this discussion. Many governments in developing countries struggle with financing of public service projects.

A study by Lam and Yang (2020) revealed that based on the evidence from smart city projects in Hong Kong, not all smart city projects are suited for funding under the PPPs. This further implies that PPP legislation, transparency, accountability and public confidence must be robust enough to attract private sector finance to viable and appropriate projects in addition to political and economic stability. Law and Lynch (2019) emphasize that engineers and smart city developers need to have deep understanding of the smart systems as well as the associated benefits and risks. Ideally, a smart city is a place that is not only about embracing technology and economic growth, but a city that is humanistic, ecologically sound, and liveable. Budrin et al. (2020) clearly points outs that integrating electronic engineering into the core processes of sustainable smart cities, and can help to create these smart cities through innovation, as well as through the redesign of existing processes, including new technologies, applications and energy systems. Information security is considered to be of critical significance to the implementation and development of smart cities and one of its most serious challenges (Khatoun and Zeadally, 2016; Hasbini et al 2018). The responsibility falls on security-oriented network engineering whose role is to ensure that citizens information is secure in the development of smart cities. The security around internet security and data protection requires continuous improvement and reviews by service providers and users in addition to coded transmission of data and transactions, handling of passwords and access control. Channi and Kumar (2022) states that smart cities provide critical infrastructure for a network of sensors, cameras, cables, wireless devices, and data centres that allow city authorities to deliver essential services more quickly and efficiently. This position suggests a multi-disciplinary approach of various engineering and management tools, professionals and systems as highlighted by Andrisano et al (2018) who emphasises that architecture, physics, ICT, finance, civil engineering and electrical engineering, etc are all important ingredients that feed into the development of smart cities.

4. Research Methods

This study took a simple participatory survey in order to obtain data from implementers of smart projects in limited cities and from the private sector. Further, reports and survey studies were obtained from literature by targeting smart city initiatives. Primary data was obtained from observations, interviews, participants surveys from the energy, water, local authority and private sectors as shown in table 1.

Table 1: Sources of participatory data

No	Organisation type	Profession	Participants
1	4 Local authorities	Building, civil and electrical Engineer	5
2	3 Water utility companies	Commercial manager and water engineers	3
3	2 Power utility companies	Electrical Engineers	5
4	2 universities	Mechanical/mechatronics Engineers/Electrical	3
5	Mining industry	Mechanical/mechatronics Engineers	2

Secondary data was obtained from official reports, websites, journal articles and other credible online sources such as smart city websites. A simple thematic analysis as shown in table 2 was carried out in order to meet the objectives of the study.

Table 2: Summary of results and findings based on the survey and literature review

A Priori Theme	Motivation	Proposed engineer involvement in improving the smart services and extending the services beyond existing boundaries with support from other stakeholders including government
Water services	Unlimited remote access to water meter readings	Mechanical, electronic, computer, network, manufacturing, civil and water engineers
Intra town Transport services	Street lighting, traffic lights, car parking	Mechanical, electronic, electrical, computer, network, civil, manufacturing and transport engineers
City security	Surveillance in inter and intra city roads and spaces	Mechanical, electronic, electrical, computer, network, civil, manufacturing and transport engineers
Energy	Remote monitoring of national system	Mechanical, electronic, electrical, computer, network, civil, manufacturing and transport engineers

Interviews with experts from the universities indicates capacity to design selected smart city services ranging from smart traffic lights to drones designed for various fields such as security and agriculture is available. At the same time the results indicate that manufacturing and mining sectors have already implemented smart technology and services on their equipment and process plants. These advances have been mainly dominant in the private sector. The study however focussed on smart projects services in the public services sector covering power supply metering, street lighting, water metering and associated virtual payment platforms. The identified areas for tagging smart city concept include municipality car parking, traffic light management, traffic monitoring and control, city safety management through closed circuit television and drone technology in strategic places.

4.1. Ethical considerations.

The respondents decided to exercise their right to remain anonymous due to the complex nature of the stakeholder matrices characterising many of the smart projects that are currently running. The study further extended the anonymity to participating organizations apart from the data that was in the public domain.

5. Results and analysis

Table 2 shows a summary of the findings based on the participatory survey and literature review. The details are discussed from 5.1 to 5.4

5.1. The water sector

According to the Nkana water and sanitation utility company Facebook page, installation of smart meters commenced in 2019. These meters remotely collect meter readings and bills are sent to customers via email and text messages. These smart water meters can disconnect and reconnect water supply through the firms remote control system at a click of computer button. The company no longer sends ground staff to physically take meter readings in these selected areas thereby circumventing corruption opportunities and transportation costs for ground staff. Finally, water bills are sent to emails and mobile phones while payments can be made through the same medium. The smart water meters currently in place are imported, making them unsustainable in terms of maintenance and replacement. Mechanical, electronic and network engineers are challenged to develop locally produced meters in order to support the expansion and extension of these smart water meters referred to as automated meter readers. Savenda electrical, the Zambian based electrical manufacturing company is reported to have commenced the manufacturing smart meters for water and electricity, a technology that can be tapped into to expand the smart meter agenda. With the meters relying on internet network connectivity, network engineers have a challenge ahead to improve the quality and stability of the network connectivity in order to make connectivity stable in all parts of the country that would be marked for smart water meters installation projects. Challenges of vandalism must also be addressed thorough security infrastructure installation and education to the local citizens. It must also be stated only few selected residential areas have the automated meter readers or smart meters. The rest of the residential areas still have ordinary post-paid meters and pre-paid meters.

5.2. Transport sector

5.2.1. Inter town Transportation industry

According to the Road and transport Agency (RTSA) website (https://www.rtsa.org.zm) the agency commenced a program to install Global Positioning System (GPS) on 650 public service buses in 2019 in order to remotely monitor compliance of public service buses in terms of speed limit of 100km/hr . On 19 October 2021, the RTSA website issued a statement that five public service bus drivers were to have their driving licenses revoked for exceeding the speed limit by up to 120 km/hr above the limit as remotely detected through the GPS system. This is a good example of local smart transportation of remotely monitoring performance of public service vehicles and drivers along the highway. With the integration of mechanical, electrical, electronics, computer and network engineers, this service can be extended to provide real time information on electronic bill boards regarding arrival and departure times for inter-city buses, accident and disruption information on the highways. Further, this triggers the need to have dual carriage way road between towns to improve road safety and management of traffic. Civil and transport engineers skills are required to develop sustainable infrastructure which is smart in nature.

5.2.2. Intra town Transportation industry

Street lighting

Observations and participatory survey revealed that solar street lights being installed in major cities of Kitwe, Ndola and Lusaka have sensors that detect light and darkness resulting in automated switching on and off the LED based solar lights. Not all areas within these cities have this type of street lighting system. For a long time now, Zambia has been training mechanical, electronic and electrical engineers who by now and with the support of stakeholders should step up to promote local solar panel and battery manufacture in order to make smart street lighting sustainable through local manufacturing processes. Currently, much of the smart street lighting units are imported making them expensive in terms of maintenance. Results from the survey indicate that local engineers have the capacity to fill these gaps with support from government and partners so that local smart city initiatives can be developed locally with specific focus on locally sustainable solutions. Cities and towns in Zambia do not have smart street lights apart from selected areas in major towns that recently received major road rehabilitation which were delivered with the road rehabilitation package.

Smart car parking

Smart car parking is driven by ICT as a way of allowing automation to control car parking thereby improving operational efficiency and mitigating revenue loss mainly arising from manned car parks. Currently, local authority parking fees are collected manually resulting in accountability and transparency challenges. The technology is available to support this project such as internet, cameras and solar powered energy which is reliable. Local authorities need to collect and secure revenue collection points in order to run the cities in an effective and smart manner. The internet connection to support these projects is stable enough as seen in the reliability of banking and online payment services in the country. The study observes that local authorities may not have the capacity to design, build and operate these smart car parks and yet they can engage consultants and operators under signed agreements and commitments. The study identified public PPPs as a vehicle through which design, finance, construction and operation of these specialized smart projects can be delivered if optimum results and benefits are to be realised. Civil, electrical, electronics, computer network and mechanical engineers all working together can design locally suitable smart car parks that are sustainable based on solar and battery powered systems supported by security or surveillance cameras and smart cards. Financial and economic experts can also be incorporated to advise financing mechanisms which include PPPs. Not all projects are suitable for PPPs as stated by Lam and Yang (2020) so a demand, revenue and risk analyses should always be mandatory.

5.3. Security cameras

Observations and literature indicate that security cameras have been installed on road junctions, highways and strategic places for monitoring traffic activity and safety on motorists on the roads in Kitwe, Lusaka and Ndola. Currently, there is less information on how effective the installed cameras have been in terms of reducing crime or leading to identification of offenders. Such data would be useful to the public for enhancing confidence and sense of city security especially that smart projects must operate on the basis of transparency. Effective use of cameras would improve city security thereby bringing crime levels down. These however must be supported by good road network, reliable internet connection and locally supported sustainable programs. Drone technology was identified as an effective smart city solution in city surveillance and monitoring for safety of citizens. Surveillance through drones and camera system can reduce usage of motorised and manned ground patrol. Engineers have a critical role in planning and getting this smart city agenda to work. Further this implies that the police service surveillance and patrol operation staff must be retrained in the handing of high-tech smart technology as part of the smart city agenda. Security camera installed on the highways must also be defined in terms of traffic or surveillance or both so that motorists are aware of the type of service available. Road signage in terms of cameras and their function is important for transparency purposes. The security cameras must be optimized through interaction of engineering disciplines in order to improve the quality of life for motorists.

5.4. Energy sector

Interviews with the Zambia Electricity Supply Company (ZESCO) and the report from the Energy Regulation Board (https://www.erb.org.zm) revelaed that ZESCO controls its national grid from their central control center using the SCADA system. This system monitors and controls the smart grid network for load management and protective action which can be done remotely mainly for substations across the country which are supported by the fibre optic line. This is part of the smart energy management agenda. The survey reveals that ZESCO intends to introduce smart meters that will give household self-regulation and control over energy management in their homes. ZESCO is already installing smart ready meters in residential homes which will go live once the smart system backbone is activated creating a two way traffic system that will allow customers to perform energy control, monitoring and purchasing of units using a simple mobile phone.

6. Conclusion and recommendations

This study focused on identifying existing and proposed smart city initiatives and the respective roles that Zambian engineers from various disciplines can play to ensure that these smart projects and initiatives become, attainable, sustainable and affordable. This is for the benefit of citizens through improved lives and governance by local and central governments. The study concludes that nearly all engineering disciplines in addition to social sciences, financial and economic drivers are pivotal in ensuring that smart city initiatives are attained and sustained. Internet stability in all towns, training, maintenance, availability of locally procured materials, mindset change and teamwork were identified as key success factors for attaining smart city projects, initiatives and services which eventually constitute building blocks for attaining smart city status. It must be mentioned that some smart city services move along with services such as transport, road and water which are not available in squatter areas thereby presenting challenges in rolling out smart services in some areas that are underprivileged economically. A master plan for infrastructure development must be integrated with the master plan for smart city projects, initiatives and services if the smart city agenda is to be achieved. Smart city services must also be categorized according to the smart city maturity cycle for effective monitoring of growth for the smart city agenda in areas of education, health, local government, transportation and services.. Stronger links between government units and research institutions must be strengthened and supported financially and politically to champion locally driven smart city solutions in public services.

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Application of chain filter media as a simple way to increase treatment efficiency of gaseous emissions and reduce environmental impact in material processing

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Abstract

Material processing in various industries is accompanied by intensive emissions of dust and toxic gases which have had adverse effects on the environment and human health thus deeming such processes and products as not environmentally friendly. This paper discusses and proposes an efficient way that industries can use to control gaseous emissions during material processing by introducing chain curtains (and chain garlands) into their air pollution control devices thus increasing efficiency and consequently, adding value to their products. Experiments using the chain curtain were conducted using a specifically designed laboratory stand. A simple and efficient addition to the design of an ejector scrubber has been proposed through the use of chains as a drift eliminator and filter media with an increase in efficiency of 90-95%. The use of a chain garland as a filter media and drift eliminator respectively, proved to be more effective in comparison to conventional scrubbers by up to 95%, which makes it more promising due to its simpler design and manufacture. As a result of installing pollution control equipment that is simpler in design and manufacture, a firm can protect and improve its reputation by reducing the environmental impact of its products thereby adding value to its products without incurring significant overheads. It is also an opportunity for local firms to design and manufacture efficient pollution control equipment that is simple in design to help businesses reduce on costs of importation.

Keywords: filter media, material processing, air pollution control device, chain curtain, environmental impact

1. Introduction

Considerable changes have taken place in economies worldwide during the last 30 years in terms of production and international trade among countries and businesses in general. Zambia is one such country and it is currently transitioning to a green economy which involves a fundamental transformation towards more sustainable modes of production and consumption through green engineering (Moonga and Chileshe, 2019).

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From the selection of raw materials to the packaging of the finished product, environmental factors should be considered to ensure that the lowest impact of the product on the environment is achieved (Karana *et al* 2020). Technological processes in various industries are accompanied by intensive emission of pollutant gases and dust into the working areas of production workshops ultimately into the atmosphere of cities (Goremwikin *et al.,* 2000). A rise in air pollution accompanied with the ongoing global economic and energy crisis have set the task of finding effective, simple and inexpensive ways to increase the degree of treatment of gaseous emissions. Zambian large-scale producers could benefit from such incentives including local manufacture of air pollution control devises as they annually incur high costs on import and maintenance of pollution control equipment because the country currently does not manufacture its own.

The objective of this paper is to find a simple way to increase treatment efficiency of pollution control devices in material processing thus minimizing negative environmental impacts.

2. Application of chains as filter media

In order to localize dust emissions from the main sources, air suction systems with gas treatment devices of various modifications such as cyclones, bag filters and scrubbers are used. An economical and effective addition to the design of these devices is the use of a chain curtain (or garland) and is most often the first step in the treatment system (Goremwikin *et al.,* 2000).

The device shown in Fig. 1 is designed to treat humid dust and gas emissions in humid conditions. The industrial dust collector is a modification of the cyclone and consists of a cylindrical body 5, with inlet and outlet pipes 2 and 3, a chain garland 6, suspended on a movable ring 9, which has a motor 1, an inner cone 7, a hopper 8, a service door 10. Regeneration of the internal surface of the device from humid dust is carried out by periodic vibration of the chain garland (curtain). Technical specifications of the dust collector are shown in Table 1.

Table 1: Technical specifications for dust collector

Technical specifications	Value
The volume of treated gases, m^3/ h	1000-5000
Hydraulic resistance, Pa	800-1200
Efficiency, %	85-98
Duration of regeneration, sec.	9-14
Overall dimensions: mm, Ø; H	300-600; 1200 - 4500

Source: Goremwikin et al (2001)

Despite the simple design, these air filters provide high efficiency (up to 98%) with a completely acceptable maximum pressure drop (up to 1.8 kPa). By virtue of their simple construction and operating principle, they are a preferred choice for highly humid dusts and therefore are quite promising for firms in the refractory industry (Goremwikin *et. al.,* 2001).

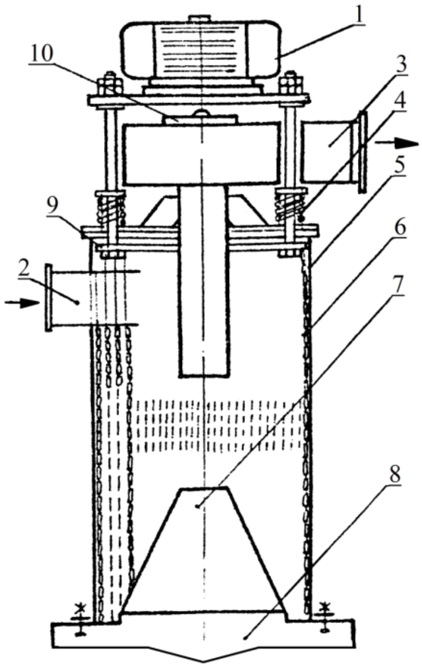


Fig. 1: Dust collector for humid (sticky) dust (Source: Goremwikin et al. (2001))

Dusty air from a dust source enters the base of the housing. The air is treated upon passing through the filter media. The treated air is later discharged from the air filter. The regeneration of the filter media is carried out automatically by raising and lowering the upper frame with chains. To switch from filtration to regeneration and vice versa, a valve device is used (not shown in Fig. 2 and 3). The captured dust does not undergo further treatment and is returned to the production process.

Table 1: Technical characteristics of FCGM and FC-1P (1E) chain bag filter types

	FCGM chain bag filter	FC-1P (1E) chain bag filter
Productivity, m^3/ h	10,000	1000
Specific gas load, m^3 / (m^2·min)	25	23.8
Filtration area, m^2	6.7	0.7
The number of sections in block	3	2
The temperature of the gas stream, °C	-3- to +120	80
Differential pressure (maximum), kPa	0.5	0.6
Moisture content in the dust and gas stream, g / nm^3	25	50
Filter layer Welded round link chain	welded, round linked chain	welded round linked chain
Grain size, mm	4x28	3x20
Layer height, mm	300	180
The porosity of the layer,%	72	72
Treatment efficiency,%	96-98	96-98
Weight, kg	750(600)	750(600)

Source: Groremwikin et al. (2001)

For preliminary purification of gases with a high mass concentration of dust, it is advisable to use chain bag filters from the FCGM (hydro-mechanical chain filter) and FC-1P (1E) (pneumatic chain filter with an electric motor) series. These bag filters are essentially fixed-bed granular filters and are designed for dry treatment of suction air with high moisture content (up to 50 g/ m^3) from weakly and strongly sticky (humid) dusts.

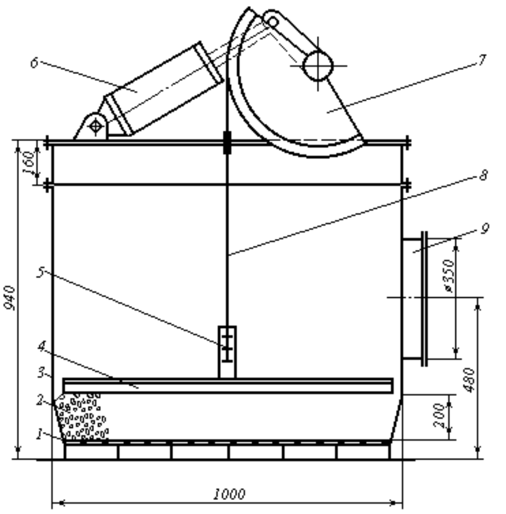


Fig. 2: Chain bag filter FC-1P (1E): 1- grid; 2 - filter element; 3 - case; 4 - upper frame; 5 - stand; 6 - pneumatic cylinder; 7 - sector; 8 - rope 9 - outlet. (Source: Goremwikin et al. (2001))

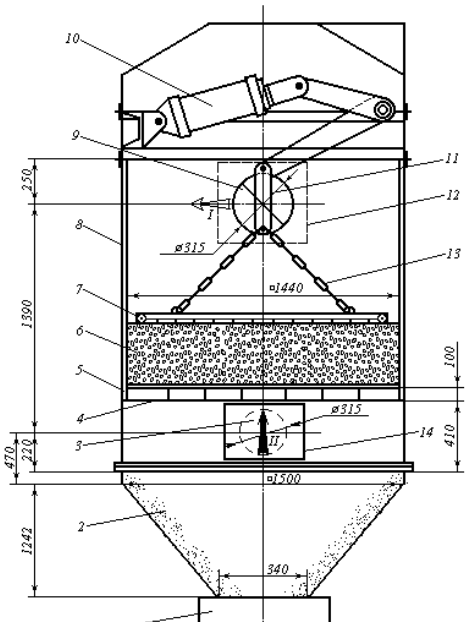


Fig. 3: Diagram of chain bag filter FCGM: 1 - transport device; 2 - bunker (mine); 3 - inlet pipe; 4 - support grid; 5 - bounding wall; 6 - filter layer of chains; 7 - movable frame; 8 - case; 9 - outlet pipe; 10 – drive; 11- throttle; 12 - hatch; 13 - load chains; 14 - hatch; I - purified air; II - dusty air. (Source: Goremwikin et al. (2001))

The principle of their action is based on the deposition of dust particles in a metallic filter media made of chains which are folded to form a filter layer. During filtration, the upper frame with chains is lowered to the bottom. Technical characteristics of chain bag filters FCGM and FC-1P (1E) are listed in Table 1.

The schematic diagrams of chain bag filters FCGM and FC-1P (1E) are presented in Fig. 2 and Fig. 3 respectively.

3. Materials / Methods / Design / Methodology

Scrubbers are categorized as air pollution control devices that use liquid to remove gases or particulate matter from industrial exhaust streams. In order to determine the treatment efficiency of an ejector scrubber after a chain curtain is attached to it as a drift eliminator, a laboratory stand consisting of an ejector scrubber S, fan F, pump P, container C, and manometers M1 and M2, gas analysers GA1, GA2 and psychrometer R, was set up for the chemical treatment of toxic gaseous emissions as shown in Fig. 4.

A U-shaped manometer filled with pure water was used to measure static pressure in the gas stream. Gas analyzers were installed at the gas inlet and outlet to measure pollutant concentration. An alcohol thermometer was used for measuring temperature and was attached to the gas inlet. A psychrometer was used to measure relative humidity and a digital differential manometer was used to measure differential pressure, flow rate and air velocity.

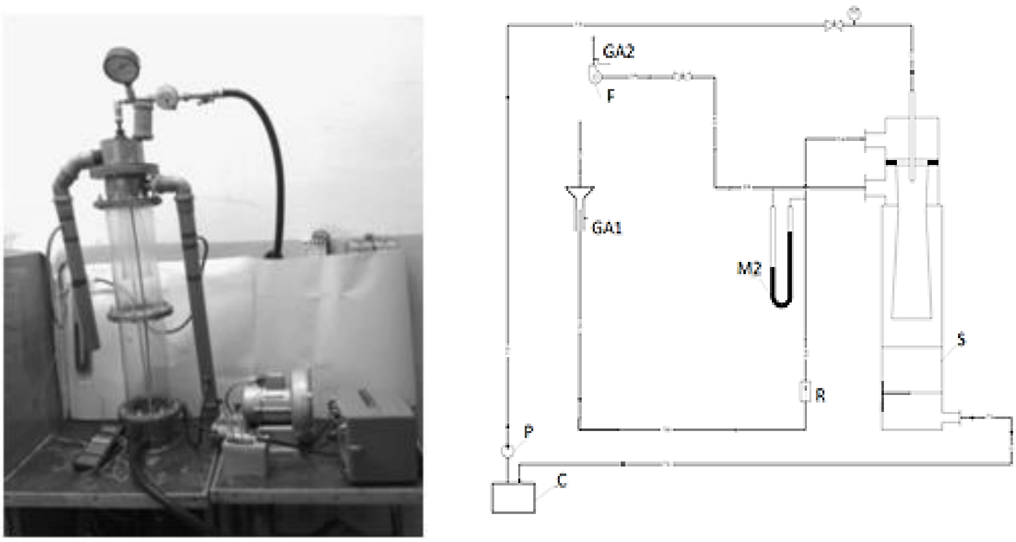
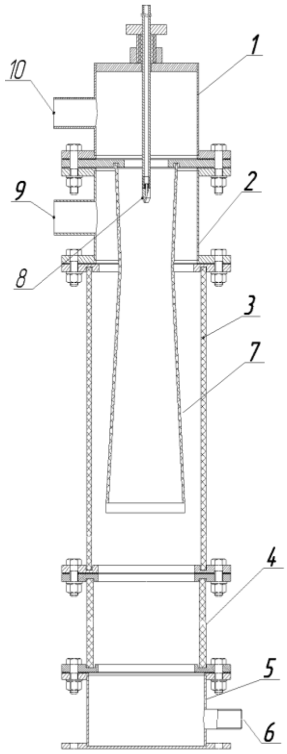


Fig. 4: Photograph and schematic diagram of the experimental unit

The cylindrical case unit of the ejector scrubber is made up of several sections with a flat base and outlets for sludge 6, and treated gas 10, which are incorporated into the housing of the contact device consisting of a convergant-diffuser (Venturi) tube 7, and nozzle 8. The drift eliminator component is made up of chains suspended on the lower part of the neck (constriction) of the inner tube. Fig 5 shows a diagram of the ejector scrubber. Three chain curtains with different sizes of the chain link were used as a contact and drift eliminator in the device for wet treatment (Himwiinga *et. al* 2019).

Fig. 5: Schematic diagram of wet scrubber



4. Results

4.1 Pollutant capture and treatment efficiency

The calculation for capture efficiency of the front-row chain curtain is carried out according to the formulae as expressed by Goremwikin et. al (2001):

$$\eta = 1 - (1 - \eta_1') - (1 - \eta_2') \ldots (1 - \eta_n') \quad (1)$$

where η_i is the efficiency of trapping by the *i*-th row of the curtain:

$$\eta_i^{/} = k(1 - f)\eta_{st} \ , \quad (2)$$

where *k* is the experimental averaged coefficient that takes into account the uneven distribution of dust particles in a two-phase flow; *f*- coefficient of main channel cross-section (see Fig. 6) and η_{st} - efficiency of inertial deposition in a single cylinder:

$$f = 1 - \frac{\delta_i}{8 \times a_i}\left[\frac{b_i \times (2\pi + 4) + \pi(2a_i - 3\delta_i)}{b_i - 2\delta_i}\right], \quad (3)$$

Where a_i, b_i - the small and large diameter respectively of the link in the *i*-th row of the chain tie; δ - diameter of the wire from which the link is made as shown in Fig. 6.

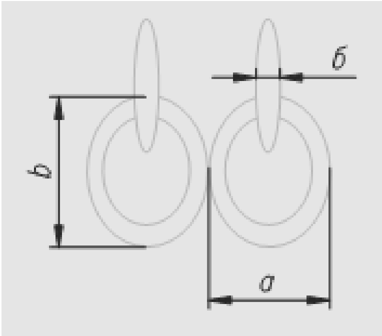


Fig. 6: Diagram of the chain links

Experiments on mass transfer processes using carbon dioxide-water were conducted and results were plotted on a graph. Carbon dioxide was selected for this experiment due to its high solubility in water.

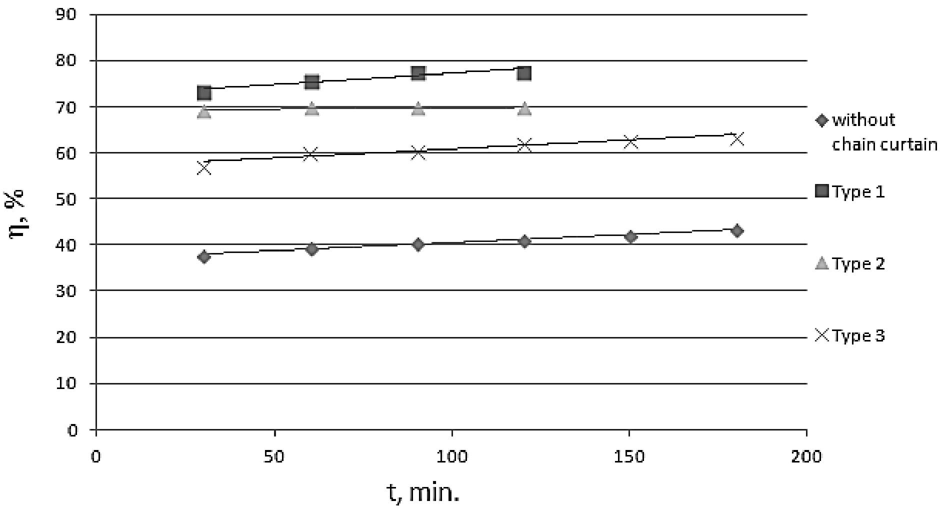


Fig. 7: Gas treatment efficiency for different chain types over time. t- time, min., η- treatment efficiency, %

The graph in fig. 7 clearly indicates that the use of a chain curtain as filter media greatly increases treatment efficiency by an average of 30% in comparison with air treatment without the chain curtain. The highest treatment efficiency was achieved when using type 1 (75%) and the least efficiency (30%) was achieved with type 3. After literature review and laboratory experiments, a device for wet treatment of gases was designed and later patented (Panov *et al* 2015).

4.2 Mass transfer

Equations describing the processes of mass transfer in phases are expressed below:

$$\mathrm{Sh}_g = \mathrm{f}(\mathrm{Re_g}, \mathrm{Sc_g}) \quad (4)$$

$$\mathrm{Sh}_l = \mathrm{f}(\mathrm{Re_g}, \mathrm{Sc_g})$$

Where: Re – Reynolds's number; Sh- Sherwood number, Sc- Schmidt number; *g* – gaseous phase, *l* – liquid phase

The following equations in generalized variables were derived after processing experimental data:

$$\mathrm{Sh}_g = 0.011\mathrm{Re_g}\mathrm{Sc_g^{0.5}} \quad (5)$$

$$\mathrm{Sh}_l = 0.002\mathrm{Re_l^{0.688}}\mathrm{Sc_l^{0.5}}$$

Analysis of experimental data shows good correlation with the data of other researchers as shown in Fig. 9, which validates and entails adequacy of the obtained equations.

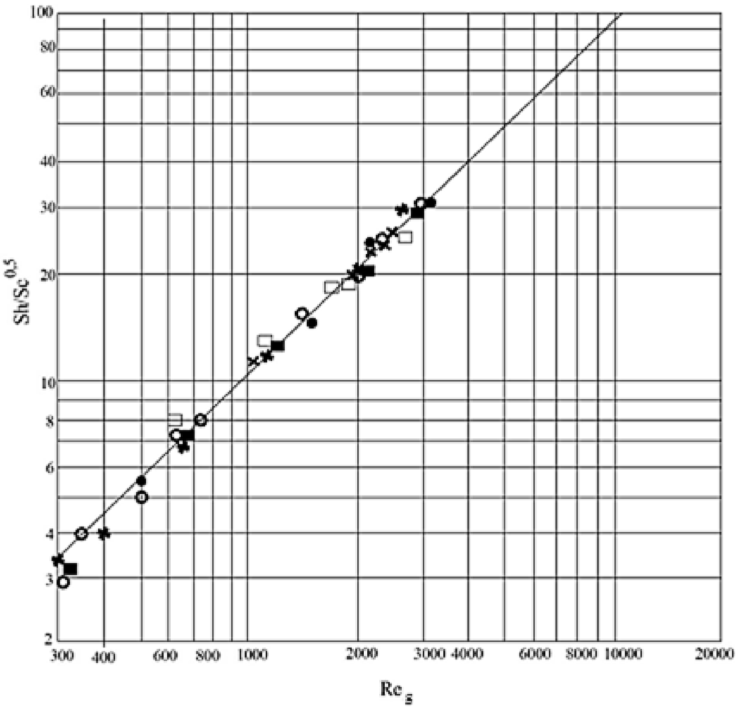


Fig. 1:Comparison of calculated and experimental mass transfer data in the gaseous phase Experimental data : □, ○, × - tube with an extended neck; ■, ●, * - Venturi tube; ×, * - type 1; ○, ● - type 2; □, ■ - type 3; Line – calculations from formula (5)

An assessment of the obtained results was conducted and the prototype was successfully officially tested under industrial conditions in Zambia at a brewery plant, in Russia at a tyre recycling plant and in Tatarstan at a sugar processing plant. The proposed device also increases treatment efficiency without the use of additional equipment, reduces metal and design complexity and the overall cost of the treatment process is reduced as a result of design simplicity.

5. Conclusion

A simple way to increase treatment efficiency for gaseous emissions as a means to lowering the environmental impact of material processing has been proposed – application of chain filters. A simple and efficient addition to the design of an ejector scrubber has been proposed through the use of chains (garland or curtain) as a drift eliminator and filter media. Experiment results indicate that use of the chain curtain as a drift eliminator in an ejector scrubber greatly increased treatment efficiency by an average of 30% in comparison with air treatment without the chain curtain. The use of a chain curtain as a filter media and drift eliminator respectively, proved to be more effective than a conventional scrubber by up to 95%, which makes it more promising due to its simpler design and manufacture. By installing pollution control devices that are simpler in design and manufacture, a firm can protect and improve its reputation by reducing the negative environmental impact of its products thereby adding value to its products without incurring significant overheads.

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An Assessment of the use of sustainability tools in the mining sector on the Copperbelt of Zambia.

Annie Nyambi[1], Jhonnah Mundike[2*]

Abstract

In this work, awareness levels and implementation of environmental sustainability tools among four major mines in the Copperbelt Province of Zambia were investigated. The sustainability tools assessed were Environmental Management System (ISO 14001), Life Cycle Assessment (ISO 14040), Corporate Social Responsibility (ISO 26000) and Energy Management System (ISO 50001) standards. The sustainability tools promote prudent management of the environment and efficient energy use. The tools also build stakeholder confidence and trust. Concurrent mixed approach and non-random data collection techniques were employed. Semi-structured questionnaires with virtual follow-up interviews were used to validate the collected data. Respondents were selected based on their responsibilities and hierarchical status and expert knowledge of the mine processes of interest. Most of the mines assessed were aware of the existence of the ISO 14001, 14040, and 26000 standards. ISO 50001 scored the least awareness levels, despite the importance of energy in mining operations. ISO 14001 was implemented and integrated in strategic plans, processes, and environmental governance in all the mines. 75% of the mines used cradle-to-grave type of LCA. Implementation of ISO 26000 was mainly reported in form of water facilities, health and educational infrastructure projects. ISO 50001 was the least known and implemented standard in all the mines. Despite widespread awareness levels of sustainability tools, there is still room for improvement in the mining industry, especially ISO 50001.

Keywords: Awareness, ISO standards, sustainability.

1. Introduction

Globally, the mining sector faces many challenges related to environmental and social sustainability. As a result, the first decade of the 21st Century has seen a renewed debate about mining and its sustainability (Östensson and Roe, 2017; Vintró, *et al*, 2014). The major issues of concern facing the mining industry globally are in trying to strike a balance between economic benefits, social wellbeing and environmental integrity. These global challenges in the mining sector may be solved by increasing the efficiency of resource use, reducing waste generation, and maximizing resource recovery and recycling (Keeble, 1987). Inadequate management systems have cost firms and organizations in terms of cleanup costs and damaged reputations (The World Bank, 2012). One of the biggest challenges facing the mining industry in Zambia is the increased

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production costs amidst energy deficits (Mining for Zambia, 2016). Mining is an energy intensive sector requiring huge amounts of power to run various processes. The demand for energy (power) to run the mines requires energy conservation and energy efficiency measures. The International Organisation for Standardization (ISO) standards could therefore guide mining companies to reorganize their priorities and commitments and put in place robust sustainability management systems

ISO standards represent a global consensus on good practice and provide practical tools for all three dimensions of sustainable development: economic, environmental and societal (Klöpffer, *et al.*, 2015; Welford, 2004). Standards like environmental management system (ISO 14001), life cycle assessment (ISO 14040), corporate social responsibility (ISO 26000) and energy management system (ISO 50001) can provide technical tools that could promote sustainability in the mining sector. ISO14001 provides organizations with a framework to protect the environment and respond to changing environmental conditions in balance with socio-economic needs (Kristensen *et al.*, 2021; Heerden, 2014). In addition, the energy management system (ISO 50001) is aimed at enabling organizations to establish the systems and processes necessary to improve energy performance. Furthermore, the Life Cycle assessment (ISO 14040) evaluates the potential environmental aspects and potential impacts throughout a product's life (Graedel and Allenby, 2003). The Corporate Social Responsibility standard (ISO 26000) provides guidance on recognizing social responsibility and engaging stakeholders (Sie, 2018; Welford, 2004).

The study of sustainability in the mining industry has gained importance in the last few years. Several studies regarding mining sustainability have been conducted in different countries. Vintró *et al.* (2014) examined the adoption of safe environmental practices in the small- and medium-sized surface mining industries in Spain. Suppen *et al.* (2006) assessed the efforts made by the mining companies in Mexico in addressing issues of environmental management and sustainable development using national and international frameworks. Similarly, Barba-Sánchez and Atienza-sahuquillo (2010), suggested that environmental management strategies lead to improvements in product quality, cost reduction, and new market penetration. Balanay and Halog (2016), explored life cycle thinking to facilitate the identification of sustainable mitigation strategies.

There is limited information in literature concerning the use of sustainability tools in the mining sector in Zambia. The aim of this study was to assess the level of awareness and use of sustainability tools (ISO 14001, 14040, 26000 and 50001) in the mining sector on the Copperbelt Province of Zambia. The study was limited to the major mines in Zambia which account for the largest share of the country's copper production.

2. Methodology

The study was restricted to the Copperbelt Province of Zambia, focusing on large-scale copper mining. There are six large-scale mining companies that are operational on the Copperbelt, Lubambe Copper mine, Mopani Copper Mines, Konkola Copper Mines (KCM), Non Ferrous China Africa (NFCA) mining, Chambishi Copper Smelter (CCS), and China Nonferrous Metal Mining Company Limited (CNMC) Luanshya Copper mines. Only four mines were considered, leaving out two mines due to management restrictions. The data for the respective ISO standards was collected using semi-structured questionnaires and follow-up virtual interviews. Each questionnaire was structured according to the themes of the respective ISO standards.

Concurrently the triangulation method was employed, where both qualitative and quantitative data was collected at the same time from each mine. Purposive sampling was used because of the limited number of the mines in the Copperbelt Province. The sample size was 20 respondents for each ISO standard from each of the four mines assessed. The respondents were selected based on their work responsibilities, technical and professional knowledge of the mine processes in relation to the sustainability tools. The mine processes or departments were categorized into safety and environment, production, engineering, human resource, and corporate affairs/public relations and the head/managers.

3. Results and discussion

3.1 Level of awareness concerning the existence of ISO 14001, 14040, 26000 and 50001 in the mining sector

The awareness of ISO standards is cardinal in the implementation of a robust Environmental Management Systems (EMS) and the promotion of environmental sustainability. Figure 1 shows the results of the awareness levels of four ISO standards (14001, 14040, 26000 and 50001) from the four mines situated in the Copperbelt Province. The results clearly indicate that there was complete awareness and knowledge of the existence of ISO 14001 and ISO 14040 in all the sampled mines sites. ISO 14001 provides the mines with an outline to safeguard the environment within their sphere of influence (Heerden, 2014). ISO 14040 or Life Cycle Assessment (LCA) deals with the environmental aspects and potential impacts throughout a product's life cycle (Welford, 2004; Graedel and Allenby, 2003)

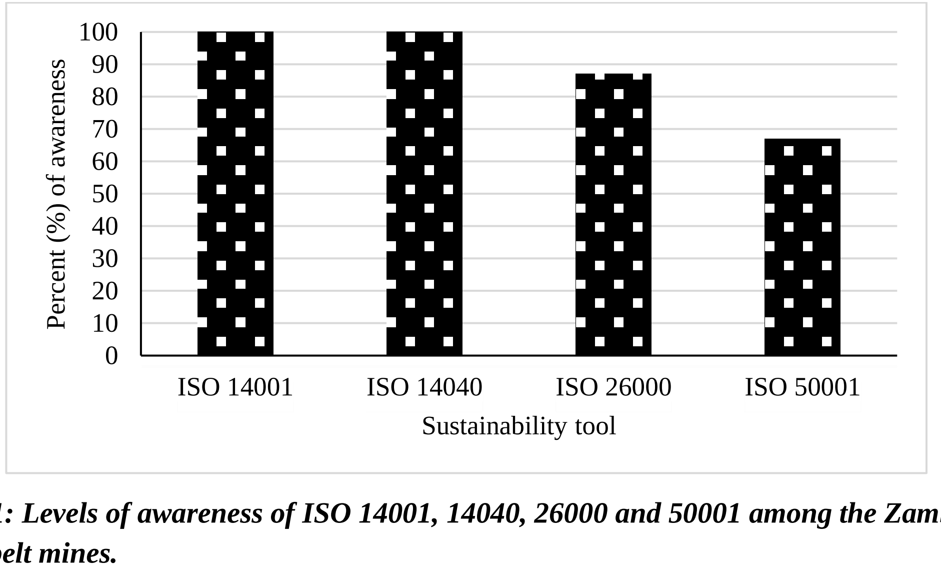

Figure 1: Levels of awareness of ISO 14001, 14040, 26000 and 50001 among the Zambian Copperbelt mines.

ISO 14001 and 14040 were the most well-known sustainability tools in the mining sector. More than 80% of the respondents (Figure 1) in the mines on the Copperbelt were aware of ISO 26000, as a social corporate responsibility technique. In case of energy management, the results show that <70% of the employees of the assessed mines were aware of the existence of ISO 50001.

Though some mines had no ISO 50001 standard, some of their employees confirmed prior knowledge of the energy management standard based on past experiences from former employers.

Energy is the driver of any economic activity, with the mining sector being an energy intensive industry. The relatively low awareness levels of ISO 50001 (Figure 1) in the mining sector on the Copperbelt are of serious concern. Zambia has of late been experiencing energy deficits that require efficient use and management. Therefore, the promotion of ISO 50001 in the mining sector in Zambia could play a key role in energy conservation, efficient use and management. Some of the benefits of promoting ISO 50001 are saving energy (electricity), thereby increasing profitability, and reducing greenhouse gas emissions. This could be achieved through modifications or changes in operational practices, as well creating conducive environments for adoption of more capital-intensive energy-efficiency measures and technologies.

3.2 Implementation of Environmental Management System (ISO 14001) in the mines

The implementation of EMS in the mines was assessed against the various components of ISO 14001. Table 2 shows the results for the various components of ISO 14001 that acted as proof of the existence and implementation of EMS in each of the assessed mines.

Table 1: Various components of ISO 14001 as proof of its existence and implementation at each mine.

Response	Existence of written policy	Targets and impacts	Compliance and safety	Monitoring and mitigation measures	Environmental audit
Yes	93%	47%	80%	87%	60%
No	7%	53%	20%	13%	40%

The results in Table 1 show that 93% of the respondents confirmed the existence of written environmental policies in their respective mines. An environmental policy enables any organization (mine) to set its environmental objectives that address the set targets. Therefore, an environmental policy should be communicated to every stakeholder involved in mining operations, including contractors. Despite the existence of EMS, some mines (47%**)** had set environmental targets and assessments of possible impacts. The overall intent of identifying environmental impacts is to ensure that mines can achieve the intended outcomes of their EMS. Additionally, the potential environmental impacts associated with the employees' various working stations should be communicated to employees and contractors.

It can be seen from Table 1 that 80% of the respondents indicated that the mines had prioritized environmental compliance and safety. This was substantiated by the readily available procedures for handling emergency incidents. All the assessed mines reviewed their emergency preparedness procedures after every accident or incidence. The review of these incidents allows for the improvement of the emergency preparedness procedures. In the same vein, 80% of the respondents indicated that mining companies were aware of the implications of contractors not conforming to EMS requirements. It was also found that most of the mines had established performance measurement and monitoring programmes. The environmental performance and monitoring programmes are meant to evaluate and track progress towards achieving set environmental targets. On the other hand, environmental audit activities were conducted periodically by some (60%) of the respondents. The audit plans contained details on how to conduct the environmental audit and the dates on which the audit was to be conducted. Nevertheless, these results signified low compliance with environmental audits.

Although most of the mines on the Copperbelt are on the right path towards environmental sustainability, there are still some challenges that need urgent attention. Full implementation of ISO 14001 was lacking in terms of setting environmental targets and the assessments of possible impacts. Additionally, environmental audits need to be promoted in the mining sector to improve on environmental performance and compliance. ISO 14001 can also help mining companies to manage environmental responsibilities systematically, as this standard contributes to the environmental pillar of sustainability.

3.3 Implementation of Life Cycle Assessment (ISO 14040) in the mining sector

Life cycle assessment (ISO 14040) evaluates the potential environmental aspects and potential impacts throughout a product's life (Graedel and Allenby, 2003). Table 2 illustrates the various components in the implementation of ISO14040. Most of the respondents reported that they had received environmental audit queries from external auditors. The audit queries should be addressed in order to provide corrective measures on environmental problematic areas in the mine production chain. More than 80% of the satisfaction levels of compliance and corrective measures were recorded, as indicated in Table 2.

Table 2: Various components of ISO 14040 implementation in the Zambian Copperbelt mines.

Response	Satisfaction levels of compliance	Audit queries	Corrective measures
Yes	93%	13%	87%
No	7%	87%	13%

3.3.1 Types of Life Cycle Assessments (LCA) adopted by various mines

The four types of LCA assessed were: (i) cradle-to-grave (ii) cradle-to-gate (iii) cradle-to-cradle (iv) gate-to-gate. Out of the four different types of LCA considered, three-quarters of the mines adopted the cradle-to-grave type of LCA, while only a quarter of the mines adopted cradle-to-gate. This was possibly because cradle-to-grave kind of LCA gives a cost-effective and comprehensive outlook on environmental impacts (Graedel and Allenby, 2003). None of the mines indicated a full and detailed implementation of LCA in their operations.

3.3.2 Opportunities to improve environmental aspects using Life Cycle Assessment

Table 3 presents the three opportunity areas that could improve the assessment of environmental aspects in the mining sector. The results indicated that production data was not easily accessible or retrievable by some mines (20%). The production data included inputs and outputs of all the processes. 80% of the respondents indicated that input and output production data was retrievable and readily available. Production data availability plays a key role on the time taken and ultimately, the cost of conducting LCAs. More than 60% of the respondents indicated that they were concerned with the environmental impacts of their product's life cycle, especially effluents and emissions. The improvements needed in production data retrieval can be beneficial to the mines in trying to achieve environmental sustainability (sustainable production/operation, and good disposal practices).

Table 3: Areas of opportunities for improving environmental aspects using LCA in the mines.

Response	Retrieval of production data	Identification of retrieval areas	Concerns with environmental impacts
Yes	80%	73%	67%
No	20%	27%	33%

3.4 Implementation of Corporate Social Responsibility (ISO 26000) in the mines

The results revealed that all the mines assessed in this study adhered to the key aspects of ISO 26000. Table 4 shows the results of the existence and implementation of various components of ISO 26000 in all the mines surveyed. The characteristics of social responsibility and their relationship with sustainable development form the basis of ISO 26000. Any organization should win the confidence of surrounding communities through practical activities promoted by ISO 26000, as partly outlined in Table 4.

Table 4: Four key components of the existence and implementation of ISO 26000 in mines

Response	Standard and principles	Stakeholder engagement	Corporate social responsibility integration	Communication and reporting
Yes	100%	100%	100%	93%
No	0%	0%	0%	7%

The results showed that 93% of the respondents indicated that Corporate Social Responsibility (CSR) was communicated internally and externally. Internal and external communication plays a vital role in the implementation structure of ISO 26000. Principles that are adhered to when implementing CSR need to be communicated to all relevant stakeholders. This leads to a well-planned CSR integration system. The CSR integrated system creates conditions for transparent and reliable exchange of information. The mines in this study were broadly involved in CSR activities such as agriculture, charity donations, infrastructure development projects like community schools and health.

3.5 Implementation of Energy Management System (ISO 50001) in the mines

Table 5 shows the four key components of the implementation of ISO 50001. 60% of the respondents indicated the existence of energy policies, with set out communication channels. Systems that support the communication of information must be put in place for employees to provide feedback, as they are the main users of energy. The results revealed that the mining companies had well established programs for assessing energy performance. 93% of the respondents indicated that this was achieved by setting up indicators and competence levels of energy management. ISO 50001 requires that employees are trained in energy management.

It can be seen from table 5 that more than 87% of the respondents indicated that they had put up energy measuring and monitoring instruments in their various operations. All the respondents indicated that strategic energy audits and periodical management reviews were conducted. These activities facilitate the understanding of various successes and failures that could be encountered in any mining operations in terms of energy use. Internal energy consumption audits help to ensure that the Energy Management System (EnMS) is in line with ISO 50001. Furthermore, it was found that top management conducted scheduled reviews of EnMS performances.

Table 5: Various key components of ISO 50001 implementation in the mines

Response	Existence of written energy policy, commitment and communication	Performance indicators and competence	Energy measurement and monitoring	Auditing and management review
Yes	60%	93%	87%	100%
No	40%	7%	13%	0%

3.6 Challenges of implementing ISO standards in the Zambian Copperbelt mines

One of the main challenges identified by the respondents (80%) was the lack of funding in addressing identified environmental impacts in their operations. In identifying and quantifying environmental impacts, financial resources and time play a key role. Old infrastructure and equipment were another identified hindrance towards mitigation of environmental impacts. Latest equipment and modern infrastructure equally require a dedicated budget with commitment from management. Another challenge identified was the resistance by some employees to adapt to changes in mine processes and procedures. Employees with low levels of educational and technical competencies are more likely to resist changes due to introduction of latest technologies and equipment that they may have difficulties in coping with. Most mine employees had basic and general knowledge of some of the ISO standards (14040 and 50001). There is therefore need to educate and train key employees through refresher short courses or seminars for some of these ISO standards.

4. Conclusion

The awareness levels of the existence of the four sustainability tools (ISO 14001, 14040, 26000 and 50001) in the mining sector were assessed on the Copperbelt. Most of the mines had implemented ISO14001 and integrated environmental management into their business strategies, processes, and environmental governance. Three-quarters of the mines implemented cradle-to-gate type of Life Cycle Assessment (LCA), with well-established production data inventories, and conducted partial impact assessments of their LCAs. Most of the mines implemented corporate social responsibility (ISO 26000) through community projects in the health sector, education and community roads and agricultural projects.

Out of the four sustainability standards, ISO 50001 recorded the least awareness level in all the mines, despite mining being an energy intensive industry. In terms of energy use, most mines assessed lacked detailed information to support energy efficiency, conservation and management, an area that requires improvement.

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A review of mine closure and rehabilitation plans during the operations of Nchanga open pit mine

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Abstract

The increase in the world population has resulted in a high demand for goods and services, which has consequently triggered an increase in demand for mineral resources. Despite the positive economic impacts that come with mining activities, open pit mines have an adverse environmental impact. Zambia has no large-scale open pit mines that have closed which gives an opportunity for the mines to operate and close sustainably. The aim of this study was to review the incorporation of mine closure plans and progressive rehabilitation activities into the life cycle of Large Scale Open Pit Mines in Zambia with a focus on Nchanga mine. This was done by an assessment of the current mine closure plans and a review of the benefits of incorporating these closure plans and progressive rehabilitation activities into the life cycle of large-scale open pit mines. The relevant laws and regulations of Zambia were also examined on order to identify gaps and propose recommendations for improvement. The recommendations were drawn from an assessment the best current practices and regulations and reviewing of international practices in Rwanda, South Africa and Western Australia. The methodology involved the interviews that were conducted with key stakeholders, a site visit that was conducted at Nchanga Open Pit mine and the desktop review of current laws and regulations on mine closure in Zambia. The findings revealed that the Environmental Protection Fund is the main framework used to deal with the issues of mine closure in the country. However, due to various factors including the inability of local banks to provide bank bonds or guarantees to the mines and limited resources to carry out site inspections, the framework is ineffectual. There is therefore a need to review the framework and revise it to be an effective tool for continuous rehabilitation and mine closure.

Key words: Mine closure, rehabilitation, sustainable, environmental protection fund

1. Introduction

Zambia is one of Africa's largest producers of copper and cobalt (Zambia Development Agency, 2019). The economy of Zambia is largely dependent on mining of copper for foreign exchange earnings and hence necessary for its economic growth. Every year, thousands of tonnes of material (ore and waste) is removed from the Earth through open pit mining to sustain the economy. Copper production in Zambia increased to 572,793 tonnes in 2007 from 256,884 tonnes in 2000, representing

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an increase of over 100% (Zambia Development Agency, 2019). In 2018, the copper produced was 861,946 tonnes (Zambia Chamber of Mines, 2019). The increase in production over the past years, implies a possible increase in land clearance for mine development which is an environmental concern. Since minerals are a non-renewable resource, open pit mines create massive voids on the surface of the earth. Thus, progressive rehabilitation and proper mine closure plans need to be implemented for the land to be restored for alternative land use.

With the drive towards sustainable development, mine closure has increasingly become a topic of focus. Emphasis is now being placed on thinking about mine closure at the initial design stages of a mining project, and with increased focus on stakeholder engagement and participation in mine planning throughout the entire life of the mine. Fourie and Brent (2006) suggest that the rehabilitation process must meet the end requirements of the stakeholder groups in order for its objectives to be achieved. Companies need to begin looking at an integrated progressive mine closure which is the incorporation of the environmental and socio-economic aspects. This could work particularly well if progressive mining is integrated into a Project-based Mine Closure Model (MCM). This will allow for resources to be allocated to and utilized for closure during mining operations (Fourie and Brent, 2006).

With the increase in exploration activities around Zambia, many mines are yet to be established and more ecosystems may be disturbed. Solving the issue of mine closure to make it more environmentally friendly will have a positive domino effect and help tackle social-economic problems that would arise later like hunger due to degraded land, infertile lands and unsafe drinking water. Integration of mine closure practices into the life cycle of the mines will not only limit the extent of ecological disturbance but also manage the costs of closure as opposed to at the end of mining.

1.1 Aims and objectives

The main objective of this study was to review the incorporation of mine closure plans and progressive rehabilitation activities into the life cycle of Large Scale Open Pit Mines in Zambia. The sub objectives were as follows:

a. To investigate the socio-economic and key environmental impacts due to mining at Nchanga Open Pit Mine
b. To investigate the extent to which mine closure plans and rehabilitation are being incorporated into the mine life cycle of Nchanga Open Pit Mine
c. To assess the benefits of incorporating mine closure and rehabilitation into the mine life cycle of a large-scale open pit mine.
d. To identify the limitations or gaps of the current closure and rehabilitation practices and make recommendations for improvement

2. Mining Operations at Nchanga Mine

The Nchanga Open Pit Mine is located in Chingola, a mining town on the North-Western end of the Copperbelt Province of Zambia. Mining activities at the Nchanga mine site consists of both underground and open pit mining operations. The ore body was discovered in 1923, however underground mining only started in 1937 due to the low prices of copper at the time. Open pit mining commenced in the late 1950's, first with the main pit which is currently over 400m deep and subsequently extended to nine satellite pits totaling over 30km² of excavated area. Besides the underground and open pit mines, Nchanga mine has a processing plant which consists of the East mill, West mill, Tailing's leach plant and smelter.

Nchanga Open Pit (NOP) mine was owned by the state after nationalization in 1971 but over the years changed ownership from state-owned to private-owned. Over this period, billions of US Dollars have been invested in the mine to improve operations, environmental footprint and safety standards and substantially increase in research and development activities (Konkola Copper Mines, 2021)

3. Materials and Methods

A mixed methods approach was used to collect quantitative and qualitative data through administering of questionnaires to the local community and through site visits, interviews and desktop research.

3.1 Study Population and sample

The study population for the administration of questionnaires comprised of one representative (preferably the head of the house) of the 2139 households around the mine area (Central Statistical Office, 2012).

The study sample comprised a total of 66 representatives of households. The sample size was determined using Equation 3.1 (Israel, 2003) which is a modification of Cochran's Formula.

$$\text{Sample Size} = \frac{\frac{z^2 \times p(1-p)}{e^2}}{1 + \left[\frac{[z^2 \times p(1-p)]}{e^2 N}\right]} \qquad [3.1]$$

Where;
N = Population size
e = Margin of error (0.1)
z = z-score (1.65)
p = Estimated proportion of the population that presents the characteristic (when unknown p = 0.5)

3.2 Data Collection Instruments

The data collection instruments were interview schedules, questionnaires and a camera to take pictures. Questionnaires were administered to the representatives from the households. The questions asked included both open and closed ended questions. An interview schedule was preferred for the key informants and Mine management. Pictures of the mine operations provided the visual interpretation needed to correlate the reports and information collected during the interviews.

3.3 Data Collection and Analysis Techniques

The data was collected and analysed as outlined below;

i. A tour of the decommissioned mine sites and areas of progressive rehabilitation was undertaken. Interviews were carried out with key informants from Nchanga Open Pit Mine, Ministry of Mines and Minerals Development - Mine Safety Department and Zambia Environmental Management Authority (ZEMA). Questionnaires were then administered to the study sample (66 representatives of surrounding households) and processed through Microsoft Forms. This data was analysed using graphs in Microsoft excel to generate general trends for interpretation. In addition, Konkola Copper Mines (KCM) environmental and social reports were reviewed to qualitatively analyse using content analysis, the impacts and their mitigating measures.
ii. Studies on local practices included collection of documents at Nchanga Open Pit such as mine closure plans, environmental reports and reviews relevant laws and regulations of Zambia. Analysis and interpretation of this data was done to compare and contrast the Nchanga Open Pit mine practices against existing legislature.
iii. Studies on international best practices included online research on of various laws and regulations guiding mine operations and current progressive rehabilitation and closure practices. This is in Western Australia, South Africa and Rwanda representing the high, middle and low income economies respectively. Standard assessment criteria were set to compare the different cases to identify their strengths which can be adapted to Nchanga Open Pit mine and the Zambian setup.

4. Results and Discussion

4.1 Socio-economic and Environmental Impacts of Mining Activities at Nchanga Mine

The socio-economic impacts of mining at Nchanga have brought both positive and negative impacts. Negative impacts identified during the study were the displacement of initial settlers and disturbance to the ecosystem while the positive impacts include job creation, improved health facilities, recreational centers and increased education. Corporate Social Responsibility is a deliberate effort made by the mine to enhance the positive impacts and mitigate the negative impacts. It involves engagement with the community to assess their needs while attending to their grievances through a stakeholder management plan which has been set up. There is also the community sensitization of emergencies, incident reporting and community safety which have been initiated by mine management. The company practices responsible mining and builds relationships using the social investment program in areas such as environmental awareness, public health, education, sports and sustainable livelihoods.

It was also found that the previous key environmental challenges included the quality of mine effluent discharged into the ambient water courses (total dissolved solids > 35ppm), mine emissions affecting ambient air quality and loss of biodiversity as a result of displacement of wildlife, resource use and pollution (Konkola Copper Mines, 2017).

4.2 Incorporation of Closure Plans and Continuous Rehabilitation During Operations at Nchanga Open Pit Mine

In terms of socio-economic preparation for closure, a community assessment is done every 3 years to identify the immediate needs of the community. Key stakeholders include the Government, Non-Governmental Organizations (NGO's), surrounding communities, interest groups (HR defenders). However, based on the survey responses (Figure 4.1) there is little community involvement in closure and continuous rehabilitation activities including post closure community preparedness.

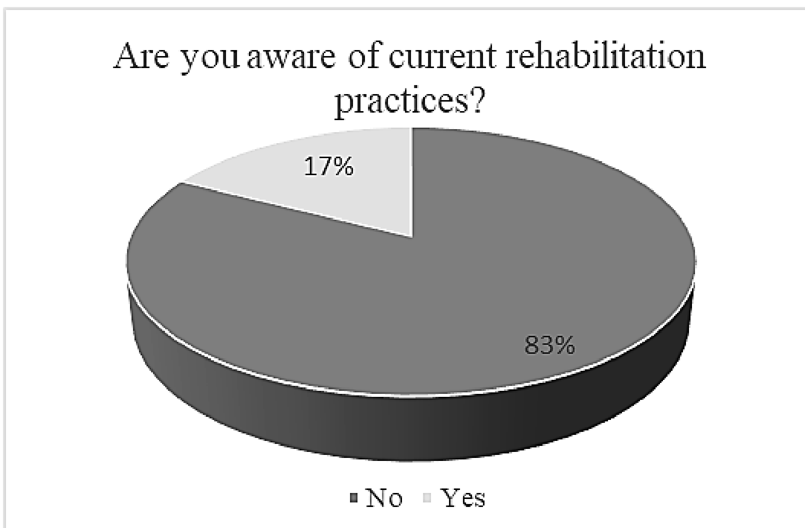

Figure 1: Analysis of survey respondents' awareness of rehabilitation practices

The budget is a key aspect of setting up an Environmental Management System and Nchanga strives to incorporate this as part of the mitigation measures of environmental harm. As a result, the controls of environment are pushed into the operations. A review of NOP documents showed that in 2001, the Environmental Management Plan (EMP) was developed creating a paradigm shift in the environmental operations at NOP. By 2007, Nchanga had achieved ISO 14001 certification which stipulates the standards for an environmental management system. The mine closure plan was reviewed in 2009 and since then annual audits of the mine are carried out by the British Safety Institute (BSI).

The mine has complied to the various environmental plans and has embarked on journey to decommission and rehabilitation of facilities that are no longer in use including old power plant replaced by an environmentally friendly acid plant, in pit filling of COP B open pit and overburden OB1, OB2 and OB22 were revegetated by planting of 2000 native trees. Some challenges faced during the continuous rehabilitation of the mine include:

1. Illegal miners uprooting trees that are being planted on dumps and backfilled areas
2. Changes in rainfall patterns affecting the growth of reforested areas
3. Legacy burden of rehabilitating old facilities that have increased the cost of operations.
4. Efforts to carry out rehabilitation are not efficient in that employees including part of management are not aware of the need for continuous rehabilitation or the site closure procedures and policies.
5. High cost of site decommissioning and closure (e.g. backfilling of the open pits which requires a high financial investment with little to no financial return)

4.3 Evaluation of Local and International Mine Closure and Continuous Rehabilitation Practices

Desktop studies of laws and regulations pertaining to mine closure practices in Western Australia, South Africa and Rwanda revealed that they have similar frameworks. However, Western Australia has the longest experience and the most advanced financial framework for mine closure. The Western Australian regulations stipulate that mine closure plans must incorporate the financial requirements for the complete closure of the mine, and the company must ensure that these funds are available at the time of closure through a bond. However, since the implementation of this law in 1985, it came to be seen that the bond amount did not reflect the true cost of mine closure, which was evidenced by the lack of successfully closed and/or rehabilitated mines in the region. The intervention of the state resulted in the formation of a Mine Rehabilitation Fund in 2013 which has been used to close and rehabilitate abandoned mine sites (Government of Western Australia, 2020).

The three African countries, i.e., Zambia, South Africa and Rwanda, have less experience with mine closure as compared to Western Australia, and the prevalent constraints in resources have resulted in intermittent audits and reviews. However, South Africa has taken deliberate measures in their policies to ensure application for licenses is supported by an environmental management plan, environmental impact assessment and an elaborate mine closure plan with sufficient provision for finances to rehabilitate and sustainably close the mine. In the current Zambian legislation regulating mine operations and environmental management in the mining sector such as the Mines and Minerals Act of 1997, the Mines and Minerals Regulations Statutory Instrument 29 of 1997 and Statutory Instrument 21 of 1998, a closure plan is not explicitly stated as a requirement. Therefore, it is likely that mining companies can operate without incorporating the ideal post closure land use plan.

4.4 Inadequacies of the Current Closure and Rehabilitation Practices in Zambia

From desk studies, it has been established that Zambia has laws and regulations that support mine closure and to some degree, the incorporation of continuous rehabilitation during the mining operations. However, there are no well-defined guidelines in place that outline the contents of a mine closure plan or how the progressive rehabilitation should be incorporated into the actual mining operations. The Zambian law highlights the framework of the Environmental Protection Fund as the main tool to implement mine closure practices. The framework encourages compliance to the Environmental Impact Assessment and continuous rehabilitation.

Contributions to the fund are based on closure costs and the remainder of the cost is to be secured as a bank bond. The continuous rehabilitation of the mine reduces the closure costs and thus reduces the mining company's contribution to the fund. Conversely, due to the high costs of incorporation of continuous rehabilitation during the operations, most mining companies are reluctant to practice this as it erodes profit. This poses a challenge in the restoration of the environment. Mining companies would rather contribute to the fund than spend money on closing off areas of the mine that have been decommissioned. In the past, this has caused legacy issues on decommissioned sites that have not been demolished and rehabilitated. It was established through interviews that a shortcoming of the EPF framework is that none of the approved banks in the regulation nor any other bank in Zambia are able to guarantee the remainder of the cost thereby presenting a loophole in the system and rendering it inefficient. This may cause challenges in financing the closure of mines as the funds will not be secured to sustainably close the mine.

The review of the Zambian laws and regulations revealed that the aspect of dealing with the socio-economic impact of mine closure has not been addressed. This presents a business continuity risk to the community whose business activities are linked to the mining activity and would be crippled in the event of unforeseen closure.

4.5 Benefits Analysis of Incorporating Mine Closure and Continuous Rehabilitation Plans into Mining Operations

The following benefits of incorporating mine closure and continuous rehabilitation plans into mining operations were identified:

i. Community preparedness – equipping the community with skills and facilities not dependent on the mining activity will deal with the possibility of the town being abandoned post closure.
ii. Managed cost of rehabilitation – legacy burden of rehabilitating decommissioned sites has proven to be a huge financial burden. The cost of rehabilitating these old sites has proven to be profit-eroding. Being able to rehabilitate old sites by annual budgetary allocation manages this financial burden as closure is done using a phased approach during operations.
iii. Minimal environmental damage – being able to continuously rehabilitate reduces the impact of mining on the environment. Case in point is the reduction in total dissolved solids of waste

water and planting of trees which endeavors to keep the environment in its natural state and preserves the local ecosystem.

iv. Maximum use of land – an added benefit to minimizing environmental damage is maximizing the use of land. Renovation of infrastructure or bringing down of old sites allows for the reuse of land that was once occupied for other purposes rather than clearing out 'virgin' land.

5. Conclusion

It was established that Nchanga mine was compliant to the law guiding this framework and onsite visitations verified the efforts to practice continuous rehabilitation. Despite this, there have been environmental impacts due to mining including changes to the quality of ambient air and water courses and loss of biodiversity. The socio-economic impacts include displacement of initial settlers, job creation, improved health facilities, recreational centers and increased education though there is minimal post closure community preparedness.

The Environmental Protection Fund was identified as the framework used to ensure the sustainable closure of mines in Zambia. However, it is not efficient in that none of the approved banks in the regulation are able to provide bank guarantees or bonds for the majority of the closure costs. In addition, the laws of Zambia do not highlight the need for an integrated approach to mine closure. Recommendation is therefore to revise the regulations to take into account these observations.

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Global warming, energy and sanitation solution for Zambia

Choolwe Knivel Mulamfu[1]

Abstract

This paper proposes a solution to Zambia's Global warming, Energy and Sanitation challenges. The model proposed tackles all three (3) individual challenges by leveraging each other's costs to make them achievable, sustainable and relatively cheap. Apart from the cost aspect, the solution creates benefits from the rather unfortunate impacts the three aforementioned challenges present by: 1. Harvesting all storm water from residential areas by draining it to artificial dams thereby preventing floods. 2. Generation of biogas from human, animal and plant waste to address the sanitation challenges in most urban and peri urban areas of Zambia. 3. Using the harvested water and the generated biogas in a thermal power plant to generate electricity, as opposed to the tradition use of biogas generators. 4. Designing and building the said biogas powered thermal power plant in such a way that it prevents any heat loss to the environment so as to keep ambient temperatures relatively stable, thereby controlling global warming.

KEYWORDS: Global Warming, Energy, Sanitation, Biogas, Thermal Power plant

1.0 Introduction

Global warming has brought about a lot of weather variations in Zambia. Floods in one wet season and droughts in another wet season have over the years affected among other things, food security, Zambia's electricity generation capacity, which is predominantly hydro-electric power generation. With poor sanitation standards both in urban and rural areas, water borne diseases have also become rampant in wet season, causing lots of social – economic setbacks.

In the proposed solution, artificial dams with spill ways into natural rivers will be constructed after careful environmental impact assessment. This will help reduce dangerous river rising effects, thereby controlling subsequent river bank flooding. This will mean safety for many people domiciled along the river banks in many parts of Zambia.

Proper sanitation facilities will be built for both human and solid waste management. This waste will be used to generate biogas. The by-product of waste decomposition will be used as fertilizer and biomass for afforestation, farming and heating respectively, as a global warming preventive measure.

The water harvested in artificial dams with the biogas and biomass generated from human and solid waste will then be used to generate electricity in a special power plant, that combines both

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hydro and thermal power generation. This power plant is designed to reduce heat emission into the environment as much as possible by recovering it for feed water pre-heat and steam reheating.

Built for the purpose of electricity generation, the storm water harvesting and sanitation facilities' construction and maintenance costs will eventually be repaid, making them sustainable and cheaper.

2.0 Methods

The data collected for this proposal consists of both interviews and written reports. The interviews gave a deeper understanding of the challenges being addressed. The reports gave insight to what the current situation is about in terms of global warming, sanitation and energy challenges.

The main data involves the interviews of 10 important actors across 7 different Zambian organizations which experience these challenges in different forms. Key players from the Lusaka City Council (LCC), Disaster and Mitigation Unit (DMMU), Ministry of Health (MoH), Ministry of Energy (ME), Water Resources Management Authority (WARMA), North Western Water and Sewerage Company and Zambia Electricity Supply Corporation Limited (ZESCO). All the interviews were conducted during October 2021 – March 2022. The respondents were promised anonymity whenever they so wished and it is to be noted that their opinions are not necessarily those of the organization they represent. Apart from gathering the data for this paper, the interviews also assisted in understanding how the projects proposed would affect a common Zambian, since the interviewees are themselves Zambians.

The material was backed up with several documents drawn by different parties to authenticate everything that was gotten from the interviews. The official documents by the Zambian government of the national energy mix ((2016), Freedom to create's policy on electricity sector of 2016, Electricity Supply Industry in Zambia by the USA agency for international development (2008) helped in giving insights on the energy related opportunities as well as current problems. On the biogas front, Potential/barriers of biogas production (Journal of Sustainable Energy & Environment 6 (2015) 21-27) was very useful. The UNICEF championed WASH 2019-2030 strategy and UNICEF (Globalwaters.com) – 2018 gave further understanding of the sanitation framework.

3.0 Results and discussion

With 25% access to electricity and 100% of petroleum fuel imported (Price of which is dictated by supply chains), a greater part of rural Zambia depends on fire wood. Between 1990 and 2010, Zambia lost an average of 166,600 hectares of its forest or 0.32% per year. In total, Zambia lost 6.3%nof its forest cover, (Around 3, 332,000 hectares), mainly to fire wood and charcoal. In the later years after 2010, the trend hasn't changed much. This has been one of the major contributors to the country's global warming as the most stored carbon is released into the atmosphere as Carbon dioxide.

Poor waste disposal and non-recycling has also been one of the top contenders in global warming. A report on the waste management options in the EU stated that "the impact of solid waste management on the global warming equivalence of European greenhouse gas emissions comes mostly from methane, which is released as biodegradable matter decay in anaerobic landfill conditions Azo cleantech (12th April, 2019). Organic matter driven global warming is true to Zambia as shown by data from United Nations Children's Fund water, Sanitation and Hygiene (UNICEF WASH) project, 2018 Demographic and health survey which shows that:

- 10 per cent of the population practices open defecation (1 per cent in urban areas, 16 per cent in rural areas).

- Solid Waste Management challenges with less than 20% of the waste being disposed to proper sites.

The extreme activities of droughts and floods have also hit Zambia in seemingly alternating fashion. In 2020, climate change brought a combination of devastating droughts and ruinous floods to Zambia, with no solution in sight. In eastern and central parts of the country, floods caused by heavy rains washed away houses, bridges and roads, leaving families homeless and entire regions devastated. In Muchinga province, four people died while trying to cross the flooded Luangwa River. In Lusaka province, many roads and bridges collapsed under the weight of floods.

Zambia has more than 700MW electrical energy deficit. Being landlocked and mainly an import dependent economy, Zambia has always been hit with unpredictable petroleum products prices. The energy mix is very unbalanced with 94% of the electrical energy being hydro – electric generated, Zambia has suffered reduction in power generation. According to Zambezi River Authority studies, Lake Kariba was created to operate between 475.50m and 488.50m but the levels dropped by 0.13m in 2017.

The entire problem can therefore be summarized as shown in figure 1.

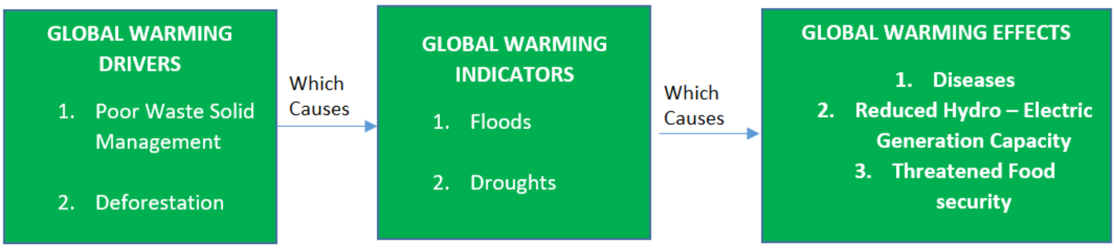

Fig 1. Summary of the global warming, energy and sanitation problems' relationship in Zambia

At this point, the world will experience the effects of global warming in many years to come. Many countries are therefore developing both adaptive and preventive measures. From Zambia's National Adaptation Programme of Action (NAPA) of September 2007, it is clear that Zambia has a lot of adaptation strategies against Global warming, Sanitation and energy. These include flood management facilities such as drainages, reducing open defecation by provision of flushable toilets, increasing access to electricity by improving the energy generation mix etc. To make all these projects practical, sustainable and easy to execute, value has to be created out of them for instance:

- Construction and maintenance of drainages and artificial dams just for the purpose of dumping off water from residential area is very expensive as compared to building the same drainages/launders (as pen stalks) for the purpose of electricity generation. The value gotten from the power generated closes the cost gap.
- Construction and maintenance of flushable toilets and solid waste management facilities simply for the purpose of reducing open biodegradation which would increase atmospheric Carbon Dioxide levels will be expensive as compared to building the same facilities for the purpose of biogas generation (Which will be one of the sources of heat energy in the thermal power plants).
- Construction and maintenance of traditional thermal power plants that release heat and other toxins into the environment to fight the electricity challenge will increase global warming as opposed to generating power using a thermal power plant that uses burning fuels for reheat, condenses the water back into the reservoir, thereby conserving it for years of droughts.
- Tree planting exercise would be expensive if inorganic fertilizers are to be used. Products of biogas digesters will be used for the purpose of afforestation to both accelerate and make the process sustainable.

A summary of the execution of these interventions is shown in figure 2.

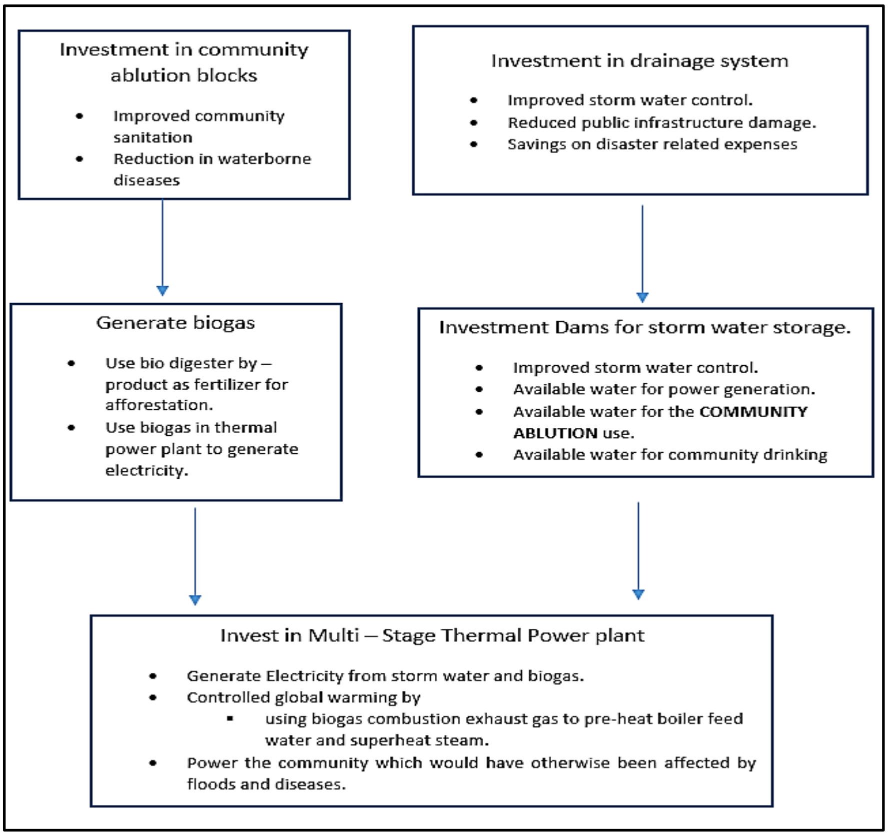

Fig 2. Summary of the global warming, energy and sanitation problems' relationship in Zambia

3.1 Storm Water Drainage

The Zambian government undertakes lots of reactive measures to floods through the Disaster Management and Mitigation Unit (DMMU) as seen in in the 2021/2022 season in which an estimated 15,000 people were evacuated to safety. The ideal situation would be to drain this water before it raises to dangerous levels. It should be noted here that the geomorphology of different flood prone areas will pay a vital role in this design.

To calculate the size of the drainages/canals to be used for storm water drainages purposes, the Rational Method was used. The formula is given by equation (1).

$$Q = C \times I \times A \quad (1)$$

where,

Q = Storm water runoff in gallons per minute (GPM).
C = Runoff coefficient (percentage of water that runs off of a given surface)
I = Rainfall intensity in inches per hour
A = Drainage area.

The storm water collected from different areas will consist lots of impurities such as:

1. Suspended (Macro size) - Sand, dirt, silt. This contributesturbidity to raw water.
2. Colloidal - Micro size particles(1-100nm)
3. Dissolved form - Alkaline salts and neutral salts, organicmatter,
   - Alkaline salts are mainly bicarbonates rarely carbonatesand hydrates of calcium, magnesium and sodium.
4. Neutral salts are sulphates, chlorides, nitrates ofcalcium, magnesium and sodium

The water delivered to this thermal power plant will be purified according to use and identified as either Cooling water, Boiler Water, Process water or Consumptive water.

The flow of raw water will be planned as in figure 3.

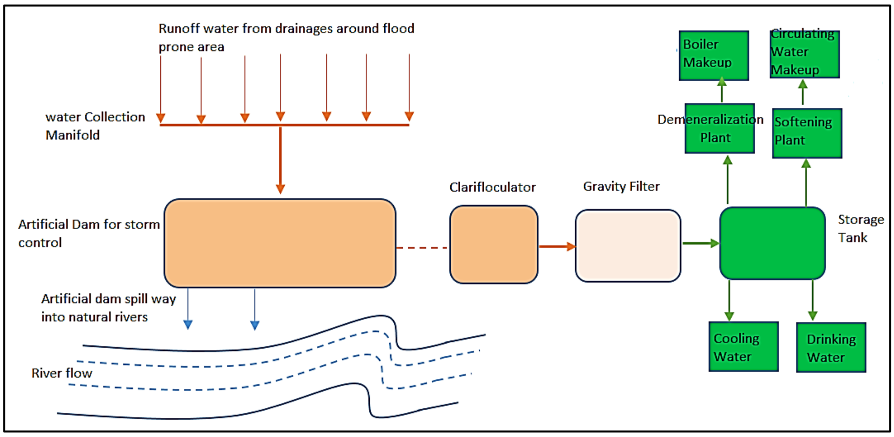

Fig 3. Flow of storm water

The storm water will be collected from drainage system around flood prone areas. This water will get into a common manifold and into the canal leading to the artificial dam. This dam will have spill ways into any natural river close, thereby controlling river bank floods, saving losses of lives and property along the river banks.

For the purpose of electricity generation, water gets further purification via a clarifloculator. This combines a clarifier and a flocculator. Chlorine, turbidity and PH levels are monitored at the outlet to make sure they remain in bearable levels, typically Turbidity - <20 NTU, Residual Chlorine = 0.2 ppm and PH – 5.5 to 0.8.

Filtration involves mechanical processes to remover suspended solids in the water. Pressure filters or gravity filters will be used here. All dissolved impurities will not be removed at this stage.

In the demoralization section, Active Carbon filters will be used to eliminate chlorine byproducts from water. Subsequent weak and strong acid, weak and strong bases are added to avoid scale formation., Control Corrosion, Control micro biological growth and Control vacuum in condenser. Circulating water is maintained to avoid corrosion and disallow scale formation. Scale formation can greatly reduce the efficiency of a thermal power plant by increasing back pressure in the condenser, leading to loss of condenser vacuum subsequently, turbine efficiency. Closed water circulating systems will be adopted.

3.2 Community Bio digesters

These will provide collection points for all the heating gas needed for heating in the thermal power plant. A combination of human feces and community food waste in the ratio of 2:1 will be used to produce approximately $0.59M^3/Kg$ – VS as per KhonKaen University research (Biogas Production from Human Feces and Community Waste Food). The organic compost produced will be used as fertilizer in afforestation projects.

3.3 The Power Plant

The demineralized storm water will be used as feed water to the first boiler of the thermal power plant. The exhaust gases from methane combustion will not be released into the atmosphere but used to pre-heat the water and reheat the steam, thereby avoiding ambient temperature raise.

This power plant got the concept of pumped storage. Since pumped storage are load balancing power plants that are not used for any commercial purposes, owing to the law of conservation of energy. During low load hours on the power network, excess energy is used to pump water into elevated storage tanks. When the demand for power on the network hikes, the potential energy in the water is converted into kinetic and finally electrical via generators.

For this power plant, chemical energy in biogas converts the water into steam. The steam turns the turbine but is given more heat energy by the reheating from the biogas combustion circuit to go higher. It is then condensed into the second boiler, which will be at a higher elevation. This boiler gets fired also and the steam rotates turbine 2, generating more electricity. When the steam reaches the highest point, it is condensed into an elevated tank. When sufficient water collects, it is released, turning the hydro-electric turbine and also generating electricity. Sufficient insulation will be used to increase the heat recovery as much as possible. Figure 4 summarizes these energy changes.

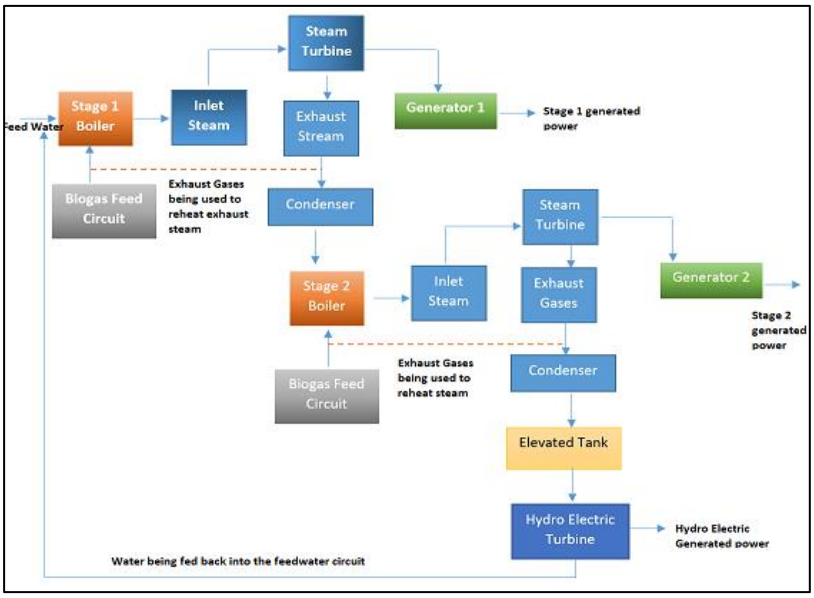

Fig 4. A block diagram of the multi-stage thermal power plant

The generated electricity will help bridge the more than 700MW power deficit that the country of Zambia is currently struggling with. With sure sales of electricity generated, the cost of constructing all related facilities i.e. drainages, canals and the power plants will eventually be repaid, making the project viable. As one of the global warming effects being extreme events, we expect to have a better water retention system because this power plant condenses the water back into the reservoir. This means in years of droughts, we will still have enough water to keep generating power.

4.0 Conclusion

Handling global warming, sanitation and energy deficit problems independently makes them a lot expensive because there is no payback expected. However, handling as written herein will not only help us adapt to global warming challenges, but also increase our electrical energy installed capacity. The energy mix will also be improved, thereby increasing the reliability of our energy system. The ideal and ultimate measure of success will be an improvement in eradicating open defecation, reduced flood water effects and increased electrical energy produced. Increased Electrical energy generation will help the country migrate from dependency on imported petroleum products to the use of electrically powered production systems. Ultimately, this will lower the general cost of living because energy cost affects the cost of production.

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Comparison of soil water characteristic curves for an unsaturated silt soil obtained by laboratory and model tests with application of different stress conditions.

Paul Habasimbi[1], Tomoyoshi Nishimura[2]

Abstract

Understanding unsaturated soil behavior is significant to the design of foundations and embankment structures. Geotechnical engineers have applied net normal stress and matric suction to develop unsaturated soil mechanics. The Soil Water Characteristic Curve (SWCC), is defined as the relationship between matric suction and degree of saturation or gravimetric water content for unsaturated soils. It is a piece of fundamental soil information used to predict seepage problems and stability of slope failures involving unsaturated soils. Thus, SWCC tests are conducted to explain matric suction effort on hydro-mechanical properties for unsaturated soil. Mathematical models of SWCCs though commonly accepted in geotechnical engineering practices, rarely adequately capture the effect of different stress conditions on SWCCs. This study conducted SWCC tests of silt soil under one-dimensional and isotropic stress conditions. This study aimed to compare the SWCC data sets experimentally obtained in the laboratory under different stress conditions. The SWCCs were measured under stresses ranging from 100 to 600Kpa. SWCCs appears to be affected by the influence of different stress conditions. Experimental results showed that lateral pressure on the isotropic condition was larger than that on one-dimensional condition and caused the soil specimens to become dense in void structure and soil moisture flow movement decreased. This probably induced high water retention activities in the silt soil and a reduction in the hydraulic conductivity. The current SWCC models require further development to take into account the effect of different stress conditions. A simple modification of the van Genuchten (1980) model was attempted and three parameters **a**, **n** and **m** described perfectly well the SWCC. The performance of the simplified model equation fitted well with the entire range of experimental data sets. Further results of this research indicate that the simplified model equation can be used as an alternative to the current SWCC models.

Keywords: Soil water characteristic curve, matric suction, microporous membrane technique, unsaturated silt soil.[1]

1. Introduction

Most of infrastructures are constructed on compacted soils that are typically unsaturated above the ground water table. In virtually part of the Zambia, civil and transportation engineers face problems with cut and fill, slopes and embankments, earth dams, and subgrade/foundation materials that remain under partially saturated soil conditions throughout the year. The

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mechanical behaviors of these soils have a greater influence on the stability of geotechnical structures such as foundations, road pavements, dams, or even nuclear waste disposal sites. Geotechnical engineers have applied two stress state variables (i.e., net normal stress and matric suction) to develop unsaturated soil mechanics. One of the key features in unsaturated soil mechanics is water retention activity in soils which is used to predict the stability or seepage problems in the ground. The Soil Water Characteristic Curve (SWCC), which represents a soil's ability to store and release water as it is subjected to various soil suctions, is defined as the relationship between the suction and the degree of saturation or gravimetric water content for unsaturated soils. It reflects the behavior of unsaturated soils regarding its hydraulic conductivity, shear strength, and volume change behavior (Nishimura and Habasimbi, 2017). Therefore, accurate determination of SWCCs under stress conditions like those in the field is key for interpretation of the mechanical behavior of unsaturated soils. Many researchers have investigated factors affecting SWCCs including stress; however, the influence of stress conditions such as the difference between one-dimensional condition and isotropic confining stress conditions have not received great attention. This research seeks to address the limited number of experimental data on the differences in these types of SWCCs. The study compares SWCCs obtained through experimental testing performed on silt soil under one-dimensional and isotropic confining stress conditions for both drying and wetting directions. The SWCCs were measured under vertical and confining stresses ranging from 100 kPa to 600 kPa allowing assessment of the differences in these types of SWCCs. To approach the target of this research, three testing methods were utilized. The microporous membrane (Nishimura et al. 2012, Uchimura et al. 2013, Wang et al. 2017, Habasimbi and Nishimura, 2018, Nishimura and Habasimbi, 2018) with an air entry value of 250 kPa was used for controlling relatively low matric suction (i.e., less than 20 kPa) which is one of the innovative and latest testing methods in SWCC tests. The microporous membrane technology has the advantage of improving the time required to reach matric suction equalization in SWCC tests. To this extent, the microporous membrane was significantly useful in shortening the testing time for the experiments. The pressure plate technique with a 500 kPa high air entry ceramic disc was used to control matric suctions from 20 to 500 kPa. For control of matric suctions beyond 500 kPa, the vapour equilibrium technique was employed.

2. Soil material and specimens

The soil material used in this experimental program is a silt soil known as DL-clay in Japan with a relatively uniform grain size distribution as shown in Fig. 1 (a). The soil material was chosen because it has a low degree of saturation and is non-plastic. DL-clay had a fine content of 99.0% (i.e., particles smaller than 0.075 mm in diameter) by dry weight. Some of its properties such as soil particle density, plasticity index and mean grain diameter of silt (D_{50}) are given in Tab. 1. The material behaves poorly under standard compaction methods and hence compacted specimens were prepared using a compaction steel mold intended specially for static compaction. According to the Japanese test methods for compaction, JIS (2009a) standard A1210, the results of the standard proctor compaction test indicated a maximum dry density of 1.535 g/cm^3 at an optimum water content of 17%. Figure 1 (b) shows the relationship between water content and dry density as compaction curve of the soil.

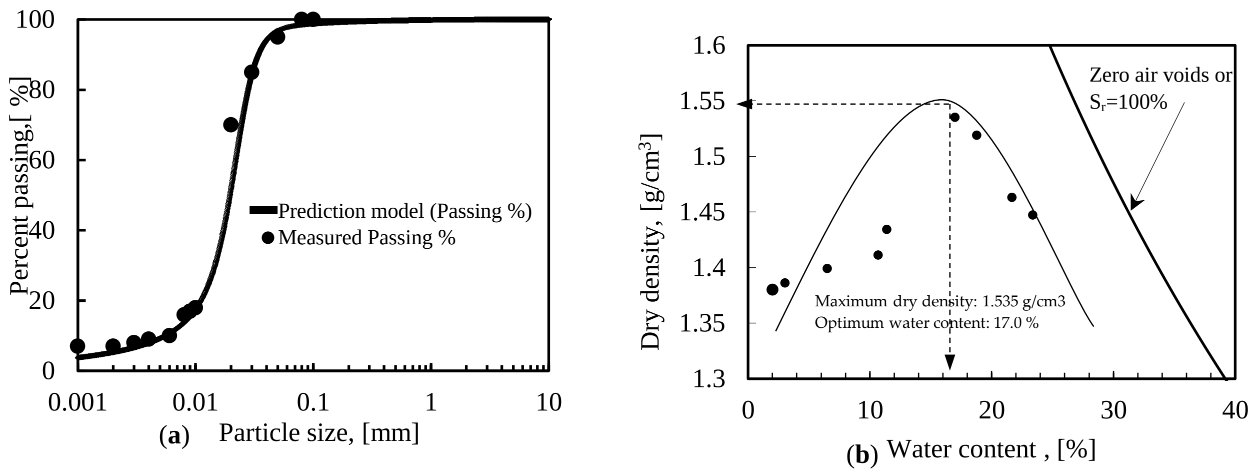

Figure 1. Grain size distribution and compaction curve of silt (a) Grain size distribution for silt soil; (b) Compaction curve for silt soil.

Table 1. Soil classification data of statically compacted silt soil

Material	G_s	D_{50} (mm)	F_c (%)	ρ_{dmax} (g/cm³)	W_{opt} (%)	LL (%)	PL (%)	PI
Silt	2.65	0.02	99.00	1.535	17.00	24.70	22.80	1.90

Note: G_s, Specific gravity; D_{50}, median diameter; F_c, fines content; ρ_{dmax} and W_{opt}, maximum dry density and optimum water content obtained by compaction tests; LL, Liquid Limit, PL, Plastic Limit and PI, Plasticity Index.

Table 2. Test methods and suction ranges.

Measurement Method	Authors	Suction Range (kPa)	Total Number of Tests Conducted
Membrane Filter Technique	Nishimura et al. 2012	0–20	14
Pressure Plate Technique	Fredlund & Rahardjo, 1993	20–500	1
Vapour Pressure Technique, VPT	Delage et al. 1998	2000–296,000	1

Note*: The test duration for each method listed above varied accordingly. Testing using the microporous membrane filter technique for each sample took approximately 2 weeks to reach equilibrium conditions. The testing duration for the pressure plate technique ranged between 3 to 4 weeks depending on the stiffness of the soil samples. Seven different saturated chemical solutions were used to control relative humidity and determination of total suction using the vapour pressure technique. Each specimen reached equilibrium conditions every after 3 weeks. To complete the testing for both drying and wetting directions, approximately 9 months were required. Overall, testing duration for all the samples took approximately one and half years.*

Soil specimens with different dimensions were prepared for SWCC tests. For one-dimensional condition, a diameter of 60 mm and height of 65 mm specimen was prepared. Furthermore, a diameter of 50 mm and height of 100 mm was prepared for the isotropic condition testing. Two additional specimens of diameter 6.0 cm and height 2.0 cm were also prepared and placed in the glass desiccator for SWCC test using the vapour pressure technique (VPT).

3. Experimental procedure

The testing methods adopted in this study involved establishing SWCCs in both low and high matric suction ranges. Essentially 14 No. SWCC tests were conducted using the microporous membrane technique with application of stress ranging from 100 to 600 kPa under one-dimensional and isotropic compression conditions. Another SWCC test in isotropic compression condition at a confining stress of 300 kPa was conducted using a 5 bar ceramic disc. The range of matric suction applied was from 20 to 500 kPa. Two specimens of diameter 6 cm and height 2 cm were further placed in the glass desiccator for SWCC test using the vapour pressure technique. In this test, seven different saturated chemical solutions (i.e., K_2SO_4, KNO_3, $NH_4H_2PO_4$, NaCl, $Mg(NO_3)_2.6H_2O$, $MgCl_2.6H_2O$ and Licl) were used to control relative humidity and eventually for the determination of total suctions. The mass, height and diameter of the specimens were measured every three weeks with the assumption that equilibrium of the specimens was achieved with respect to suction values. The test procedures and suction ranges adopted in the present study are summarized in Tab. 2.

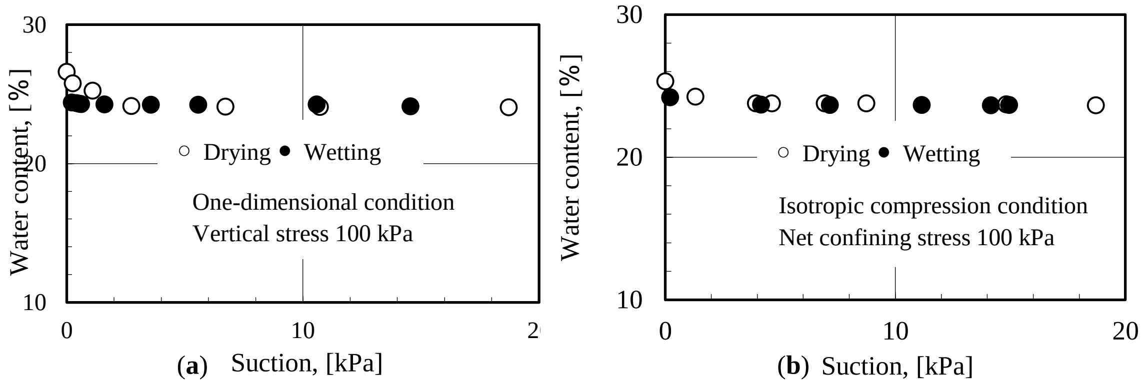

Figure 2. Relationship between suction and water content (a) Suction vs. water content in one-dimensional stress condition; (b) Suction vs. water content in isotropic stress condition.

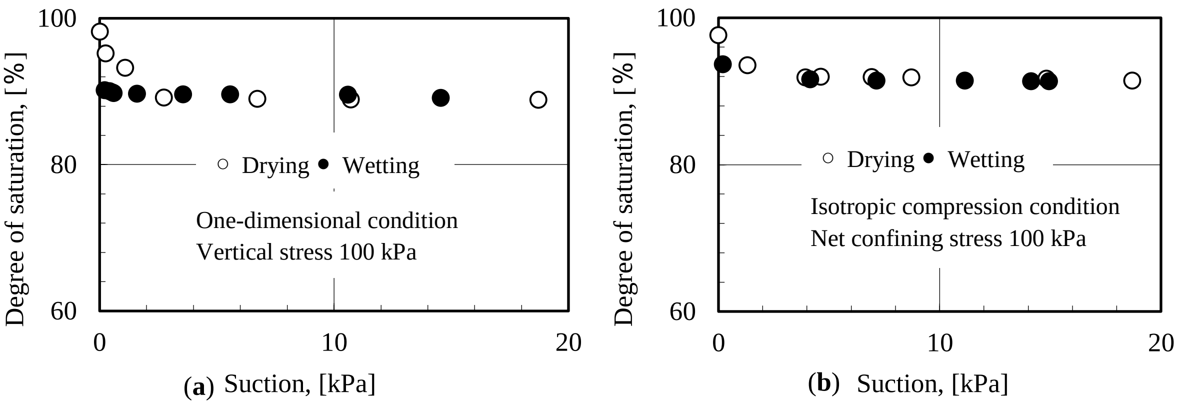

Figure 3. Relationship between suction and degree of saturation (a) Suction vs. degree of saturation in one-dimensional stress condition; (b) Suction vs. degree of saturation in isotropic stress condition.

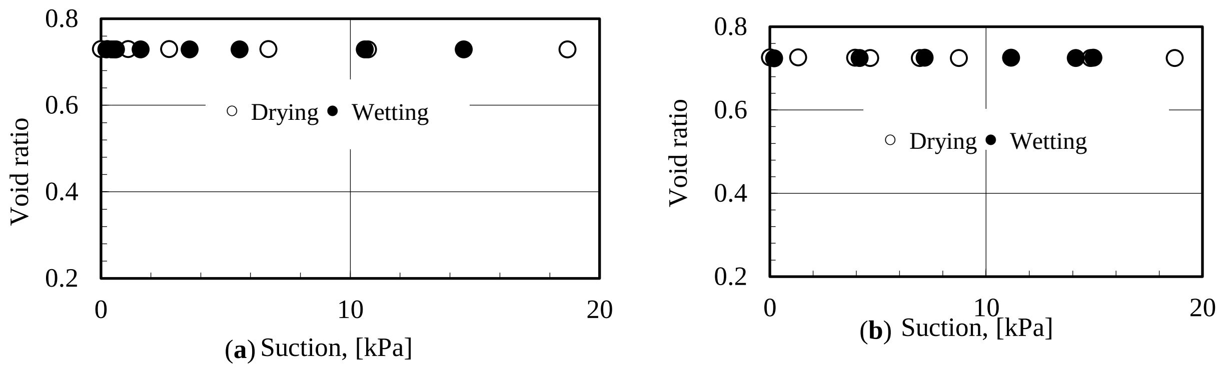

Figure 4. Relationship between suction and void ratio (a) Suction vs. void ratio in one-dimensional stress condition; (b) Suction vs. void ratio in isotropic stress condition.

4. Results and discussions

4.1. Soil water characteristic curves of unsaturated silt soil

The experimental data describing the Soil Water Characteristic Curves of unsaturated silt soil in low suction ranges (0-20 kPa) and under different stress conditions are shown in section 3. It can be seen from the results obtained that there are some differences in the SWCC curves obtained in one-dimensional and isotropic stress conditions. Figure 2, show that the water content obtained for the specimen under one-dimensional stress condition in the drying process was higher than that under isotropic stress conditions when the suction was less than 4 kPa. Equilibrium conditions were attained much faster for the specimen tested in isotropic stress conditions compared to that in one-dimensional stress conditions. It seems this variation in water content could be related to the micro and macro structure of the soil specimen. When suction is greater than 4 kPa, the quantity of free water existing inside the inter-aggregate pores of the soil specimen is reduced. This change in the water volume maybe related to the variation of the water content in the inter-aggregate and intra-aggregate pores of the soil specimen. The drying and wetting branches of SWCC showed less hysteresis when suction was less than 4 kPa and thereafter no hysteresis was observed. It was further observed in Fig. 3, that the degree of saturation for the specimen tested in one-dimensional stress condition was lower than that obtained for the isotropic stress condition in the drying and wetting paths. The increase in the degree of saturation recorded for isotropic conditions seem to have been induced by lateral pressure. This is as one result of confining the specimen under isotropic conditions thereby causing high retention activities in the soil specimen. Isotropic stress caused the soil specimen to become dense in void structure and thereby decreasing soil moisture flow movement. On the other hand, Fig. 4 shows that there was no significant change in void ratio for both stress conditions for the matric suction range from zero to 20 kPa. Therefore, void ratio seems to have no effect on the shape of the SWCC curves in both stress conditions. However, the small change in void ratio could have an effect on the degree of saturation of the specimens.

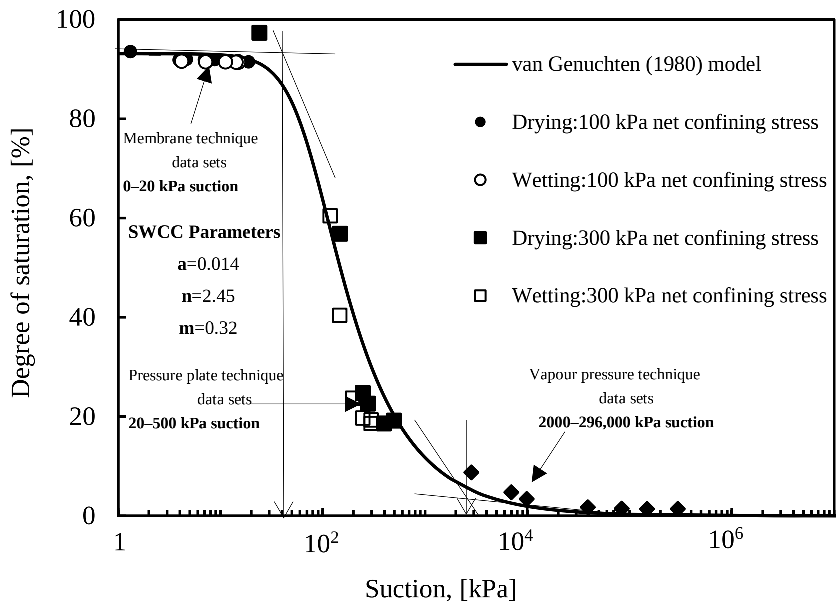

Figure 5. Curve fitting of soil-water characteristic curve data sets with different stress conditions.

Figure 5, shows curve fitting of the entire experimental data sets using the van Genuchten (1980) empirical model. Using some form of nonlinear regression analysis, parameters **a**, **n** and **m** were optimized to fit the measured data sets to the empirical model. It was observed that parameter **'a'** did not seem to affect the shape of the SWCC, but shifts the curve towards the higher or lower suction regions depending on the value. A smaller value of **'m'** corresponded to a smooth slope in low suction range while the larger the value of **'n'**, the steeper the shape of the SWCC (van Genuchten, 1980).

5. Conclusions

This research compared soil-water characteristic curves for an unsaturated silt soil obtained by experimental testing in the laboratory and model testing with the application of different stress ranges both in one-dimensional and isotropic stress conditions and using a modified triaxial apparatus. Key issues drawn from the study include;

1. The obtained soil-water characteristic curves appear to be affected by the influence of stress conditions (i.e., one-dimensional, and isotropic stress conditions).
2. Lateral pressure and confinement of the soil specimen probably induced high retention activities in the soil specimens.
3. Isotropic stress caused the specimen's void structure to become dense and hence soil moisture flow movement also decreased.
4. SWCC models require further development to take into account the effect of stress conditions.

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An investigation into the PVC conduits used in residential and commercial properties in Zambia

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Abstract

This paper investigates the quality and efficacy of PVC conduits sold and used in electrical wiring for residential and commercial properties in Zambia. Are these 'PVC' conduits really conduits or conductors? Conduits are circular tubes made of polyvinyl chloride (PVC) material, an insulator with high electrical resistivity. They are used to house a network of electrical cables in residential and commercial buildings and can be placed in concrete slabs, walls and roof ceilings to provide safe passage of cables within the building wiring network. Additionally, conduits reduce the effect of heat on electrical cables especially when housed in roof ceilings. A survey and interviews were conducted to ascertain the quality and efficacy of the conduits sold and used in residential and commercial properties in Zambia. Results from the 50 hardware shops sampled showed that 50% sold fake conduit pipes, while only 20% sold genuine conduit pipes. 70% of consumers are unaware of the difference between genuine and fake conduits. 30% of the fires in residential and commercial properties is caused by use of fake conduits.

Keywords: **PVC Conduit, Electrical Cables, House wiring, quality and efficacy**.

1. Introduction

Conduits are circular tubes made of metallic or non-metallic materials. The metallic conduits include; Electrical Metallic Tubing (EMT), Intermediate Metal Conduit (IMC), Galvanized Rigid Conduit (GRC) and Aluminium Conduit (ARC) Glytsis *et al*, 2001. Non-metallic conduit examples include; Electrical Non-metallic Tubing (ENT) and Polyvinyl chloride (PVC). In this paper focus is on the Polyvinyl chloride. PVC is an insulator with high electrical resistivity. Inside these conduits pipes, electrical installers or property wiring experts run their electrical cables to provide lighting, heating and for connecting appliances and equipment. Conduits also prevent physical damages and injury to electrical cables caused by rodents and other objects. PVC conduits are made of insulating materials which have carefully been designed and conform to specific conduit standards in terms of heat and electrical resistance, moisture corrosion and the like. The choice of conduits must take into consideration the above listed parameters to avoid damage to residential and commercial property. A poorly chosen PVC conduit can damage electrical cables and cause electrical short circuits and fire.

The rest of the paper is divided as follows: Section II looks at related works done on the quality, efficacy and use of conduits in building wiring, Section III discusses some important literature

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around conduits and section IV gives the methodology used in arriving at the results in section V. Finally, section VI gives the conclusion and ends with important recommendations..

1.1 Related work

National Fire Protection Association (Association, 2014) in their investigation observed that the higher the distance above the roof, the lower is the required temperature for effective conduit operation. As the distance from the rooftop increases, less heat will be radiated from the roof into the conduit and there will be more air circulation around the conduit. Table 1 shows the effect of roof distance on the temperature rise around the conduits.

Table 1: Effect of Roof Distance on Temperature around the Conduits (Association, 2014)

Distance above roof	Temperature adjustment	
	^{0}C	^{0}F
On roof , up to and including 1.3cm above roof	33	60
Above 1.3cm , upto and including 9cm above roof	22	40
Above 9cm, upto and including 30cm above roof	17	30
Above 30cm , upto and including 91cm above the roof	14	25

Mohammad *et al* (2015) provided more experimental data on the temperature rise of conductors in conduits that are mounted on a rooftop with full exposure to sunlight. They observed that there is a definite temperature rise inside wiring methods due to sunlight exposure though this was way below the rated conduit temperature as specified in the National Electrical Code (NEC) standards. Brender and Lindsey, 2008 observed that brighter-colored roofs, though they keep the interior of the buildings cooler, actually reflect more heat onto conduits located more than a few centimetres above the roof. This makes these conduit interiors hotter as compared to conduits located above dark-colored roofs. They also noted that in practice, the actual temperatures inside conduits are seldom taken into account when ampacity calculations are made. This can lead to serious overheating and even failure of the electrical cables inside the conduits.

Wang *et al* (2013) compared two methods of protecting the cable; the first being where one applies the fire-retardant coating on the cable surface directly and the second where one inserts the cable into a fire-retardant coated PVC conduit. The second method is more effective in protecting the cable, and the failure time is much longer.

1.2 Electrical Conduit Material

Several types of conduit materials can be simulated, including Electrical Metallic Tubing (EMT), Intermediate Metal Conduit (IMC), Galvanized Rigid Conduit (GRC), Aluminium Conduit (ARC) as well as non-conductive conduit, for example PVC, Glytsis *et al*, 2001. In the next subsection we discuss in brief for each of these conduit types, classifying them as metallic and non-metallic but with specific focus in the non-metallic PVC conduits.

1.3 Non-Metalic Conduit

There are two main types of non-metallic conduits: Electrical Non-metallic Tubing (ENT) and Polyvinyl chloride (PVC).The Electrical Non-metallic Tubing is flexible corrugated plastic tubing that is moisture resistant and flame retardant. It is easy to bend and install. However, unlike metallic conduits ENTs cannot be installed in exposed or outdoor locations. It is best to install them inside walls or in standard wood and metal frame walls. They can also be installed in concrete block structures and can be covered with concrete. Figure 3.1 shows an example of Electrical Non-metallic Tubing. PVC is a combination of plastic and vinyl that is used to make PVC pipes. These popular types of pipes are commonly used in plumbing as an alternative to copper or steel piping. PVC is also used to produce electrical conduit pipes. While water or regular PVC pipes and electrical conduit PVC pipes are both made from the same type of plastic, they are neither the same thing, nor should they be used for the same applications. Each should only be used as intended and not interchangeably. They are sometimes referred to as Rigid Non-metallic Conduit (RNC). PVC is an extensively used thermoplastic polymer due to its durability, affordability, and workability(Alsabri and Al-Ghamdi, 2020). It is an all-purpose general plastic widely used in construction, civil material, and many other consumers' products. PVC polymer is highly polar and thus has a good insulation property, but it is inferior to non-polar polymers i.e. polypropylene and polyethylene. Hence, it is used for low or medium voltage material. Heat stability of this material is very poor as it decomposes at a temperature of 140 ◦C(Alsabri and Al-Ghamdi, 2020).

When PVC is burnt, some chlorine atoms or ions are easily released (which is the reason why PVC is not flammable and has inherent flame retarding properties, because chlorines react with radicals produced during the process, hence inhibiting the process), producing toxic hydrochloric acid (HCl) fumes. When hydrogen chloride gas enters the lungs, it becomes an extremely caustic acid that can result in internal chemical burns when inhaled This acid smoke is so potent that it can even kill a person inside a house on fire, hence it will be the main danger when a PVC compound is combusted(Akovali, 2012). Figure 3.2 shows an Illustration of PVC conduit pipes.

Figure 1.1: Illustration of PVC conduit pipes

The Zambian Bureau of Standards proposes that Conduits should have adequate mechanical strength when bent or compressed, or exposed to impacts or extreme temperatures, either during or after installation. They should show no cracks and should not be deformed to such an extent that threading through cables becomes difficult, or that the cables are likely to be damaged while being drawn in []. In electrical wiring, its a standard requirement that PVC conduits be resistant to heat, self-extinguishing and be of rigid polyvinyl chloride (PVC). To achieve these requirements and since PVC is a thermally sensitive thermoplastic, various ingredients must be added to stabilize it and allow it to be processed. Heat stabilizers lubricants, fillers, processing aids, pigments, and impact modifiers are required. An approximate analytical expression of the temperature of the energized conductor as a function of load current I and maximum ambient temperature can be written as follows:

$$T_{Cond.} = (0.2I)^2 + \frac{17}{15} T^{\max}_{Amb.} + 7 \qquad \text{..........(1)}$$

Where: $T_{Cond.}$ is the temperature of the energised conductor, I is the load current flowing in the conductor and $T^{max.\ amb}$ is the maximum ambient Temperature inside the conduit.

The temperature of the air inside a conduit is the “ambient temperature” that should be used for sizing the cables. A danger point is reached when the ambient plus the I squared R heating exceeds the temperature rating of the cable insulation or other covering, which is often 90 °C (194 °F) [3].

1.4 Metallic Conduit

Metallic conduits include Electrical Metallic Tubing (EMT), Intermediate Metal Conduit (IMC), Galvanized Rigid Conduit (GRC) and Aluminum Conduit (ARC). Galvanized Rigid Conduit (GRC) sometimes referred to as rigid metal conduit (RMC) is a heavy duty galvanised steel conduit usually installed with threaded fittings. It is normally installed in outdoor environment to provide protection against external damage. It also provides structural support for electrical cables, panels and other equipment. Figure 3.3 shows an example of a Galvanized Rigid Conduit (GRC).

Figure 1.2: An Example of a Galvanized Rigid Conduit (GRC)

Intermediate Metal Conduit (IMC) is a thinner and light weight version of the RMC and can be used in all applications in place of RMC. Its main advantage is that it is lighter and therefore easier to work with than RMC. Electrical Metallic Tubing (EMT) are usually made of galvanised steel or aluminium. They are much thinner and lighter than RMC. EMT is rigid but can be bent using conduit bender. Unlike RMC and IMC, EMTs are not threaded. They are installed with couplings and fittings that are secured with screws or fastened using compressors fasteners.

2. Material and Methods

In carrying out this investigation, I adapted a qualitative research method. Figure 2.1 shows an illustration of the methods used in our investigations. A survey and interviews were conducted at several hardware shops and to individuals and/ or customers while a desk top study and analysis of building fire histories were conducted at the Lusaka Fire Departments.

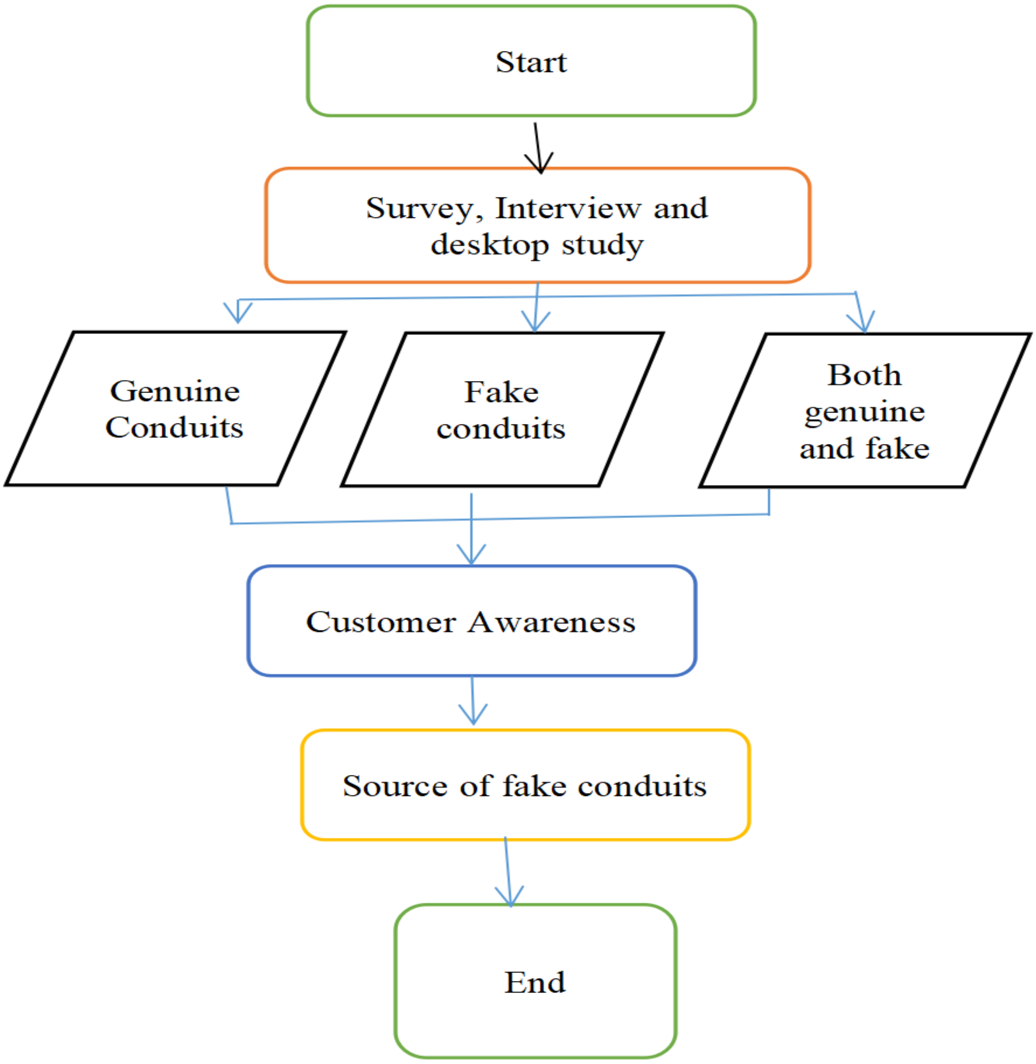

Figure 2.1: Investigation Methodology

Most of the hardware shops surveyed were from Lusaka City Centres, Chelstone, Chainda, Matero, Chipata, Mtendere, Kanyama, Kalingalinga, Mandevu, Kabwata, Bauleni and Chawama townships in Lusaka. The individual and group inputs were then aggregated and plotted into various bar charts and pies charts as shown in section V. A sample of 50 hardware shops and 20 customers were made while a history of 10 fire accidents were analysed, all in the Lusaka province of Zambia

3. Results

Figures 3.1 to 3.4 gives the results obtained following a survey and interviews conducted

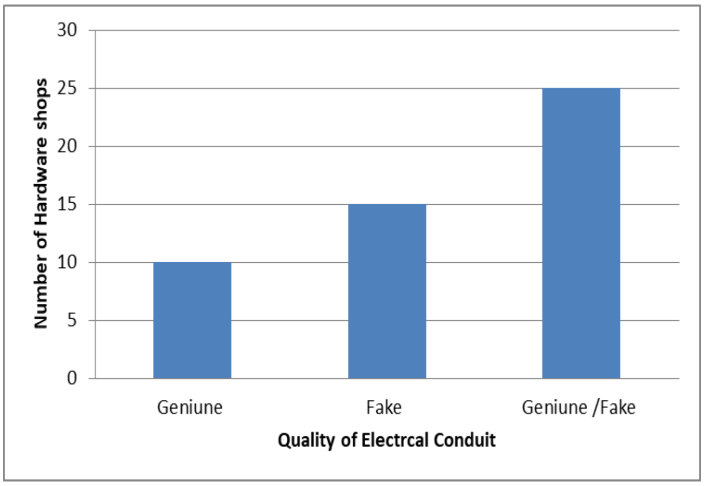

Figure 3.1: Figure 5.1: Number of hardware shops selling conduit pipes and observed quality of electrical conduits being sold.

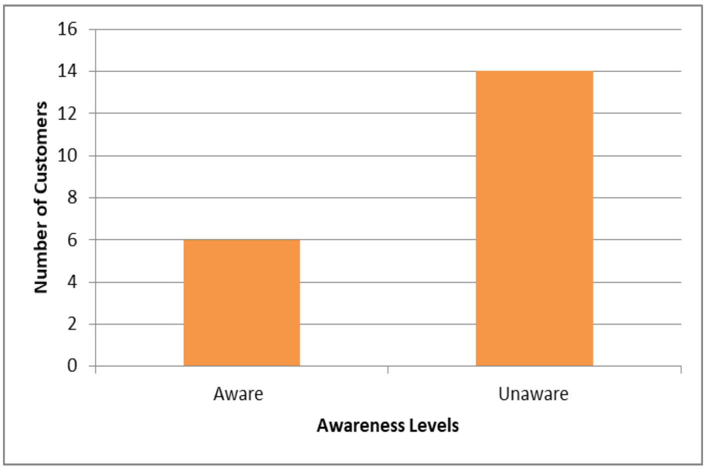

Figure 3.2: Awareness and knowledge levels on the quality of the conduits sold

Figure 3.3: Devastating Effect of Fake conduits in Relation to the Number of Fire Accidents Occasioned by it

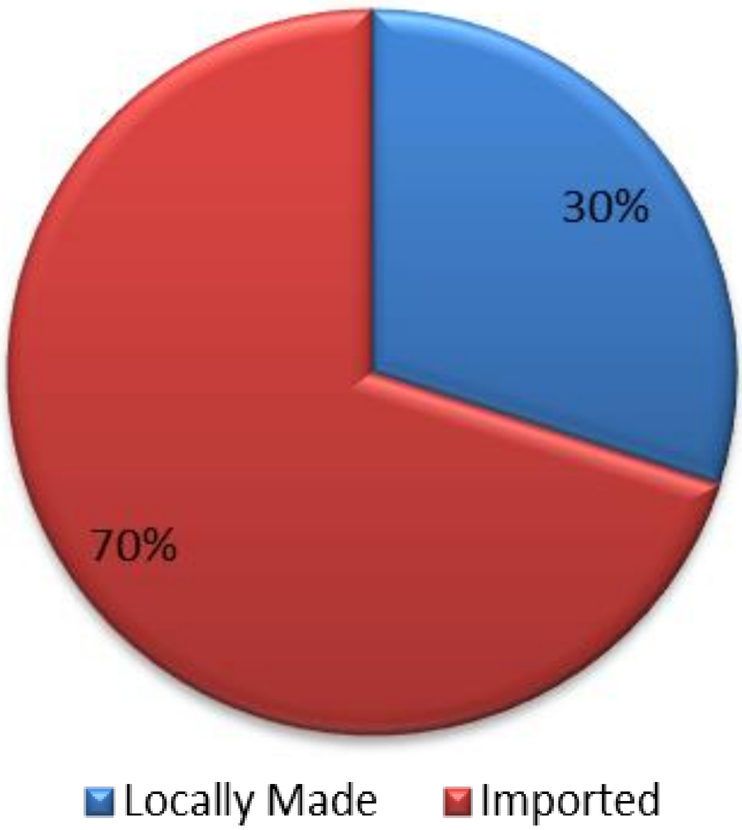

Figure 5: Sources of most of these Fake Conduits.
Figure 3.4: Sources of most of these Fake Conduits.

4. Discussion

Figure 3.1 shows the results of a number of hardware shops selling conduit pipes and observed the quality of electrical conduits being sold. Of the total of 50 hardware shops sampled, the results indicate 10 shops selling genuine conduits while 15 and 25 shops are selling fake and combined genuine and fake conduits pipes respectively. This means that 50% of the shops in the sample size sell fake conduit pipes with only 20% of the hardware shops selling genuine conduit pipes. The fake conduits are generally less rigid, cost less and unsafe. The genuine conduits are physically more rigid, cost more and fortunately safe. Most of these shops that sale fake conduit pipes do so with a lot of impunity and without any fear of the law.

In figure 3.2, we demonstrate the awareness and knowledge levels in the quality of the conduits sold by these hardware shops. From the results, we observe that only 30% of customers are aware of the difference between fake and genuine conduit pipes while 70% are completely ignorance of the differences. Most of these unaware customers think that the difference really does not matter. Their interest is just to cover the cable in the conduit and have the building connected to mains supply. The fake conduits tend to be bought more on account of its low cost.

Figure 3.3 shows the devastating effect of fake conduits in relationship to the number of fire accidents occasioned by it. For the sample size of 10 accidents, 3 of those were as a result of use of fake conduit pipes. This represents 30% and only 10% less than the accidents caused by fake cables. Fake conduits pipes tend to heat up and shrink on cables. They then affect or melt the insulation of electrical cable thereby causing electrical short circuits and fires. The heating process tends to gradual ranging from a few days to years depending on whether conditions and application of electrical energy.

This investigation also wanted to establish the source of most of these fake conduits. Figure 3.4 shows the results of our findings. 70% of these fake conduits are imported while 30% are locally made in Zambia. Most of the hardware shops did not want to mention the names of the company selling these conduits. Either way, the distribution and supply of these fake conduits is massive especially in small to medium scale hardware shops.

5. Conclusion

This paper investigated the quality and efficacy of conduit pipes sold and used in electrical wiring for residential and commercial properties in Zambia. A number of shops in Zambia sell fake conduit pipes and several customers are unaware. Statistically, 50% of shops sell fake conduit pipes while only 20% of these shops sell genuine ones. Some shops sell both fake and genuine conduit pipes. Furthermore, only 30% of the customers are aware of fake conduit pipes while the rest buy out of ignorance. 30% of building infernos are caused by fake conduits while 70% of these conduits are from outside Zambia. There is a disturbing 30% of locally made fake conduits in Zambia. These are not conduits but insulators turned conductors. They are dangerous and can cause short circuits and fires.

A strong enforcement of laws and regulation is recommended on the manufacturing, distribution and use of electrical conduit pipes in Zambia in line the Zambia bureau of standards regulations. There should also be testing of imported conduit pipes at entry points as a way of minimizing fake conduits in Zambia. Future works should consider the use of Polypropylene, a much more thermal resistant material than PVC which is able to withstand much higher temperatures (Alsabri and Al-Ghamdi, 2020),

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Prevalence and extent of heavy metals contamination from informal recycling of used lead acid batteries at identified sites in Lusaka – Zambia

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Abstract

This study determined the prevalence and extent of heavy metals contamination at informal recycling sites as well as established workers knowledge on lead pollution. Thirty-two soil and three air samples were collected and analysed for heavy metals using standard methods. A questionnaire survey (N=33) was conducted to determine the extent of workers' knowledge on lead contamination. Informal recycling activities were conducted within small shops located in commercial or residential areas of Lusaka. At different depth profiles, concentrations of heavy metals (mg/kg) ranged from 175.0 - 82300; ND - 19.1 and 2.8 - 44.1 for Pb, Cd and Cr respectively. At different distances, they ranged from 1385.0 - 24918.75, 0.9 - 16.8 and 3.9 - 39.8 for Pb, Cd and Cr respectively. Heavy metals concentration in all the air samples were below the detection. The majority of respondents (73 percent; N=33) did not have any knowledge on the harmful health effects of lead. The soils at and in the vicinity of the used lead acid batteries informal recycling sites represent potential sources of heavy metals pollution to the environment. In addition, there is a poor general awareness of the hazards of lead among ULAB informal recyclers.

Key words: Used lead acid battery, heavy metals, informal recycling, soil, contamination

1. Introduction

Heavy metal contamination to soil and other environmental parameters has been accelerated in modern society due to industrialisation, rapidly expanded world population, and intensified agriculture (Smiljanić *et al*., 2019). The Lead Acid Battery (LAB) industry is a growing but highly hazardous industry throughout the world (Gottesfeld *et al*., 2018). A LAB is a rechargeable battery, made of lead plates submerged in a bath of sulphuric acid within a plastic casing. It also contains other chemical elements such as antimony, arsenic, cadmium and tin (UNEP, 2003).

Once the LAB loses its charge, it becomes a Used Lead Acid Battery (ULAB) and is classified as a hazardous waste (Aquino *et al*., 2014). ULABs are composed of 53 percent lead metal. Therefore, their disposal and recycling have to be handled properly (UNDP, 2016). During the informal recycling of ULABs, there is a lack of adherence to environmental regulations. ULABs are manually broken releasing lead and other heavy metals into the environment (Hasan *et al*., 2017). A higher number of informal ULABs recycling sites are located within densely populated

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residential areas and the activity is accomplished without proper personal protective equipment and recycling technology (Aquino *et al*., 2014; UNDP, 2016).

This study aimed at determining the effect of informal recycling of ULABs in the environment by identifying the sites in Lusaka City, determining the prevalence and extent of heavy metals contamination in the soil and air at the unregulated recycling sites as well as workers' knowledge on lead pollution.

2. Materials and methods

2.1 Study area

The study area, Lusaka, is geographically located at 15°25' S and 28°17' E. It is the Capital City of Zambia and enjoys both wet and dry seasons. The area is a commercial, government and transportation centre of the country. It connects to the country's four main highways heading south, north, east and west.

2.2 Identification of informal recycling sites

ULAB informal recycling sites were identified through the assistance of the informal used battery buyers. These move around the residential areas with the advertising message *'ma battery yosila ya motoka tigula'* (we buy used car batteries).

2.3 Soil Sample collection

A total of 32 soil samples were collected from five selected informal recycling sites in February/March (wet season). Soil samples were collected from different sampling depths (Surface soil, 2-5cm, 6-10cm, 11-20 cm and 21-30cm) and different distances (5m, 10m and 20m) from the boundaries of the sites. From each site, one surface soil control sample was collected from an area away from the site where no human activities such as those of ULABs recycling ever existed. The collected soil samples were stored in labelled Ziploc bags and taken to the laboratory for analysis of soil heavy metals.

2.4 Determination of heavy metals concentration in soil

Soil samples were air - dried in the laboratory for 24 hours. The dried soil samples were crushed into fine particles, then they were sieved using a 2mm sieve and placed in new Ziploc bags for storage before analysis. 1.0g of sieved soil for each sample was weighed and put in a 50ml conical flask. The conical flasks with soil samples were put in the fume hood. Aqua regia (18ml of concentrated HCl: 6ml HNO_3) was added. The samples were placed on a hot plate and allowed to boil to digest the samples for 10 minutes. After boiling, samples were allowed to cool in the fume hood. The cooled samples were filtered using a Whatman No.1 filter paper into a 50ml plastic bottle. Distilled water was then added to the filtrate to make up to 50ml in a bottle. Using the standards; 10ppm, 10ppm and 1ppm for Lead (Pb), Cadmium (Cd) and Chromium (Cr) respectively, Pb, Cd and Cr concentrations were analysed using atomic absorption spectrophotometer (AAS). The average concentrations were obtained in mg/L and then converted to mg/kg.

2.5 Determination of heavy metal concentrations from the air

The air flow on the air sampler machine was set at 2.5 L/min. The filters were weighed using an analytical balance and recorded as initial weight before sampling. The filters were then placed in labelled cassettes and exposed to the air for 60 minutes by placing the machine 1.5m above the ground at the recycling site. After 60 minutes, the cassettes tightly closed and stored at room temperature before analysis. After sampling, final weight was recorded. An analysis of heavy metals was conducted using AAS.

2.6 Determination of workers' knowledge on lead contamination

A survey questionnaire was conducted to investigate workers knowledge on lead contamination. This study was approved by the University of Zambia ethics committee. All participants in this study agreed to participate.

3. Results and discussion

3.1 Identified ULABs informal recycling sites

The study identified five sites located in Lumumba Road, Kamwala business area, Comesa market, Misisi and Kanyama residential areas. Sites were small shops located in residential areas, along the road with street access and crowded business areas. These shops were used for battery storage and other equipment required at the site. The sites were found among other businesses such as sellers of clothes, cobblers, restaurants, street vendors selling a variety of provisions, mobile money agents and other retail shops. These observations agree with ILA (2020) which found that informal recycling sites are small shops located close to homes, along main city roadways and other shops. The location of these sites, allow battery sellers to access the place. The informal recycling activities have the potential to affect a large population. According to UNDP (2016), shutting down informal ULAB recycling sites illegal operations can often cause activities to resurface in another area, causing new hotspots of contamination.

3.2 Determined heavy metals concentration from soil samples

Tables 1 and 2 summarize the average heavy metals concentration in soils at various depths and distances from the recycling sites. At different depth profiles, Pb ranged from 175.0mg/kg - 82300mg/kg, Cd ranged from ND - 19.1mg/kg, and Cr ranged between 2.8mg/kg and 44.1mg/kg. At different distances from point of generation, Pb levels ranged between 1385.0 and 24918.75mg/kg, Cd ranged between 0.9 to 16.8mg/kg and Cr ranged from 3.9mg/kg - 39.8mg/kg. All heavy metals surface soil concentrations were higher than those of their respective control surface soil levels. Pb, Cd and Cr were found at all the identified informal recycling sites. Pb was the major pollutant followed by Cd and Cr. Pb concentrations in all soil samples exceeded the USEPA permissible levels for residential soils set at 400mg/kg standard (EPA, 2001) except for the site located in Lumumba Road and Kanyama at 21-30cm depth profile.

Table 1. Heavy metals concentration (mg/kg) at different profiles for all the locations

		Profile at which sample was collected (cm)					
Location	**Metal**	**Surface soil**	**2-5**	**6-10**	**11-20**	**21-30**	**Control**
	Pb	67000.0	5165.0	1996.5	549.5	188.5	174.0
	Cd	2.1	7.4	ND	ND	ND	1.1
Lumumba	**Cr**	12.3	11.3	7.2	5.3	3.6	8.1
	Pb	72375.0	5775.0	1504.0	473.3	-	80.3
	Cd	2.9	3.7	6.1	1.3	-	1.7
Kamwala	**Cr**	44.1	30	24.1	22.1	-	14.4
	Pb	82300.0	-	-	-	-	141.9
	Cd	19.1	-	-	-	-	0.7
Comesa	**Cr**	11.7	-	-	-	-	5.1
	Pb	8570.0	1001.3	806.0	624.0	570.5	162.0
	Cd	4.2	4.8	2.6	ND	ND	0.9
Misisi	**Cr**	20.8	9.5	7.1	5.5	3.9	9.4
	Pb	61500.0	9057.5	905.5	405.0	175.0	54.4
	Cd	2.7	3.9	1.6	ND	ND	1.9
Kanyama	**Cr**	38.0	23.4	22.7	5.5	2.8	5.8

N.D = Not Detected

The results are in line with the findings of Hasan et al (2017) who found lead concentrations in the residential areas around the ULAB recycling sites to be 400mg/kg to several thousand. The results also agree with UNDP (2016) statement that clearly states that tests of lead levels in soil at known recycling areas far surpass recommended international safety standards. Cd and Cr concentrations in all soil samples were within the no effect level when compared to USEPA (2002) soil screening levels of 70 and 230mg/kg respectively. This implies that study soils are not contaminated with Cd and Cr but their detection at the recycling sites and immediate vicinity is considered to be of pollution concern because of accumulation.

Hasan et al (2017) found that Pb recorded highest values, while the lowest were found for Cd and Cr, similar to the findings in this study. From the results, Pb and Cr concentrations decreased as the soil depth increased. This observation is similar to Olafisoye *et al* (2013) who found that heavy metals decrease with increasing soil depths. For Cd, the concentration down the soil profile showed an irregular pattern which contradicts the findings of Olafisoye *et al* (2013). The mobility pattern of Cd down the soil profile might have been affected by soil physiochemical properties and soil microbes. The detection of these metals down the soil profile shows that there is a downward movement of metals from the leachate to meet with the groundwater aquifer. Leaching and underground flow of percolated water from recycling sites may lead to the introduction of these metals into the groundwater system (Odipe *et al*., 2020) which is a source of drinking water. The detection of the heavy metals at 20m away from the generation point means that, there could be greater pollution as a result of ULABs recycling activities in the immediate vicinity of these workshops. Heavy metals would have spread by storm water runoff or wind as suggested by WEF (2020) who found that lead dust emitted during ULABs informal recycling may migrate from the source to nearby communities through stormwater runoff and by wind.

Table 2. Heavy metals concentration (mg/kg) at different distances from the generation point

		Distance from Point of Generation (m)			
Location	**Metal**	**0**	**5**	**10**	**20**
Lumumba	**Pb**	67000.0	24787.5	17087.8	4437
	Cd	2.1	2	1.6	0.9
	Cr	12.3	7.1	5.0	3.9
Kamwala	**Pb**	72375.0	1777.5	1659.5	-
	Cd	2.9	2.1	1.9	-
	Cr	44.1	39.8	20.7	-
Comesa	**Pb**	82300.0	24918.75	-	-
	Cd	19.1	16.8	-	-
	Cr	11.7	9.1	-	-
Misisi	**Pb**	8570.0	1385.0	-	-
	Cd	4.2	1.3	-	-
	Cr	20.8	16.9	-	-
Kanyama	**Pb**	61500.0	3115.5	-	-
	Cd	2.7	1.2	-	-
	Cr	38.0	22.5	-	-

(-) = Not Sampled

Heavy metals in studied surface soils were higher than those for control. The levels for control samples might be as a result of heavy metals accumulation due to run offs from the city during rainy season as there are no appropriate sewage and municipal waste management system (Yahaya *et al*., 2009).

3.3 Determined heavy metals concentration in air

The heavy metals concentration in all the air samples were below the detection limit (Table 3). These insignificant values over a long period of time become significant due to accumulation, and can have an effect on human and the environment.

Table 3. Determined lead concentrations (mg/kg) in air

Location	Filter paper	Pb	Cd	Cr
Lumumba	1	N. D	N. D	N. D
Kamwala	2	N. D	N. D	N. D
Misisi	3	N. D	N. D	N. D

3.4 Extent of workers knowledge on lead contamination

In the current study, all 33 participants were males (Table 4). The present survey demonstrated that workers involved in recycling LABs are not aware of all of the adverse health effects of lead pollution (Table 5).

Table 4. Social demographics characteristics of respondents

Variables	Frequency	Percentage %
Gender of the respondents		
Male	33	100
Female	0	0
Age of the respondents		
18-20 years	0	0
21-30 years	15	45
above 31 years	18	55
Education level of correspondents		
None	2	6
Primary level	11	33
Secondary level	18	55
Tertiary (University/College)	2	6

Table 5. Worker knowledge of lead pollution

Variables	Frequency	Percentage (%)
Harmful health effects of lead pollution		
Headache	0	0
Cancer	4	44
High blood pressure (BP)	3	33
Kidney failure	2	22
Knowledge of lead contamination on the environment		
Soil	14	47
Air	11	37
Water	5	17
Both soil and air	22	73
Both soil and water	10	33
Both air and water	14	47
All three (Soil, air and water)	7	23

Nayeem *et al*., 2019 reported that workers had no knowledge of the effects of lead on behavioural and cognitive development in children, similar to the findings in this study. These effects occur because lead has the ability to substitute other polyvalent cations such as calcium and zinc into the molecule machinery and disrupt various enzyme systems of living organisms (Canada, 2013; Garza *et al*., 2006). Majority of the workers recyclers worked at the recycling sites without proper protective equipment. Working in these conditions increases the risk that workers may suffer from dust-related diseases (Nayeem *et al*., 2019). The study also assessed the knowledge of respondents of the harmful impacts of lead on the environment. Nine percent of the participants believed that lead does not affect the environment in any way.

4. Conclusion

The findings of the study revealed that informal recycling sites are small shops located in highly populated residential or commercials areas where they are easily accessed by battery sellers. Based on the findings which revealed that recycling sites are located in busy parts of Lusaka, the recycling activities have the potential to expose a large population to lead and other associated heavy metals.

The study soils had elevated Pb levels and almost all samples were above the USEPA standards for residential soils while Cd and Cr were within the permissible limits. On the other hand, the levels of heavy metals concentration in all the air samples were below the detection. Although the values were below detection, over a long period of time, they can become significant due to accumulation, and can affect human and environment health. It is apparent that informal methods of recycling ULABs exacerbate the problem of environmental lead in Lusaka. It is clear from this study that Pb, Cd and Cr were prevalent in soils at the identified ULABs informal recycling sites. The extent to which these metals particularly lead can contaminate the environment can be several metres from the source due to leaching, runoff and wind. This is a reflection of anthropogenic contribution which might partly result from recycling of the ULABs.

In terms of workers' knowledge on lead contamination, it was observed that there is a poor general awareness of the harmful effects of lead among informal ULAB recyclers. Workers were constantly exposed to lead pollution during informal recycling activities due to the primitive techniques they employ and lack of personal protective equipment.

5. Recommendations

The study recommends the government to develop a framework of operation that will cover collection schemes, management practices, public awareness campaign, emission and health monitoring and clear ULABs recycling regulations. This should be supported by enaction of a responsive regulatory framework to ensure all measures, are effectively implemented.

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Assessing the impact of COVID-19 pandemic on Zambia's preparedness to train Mining Engineers for the future: A case study

Sunday Mulenga[1], Bunda Besa[2]

Abstract

The future Mining Engineer should possess knowledge and skills required to perform efficiently in the future mine. With the advent of COVID-19 and having the future mine in mind, the impact of COVID-19 pandemic on Zambia's preparedness to train Mining Engineer for the future was assessed. A case study approach, using the University of Zambia (UNZA) School of Mines was used to establish the status of Zambia's preparedness to train Mining Engineers for the future before the COVID-19 pandemic and thereafter to assess the impact of COVID-19 pandemic on the country's preparedness to train Mining Engineers for the future. The results showed that UNZA was ranked last among the Universities used in the assessment in terms of preparedness to train mining engineers for the future and that the COVID-19 pandemic had poorly affected students' performance. It was concluded from the case study results that COVID-19 pandemic had relegated Zambia's preparedness to train Mining Engineers for the future.

Keywords: COVID-19 pandemic, Future mine, Mining Engineering education

1.0 Introduction

Mining Engineering as a profession has been a major contributor to the economy of Zambia. Mining Engineering provides thousands of people with employment and supplies various products to the mining industry that are dependent on technology. In Zambia, just like elsewhere, the profession is known for issues such as profitability, social, environmental and economic responsibility. Equally, the profession is known for safety issues, especially fatalities that have an adverse impact on communities (Mulenga and Banda, 2020).

With the coming of the computer era, the mining industry has undergone through various phases of enhancement with regards to mining equipment and technologies for mineral exploration, production and processing. Giurco *et al.* (2009) predicted the challenges of the future mining industry due to the anticipated deeper deposits at low grades, higher energy costs and increased environmental limitations. The predicated challenges will demand more sophisticated equipment and technology for mineral discovery, production and processing to be viable even profitable. Several organizations and individuals have different opinions on the vision of mine of the future. Regardless of the many opinions, they all agree that the future mine will have fewer highly skilled personnel operating sophisticated systems that are able to do several tasks at the same time (Oshokoya, 2017). A number of authors (Schweikart, 2009; Klawitter *et al.,* 2010; Gipps *et al.,*

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2011; Goldsmith, 2014) have expressed their views on the components and principals of the future mine. The majority of these views are incorporated in the future mine described by Yameogo and Suarez (2013). Yameogo and Suarez (2013) envisioned a future-mine that is fully automated with various smart technologies, analytics and machines which are able to interact with the rock and the environment. This means that real time data about the quality and quantity of materials being mined as well as mining assets will be collected and reported through a communication system into a control room where proactive decisions regarding safety and production can be made. Furthermore, according to Oshokoya (2017), the four main key areas of focus for the future-mine are Operating practices and technology, Talent and leadership, Partnerships with key stakeholders; and Governance. These focus areas can be perceived as building blocks for Mining Engineering program to train Mining Engineers for the future. The components of each block requires the adoption of the talented and skilled labour force to handle the demands of the future-mine. This, therefore, requires the Mining Engineering education programme to include twenty first century Mining Engineering skills, which will enable the Mining Engineer to possess the requisite skills to solve problems across all four key areas of the future mine (Oshokoya, 2017).

With the advent of COVID-19 in late December 2019, which was reported originally from Wuhan, China and quickly spread across the globe (Rashid and Yadav, 2020), the World Health Organization (WHO) declared the disease a global pandemic (WHO, 2020; Xiang *et al.*, 2020). This declaration of the global pandemic by World health organization disrupting all known day to day activities including engineering education (WHO, 2020; Xiang *et al.*, 2020). In Zambia, for instance, during the late 2019 to early 2020, due to the COVID 19 pandemic, courses that were traditionally taught via face to face were moved to blended mode of delivery were some components were taught online while other components and practical aspects where taught via face to face learning mode within a compressed period. To that effect, some studies have been conducted to evaluate the impact of COVID-19 pandemic on the engineering education. The American Society of Engineering Education (2020) highlighted that COVID-19 pandemic brought particular challenges for providing virtue substitute for laboratory based, hands on experience and team work that the engineering discipline demands. Park *et al.*, (2021) considered the significance of student's emotional experience during online engineering training introduced by COVID-19. Park and Passmore (2020) further emphasized the importance of elucidating the importance of engineering ethics during the COVID-19 pandemic era. Kahn and Abid (2021) analyzed the challenges of virtue classroom especially in developing countries in order to provide a roadmap of quality teaching and evaluation of online engineering courses. Opris *et al.*, (2020) proposed a viable approach to quality Education in Power Engineering during the COVID-19 pandemic period. Ahag *et al.*, (2020) studied the impact of COVID-19 pandemic on engineering training, as many institutes of higher education has transitioned to emergency remote education. Furthermore, many other authors such as Cheu *et al*., (2020) and Cuesta *et al.*, (2021) have studied how the COVID-19 pandemic has affected engineering education. No studies have been done to assess the impact of COVID-19 on Zambia's Engineering or Mining Engineering education specifically.

Given the current COVID-19 situation and having the concept of the future mine in mind, this paper therefore seeks to assess the impact of COVID-19 pandemic on Zambia preparedness to train Mining Engineers for the future mine. In order to achieve the objective, firstly, the pre COVID-19 preparedness status for Zambia to train Mining Engineers for the future will be established. Thereafter, the impact of COVID-19 on the preparedness of the Zambia to train Mining Engineers for the future will be established.

The research method used in this paper to assess the impact of COVID-19 on Zambia's preparedness to train Mining Engineers for the future is a case study approach, Using the University of Zambia, School of Mines. The University of Zambia was selected as a case study because it is first ranked in University in Zambia according to the Quacquarelli Symonds (QS) ranking system of 2021.

The next sections of this paper highlight the materials and method used in this study, followed by the findings, then discussions and finally conclusion and recommendations.

2.0 Materials and Methods

2.1 Participants

The selected participants for this study were Colorado School of Mines, Curtin University, Witwatersrand University and the University of Zambia (UNZA). Colorado school of Mines is the first ranked Mining Engineering School in the world while Curtin University is Second ranked school by subject (Mining Engineering) in the world according to the Quacquarelli Symonds (QS) ranking system of 2020. Witwatersrand University is the top Mining school in Africa and the UNZA is the top ranked university in Zambia. The selection of the three external universities was further justified by Oshokoyo (2017) who concluded that the number one (1) ranked mining school in Africa and the top two (2) Mining Universities were incorporating future mine thinking in their Mining Engineering programmes. The performance of 300 undergraduate Mining Engineering students ranging from second to fifth year of study at the University of Zambia were used in the study.

2.2 Measuring instrument

The four key focus areas for the future mine which are Operating practices and technology, Talent and leadership, Partnership with key stakeholder and Governance were used to assess Mining Engineering programs preparedness to train to Mining Engineers for the future. The assessed programmes were from participant's selected Schools/Universities. The impact of the COVID-19 pandemic on UNZA's/ Zambia's preparedness to train Mining Engineers for the future was measured using the change in student performance before the COVID 19 pandemic and during the COVID-19 pandemic in courses categorized under the four the key focus areas of the future mine.

2.3 Procedure

In order to comprehensively assess the readiness of the current Mining Engineering education systems in Zambia to prepare and equip students with necessary skills required by the future mine, some courses under the Mining Engineering programme offered by all the participating universities were first fitted under the four key focus areas of the future mine. The courses were obtained from the university's websites of the participating Universities. The percentage distribution of the courses across the four key areas of the future mine for each participating University were calculated. Furthermore, the percentage of courses dealing with computing and automation from the Operating practices and technology focus area were also calculated. The percentage course distribution across the four key areas of the University of Zambia was then compared with the percentage course distributions for the other three participating Universities to establish UNZA, by extension, Zambia's preparedness to train Mining Engineers for the future.

To assess the impact of the COVID-19 pandemic on Zambia's preparedness to train Mining Engineers for the future, first the qualitative grading system used at UNZA was assigned numerical values as shown in Table 1. This was done in order to obtain the average score by students in each course as shown in Table 2 Furthermore, the average score obtained under each key area for the future mine during GER 2018 (before COVID-19) were compared to the average scores obtained under the same key area during GER 2019 (during COVID-19) and are as shown in Table 2.

Table 1: Numerical Value Assignment to grades

Grade	Assigned Numerical Value
D	0.5
D+	1
C	1.5
C+	2
B	2.5
B+	3
A	3.5
A+	4

2.4 Data Analysis

Comparative analysis of the percentage course distribution across the four key areas of the future mine using a graph was used to establish Zambia preparedness to train Mining Engineers before the COVID-19 pandemic. A comparative analysis of average student's score, computed using Microsoft excel 2018, in courses under each focus area before the COVID-19 pandemic and after the COVID-19 pandemic was done to assess the impact of COVID-19 pandemic to train Mining Engineers for the future. Furthermore, a T-test on the student's average score before the COVID-19 pandemic and during the COVID-19 pandemic was done using the T-test function in Microsoft Excel 2018 to establish the significance of the difference in student performance during the COVID -19 academic year and the academic year before COVID-19. The average score for each focus area was computed using Microsoft excel 2018.

3.0 Findings

3.1 Zambia preparedness to train Mining Engineers for the future

In line with the four key areas for a future mine, some courses in the Mining Engineering programme offered at the University of Zambia, School of Mines were fitted under the key focus areas. The results show that Mining Engineering programme at UNZA attaches more weighting to Operating practices and technology (88%) and less weighting to Partnership and key stakeholders (9%) and talent and leadership (3%). The programme has no courses under the Governance (0%).

Furthermore, Mining Engineering courses that fit under the four key areas of the future mine offered at Colorado School of Mines, Curtin University and Witwatersrand University (WITS) were considered. The results equally showed that the Mining Engineering programme at Colorado School of Mines has a higher weighting to Operating practices and technology (75%) and less weighting to Talent and leadership (14%), Partnership with key stakeholder (7%) and Governance (4%). Furthermore, the Mining Engineering programme offered at Curtin University also has more weighting towards Operating practices and technology (85%) and less weighting towards Talent and leadership (5%), Partnership with key stakeholders (10%) and Governance (0%).Wits University Mining Engineering programme also appears to assign more weighting to Operating practices and technology (81%) and less weighting on Talent and leadership (7 %), Partnership with key stakeholders (9%) and Governance (3%) as presented in Table 2.

The comparative analysis of the percentage distribution of courses under the future mine key areas is as shown in Figure 1.

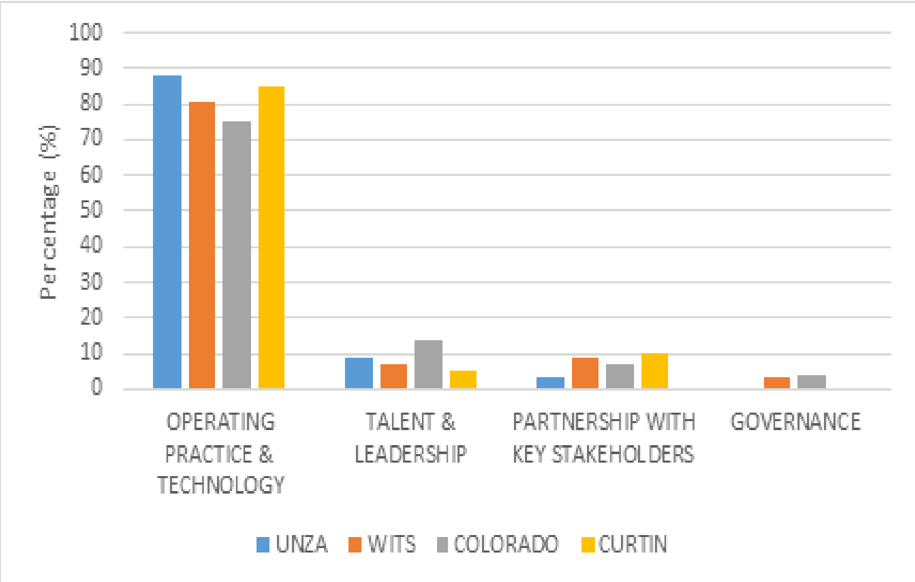

Figure 1: Comparative analysis of Mining Engineering Programmes

The results of the analysis showed that the course weighting for UNZA programme under Operating practices and technology is ranked first, second under Talent and leadership and ranked fourth on under Partnership with key stakeholder and Governance.

3.2 Impact of COVID-19 on UNZA preparedness to train Mining Engineers of future

The ability to assimilate knowledge and skills from courses at the University of Zambia is determined by the grades the students obtain in those courses. The student performance, presented by student's average score in courses fitted under the future mine key areas, for the academic year before the COVID-19 pandemic (GER 2018) and the academic year during the COVID-19 pandemic (GER 2019) are presented in Table 2.

Table 2: Student Performance for GER 2018 vs. GER 2019

Key Focus Area	**AVG. SCRE. GER 2018**	**AVG. SCRE. GER 2019**
Operating practices and technology	2.2	2.1
Talent and Leadership	2.5	2.3
Partnership with key stakeholders	2.5	2.1
Average	**2.4**	**2.2**

4.0 Discussion

The main objective of this study was to assess the impact of the COVID-19 pandemic on Zambia's preparedness to train Mining Engineers for the future. In order to achieve the objective, firstly, the pre COVID-19 pandemic preparedness status for Zambia to train Mining Engineers for the future was established. Then, the impact of the COVID-19 pandemic on Zambia's preparedness to train mining engineers for the future was determined.

The Mining engineering programme from Colorado School of Mines had no course that deal with specific computing and automation required for the Mine of the future. However, the programme allows for three free electives for students that can be used to take up computer sciences and automation courses to beef up their skills required for the future mine. Furthermore, the school houses other programmes such as computers science were students can take up mining courses under electives and Mechanical Engineering which deals with aspects of space mining. The Curtin University Mining Engineering programme has incorporated the future mine thinking into their curriculum. This can be seen from the percentage of courses (24%) under Operating practices and technology that specifically address computing and automation skills required for the future mine. Equally, it was observed that thinking of a future mine has been embraced from the courses in the programme offered by Witwatersrand University. This can also be seen from the percentage (27%) of the courses under Operating practices and technology that are developed to train or equip students with specific skills required for the future mine

Regardless of the number one (1) ranking in terms of weighting under Operating practices and technologies from the comparative analysis, UNZA preparedness to train Mining Engineers for the future, overall, can be ranked fourth judging from the percentage component of computer sciences and automation courses from the Operating practices and technology courses and the current infrastructure in place.

The results of the comparison showed the average score of student in GER 2018 (before COVID-19) under the key area of operating practices and technology was slightly higher than average of score of students in GER 2019. A 5% reduction in the average score was experienced from GER 2018 to GER 2019. The difference however was not significant as indicated by T-Test conducted on the data set which generated the value of p=0.63. Likewise, the average score of students during GER 2018 under the area Talent and leadership was higher than averages core during GER 2019. An 8% reduction in the average score was experience from GER 2018 to GER 2019. The same trend was also observed for courses under the area of Partnership with key stakeholders with a 16% reduction in the average score from GER 2018 to GER 2019.

5.0 Conclusion

The status of Zambia's preparedness to train Mining Engineers for the future before COVID-19 was established by comparing the Mining Engineering curriculum at UNZA to Mining engineering programmes from the top two ranked Mining Engineering schools in the world and the first ranked Mining Engineering school in Africa which are positioning themselves to take up potential challenges to be posed by the future mine. The comparison of the Mining Engineering program was done under the four key areas identified for the future mine. The comparative analysis showed that the course weighting for UNZA programme under Operating practices and Technology is ranked first, second under Talent and Leadership and ranked fourth under Partnership with key stakeholder and Governance. However, it was further observed that, regardless of UNZA being ranked first items of weighting under operating practices and technologies, overall, UNZA preparedness to train Mining Engineers for the future is ranked fourth in relation the compared programmes judging from the percentage component of computer sciences and automation courses from the Operating practices and technology courses and current infrastructure in place. Furthermore, it was concluded that the blended learning, introduced as a result of the advent of COVID-19, as relegated UNZA preparedness to train Mining Engineers for the future. This is because there was the knowledge and skills assimilation reduction of 5% percent in Operating practices and Technology course, 8% percent in Talent and Leadership course and 16% in Partnership with key stakeholder courses. It was concluded from the case study results that COVID-19 pandemic had relegated Zambia's preparedness to train Mining Engineers for the future

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An assessment of the solutions to the socio- economic impacts of mine closure on the livelihood of the local community: A case study of Luanshya

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Abstract

Mining undoubtedly has the capacity to transform the living standards of the people within a short period of time. Therefore, when a mine closes, the impact is often far reaching. The aim of this study was therefore, to evaluate the socio-economic impact of mine closure in Luanshya and propose solutions to mitigate them. The study was conducted in Luanshya Township on the Copperbelt Province. The study employed a descriptive research design, while data was collected using a well-designed questionnaire which had both closed and open ended questions. Data was analysed using Excel and SPSS and results presented in tables and graphs form.

Findings showed that mine closure has negative consequences on the living standards Luanshya residents. The study found that most mining companies did not have any initiatives that can be undertaken in Luanshya district to promote community development and mitigate the social economic impacts of mine closure. The research concluded with solutions that mining companies should be active in providing various educational activities such as workshops in various fields and other opportunities such as scholarships for miners to upgrade their education and have other skill sets. The researcher also called for the government to put in place policies that will protect communities where these mines operate.

Keywords: Mining, Luanshya, Living standards, Mine closure, Community

1. Introduction

Mining has been a driver of various economies globally. Mining activities have helped in reducing unemployment and improving the living standards of the people. Mining activities are also known for improving the infrastructures in the communities of their operations through Corporate Social Responsibility (CSR). It is due to this significance that mining there is drastic rise in global mining activities with more minerals being discovered in various countries. This discovery is both in developed and the developing countries (Dubey, 2017). For example, in Zambia, gold deposits were recently discovered in Mwinilunga and Mumbwa districts. And as can be seen in figure 1, a lead mine in Kabwe.

Despite mining having numerous economic benefits, it has a limited lifespan. Marais (2014) argued that the lifespan of mine operations is to a large extent dependent on the size and grade of the deposits and

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methods of mining applied, as well as the current prevailing good market prices. Mining operations tend to occur over a long period of time, lasting decades, but products prices are not constant and are likely to cause temporary suspension of operations or even extended periods of closure.

Figure 1: Occupation Status

However, when mining operations become unsustainable due to resource depletion, plans for decommissioning and mine downscaling and closure begin. Mine closure, whereby mining activities stop permanently, and its associated post-closure social and economic characteristics form part of the lifecycle of mining operations. Universally, deterioration of natural resources has become a regular occurrence (Marais, 2014). In Zambia, mining remains the most important contributor to the economic stability of the country. It is common to see most economic parameters of the country begin to change after any change in the economic prices of the copper on the international market. The mining sector is one of the major employers of the Zambian labour force. Therefore, when a mine closes, the consequences of the closure are not just experienced at the community level but also at national level (World Bank, 2019).

Luanshya is a district found on the Copperbelt Province of Zambia. It is a district whose economic activities are mining and agriculture. The district is endowed with copper ore deposits hence making mining a major economic activity. Luanshya has always enjoyed the economic benefits that come with mining. When the mines are at operational level, Luanshya town is usually in the state of economic stability. However, the town faced harsh economic situation when the mines ceased operations in the area in 2001 and 2009. When the mine closed, the town experienced a sharp increase in the levels of unemployment coupled with a decline in the general living standards of the people. Less than 10% of people living in mining areas are not dependent on mining activities but on agriculture. Majority of these households engage in multiple livelihood-sustaining activities, many of which do not produce cash income but are mainly consumed by the household itself. This study, therefore, endeavoured to determine the effects of potential negative impacts of mining on the socio-economic well-being of communities in mining towns after closure of mines.

2. Literature Review

Ayanda (2018) conducted a study on the socio-economic impacts of mine closure on local communities using the households from Mpumalanga Province in South Africa as a case study. The study by Ayanda (2018) used questionnaires as the means of data collection. The findings of this study suggested both negative and positive impacts of mine closure and the coping strategies. Ayanda (2018) concluded that the negative socio-economic impacts of mine closure include: rise in poverty, deterioration of living standards, increase in outward migration, emergence of crime and diseases, decline in the provision of services, reduction in employment opportunities in the mine and second-order employment, loss of foreign exchange, limited money circulation, reduction of buying power and in the payment of rates by the community.

The study by Ayanda (2018) equally revealed the positive impacts of mine closure which included the following: an increase in government initiatives aimed at helping the community, strong social cohesion of the local people and a focus on agriculture in the area. The coping strategies of the host community following the mine closure comprise of dependence on severance packages, support from relatives, finding jobs elsewhere, practicing agriculture, and engagement in the informal sector.

Another study on the consequences of mine closure was carried out by Waldt & Botha (2018). This study focused on ways of mitigating the socio-economic consequences of mine closure. To arrive at the findings, Waldt & Botha (2018) used the trends analysis of the mining industry in South Africa. The findings of the study suggested a general lack of understanding among mining companies of the significant socio-economic consequences that mine closure may have on affected communities.

Mpanza *et al,* (2019) carried out a study on the relationship between mine closure and the living standards of the community in which the mine operates. This study was conducted in the Democratic Republic of Congo. The results from this study suggested that there was a negative relationship between mine closure and the living standards of the people. The findings by Mpanza *et al,* (2019) were in line with the findings made by Ayanda (2018).

Studies conducted by Van Eeden *et al*. (2009), Stacey *et al.* (2010), and Du Plessis (2011) identified general socio-economic consequences of mine closure on communities. These consequences are expounded below.

Confusion about managing social risks: In most cases communities were not prepared beforehand for the loss of employment and the ensuing poverty. Most affected mining communities suffered from shock. Both the emotional and economic spheres of the inhabitants' existence were affected. This process also impacts social structures and the economic wellbeing of a mining community. Studies indicated a strong relationship between unemployment, emotional issues, and health problems such as hypertension, insomnia and psychological maladies like depression and feelings of uncertainty. Participants also reported feelings of helplessness and anger.

Inappropriate training for self-employment: The mining communities also experienced social changes related to job loss, for example unemployment and poverty. Even though plans for skills development and job creating schemes were proposed in the MPDRA, 28 of 2002, these interventions were not realized in time for the miners who faced such closures in the past. These individuals had acquired skills only for employment in the mining industry, and job creation schemes failed as well (Du Plessis 2011).

Illegal occupation of empty mine houses and ensuing vandalism: Mineworkers lose their right to housing when the mine closes. However, their dwellings are left abandoned and are then inhabited by illegal occupants. This clearly impacts negatively on the existing social structures, and on the safety of the mineworkers' neighborhoods. Mining sites are stripped of usable metal, which are then sold to metal recyclers to obtain cash. The infrastructure and facilities of the closed mine is often vandalized. Mining operations cannot re-open unless the mining structures are replaced, which would be at an extremely high cost to the new mine owner (Du Plessis 2011).

3. Methodology

This study used a descriptive research design. This study adopted this design since the major goal of the study was to identify characteristics, frequencies, and trends in the living standards of the people before and after the mine closure. According to the population census (Central Statistics Office, 2010), Luanshya has a population of over 156,059 corresponding to nearly 10, 000 household. Of the 10,000-household found in Luanshya nearly 3000 households depend on mining for their survival. Therefore, for the purpose of this research, the target population was 3000 households. Primary data was collected by giving questionnaires to 67 respondents. The sample is suitable for this research because the number was derived using Raosoft sample size calculator. The calculation used a confidence level of 90% and the margin of error of 10%.

Data was collected using a well-structured questionnaire and thereafter, analysed using SPSS. The data collected was analyzed thematically using SPSS. It was to be collated by making themes. The data was retrieved by means of obtaining it from a database management system such as Object-Oriented Database Management System (ODBMS). Once retrieved, it was stored in a file, printed or viewed on the screen. The various parameters were analyzed by grouping similar ideas or responses together, for instance, respondents with alternative income grouped together, and those with no income grouped together

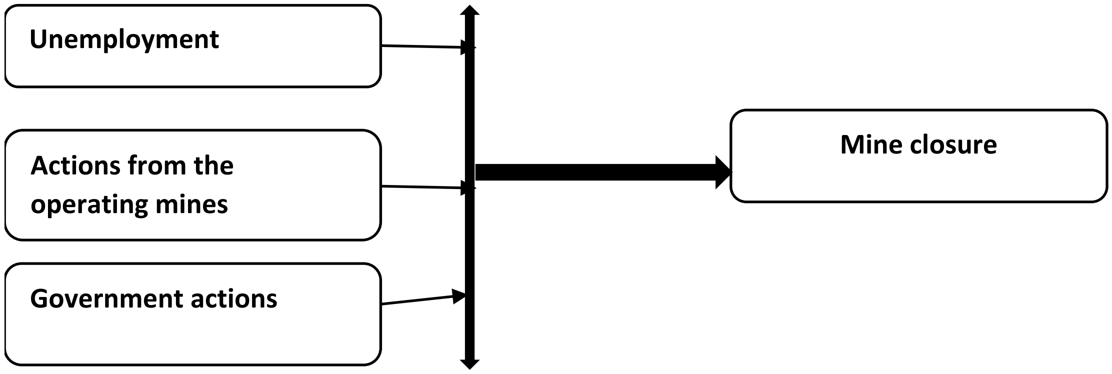

Figure 2: Conceptual framework

4. Results and Discussion

The data revealed that the majority of the respondents do not fully understand mine downscaling and what it means for the socio-economy of the community. The study revealed that there is confusion among community members due to lack of information and involvement in development matters of the town. The findings also show that even though the community does not fully understand the concept of downscaling and socio-economic development, the community perceives the ongoing downscaling to have a direct effect on the economic development of the town and loss of employment while viewing this as posing a risk to the future development of the town. As is shown in figure 2, the majority are so dependent on the mine being operational all the time which hinders them from preparing, learning or thinking of downscaling of mines. And because of this overall dependence, when mine closure happens, as can be seen in figure 3 above. The level of income distribution become so uneven. Only those who had some businesses running likely to survive the harsh conditions that come after. The majority begin to earn between k1000-k3000 and the minority group earns above k6000.

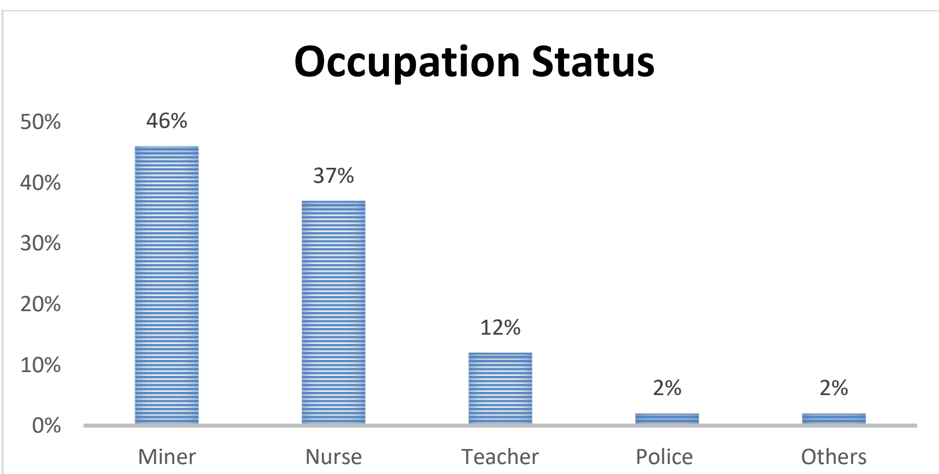

Figure 2: Occupation Status

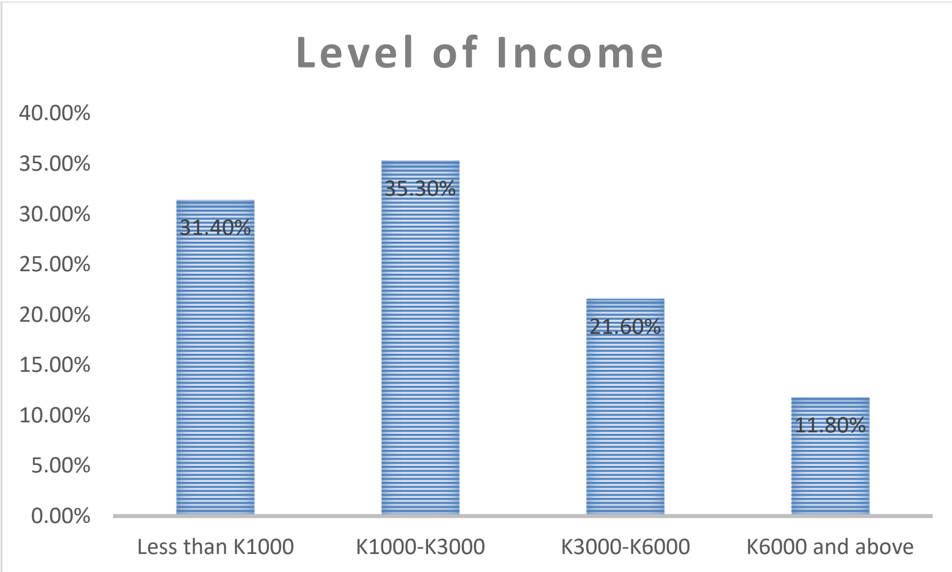

Figure 3: Level of income

Perceptions at the community level vary but mine closure is strikingly seen as an obstacle to the economic development that residents have enjoyed for several decades. According to Muntingh (2011), unemployment and desperation among other issues brings the belief within communities that mining entities are viewed to have limitless resources and are not doing enough to better the lives of the local communities.

The community views are essential considering the negative publicity surrounding the downsizing of the mine operations in Luanshya and the broader mining industry. Lack of understanding and knowledge of downscaling, with regard to socio-economic development, was evident. The findings also reveal that there is increased suspicion and mistrust among communities and the mine and stakeholders. Overall, the study findings show that there is a negative perception from the local community. According to Sheldon (2014), local communities worry because they feel mine closure is a severe blow to the economic development of a mine town.

Furthermore, the findings show that there is a general understanding of mine downscaling at the level of business owners in the study. The research analysis also revealed that mine downscaling has negative consequences on the general population of Luanshya Township particularly on business establishments. The main reason for this is the dependency of the economy and population on one source of income, which affects businesses and the economy. The data also revealed that fewer people are employed in the town, the less gross income and more people will not be able to pay municipal services. From the business community's point of view, all corners of the town will be negatively affected and citizens will need to device coping mechanisms to survive until the economy of the town improves.

Based on the presented data, the majority of the respondents described the status of the socio-economy as depressing as can be shown below in figure 4, the social and economic aspects of the study area are unhealthy. These findings suggest that there is a high dependency in the study area on mining activities, as the results, the economy declines along with the reduction in mine operations.

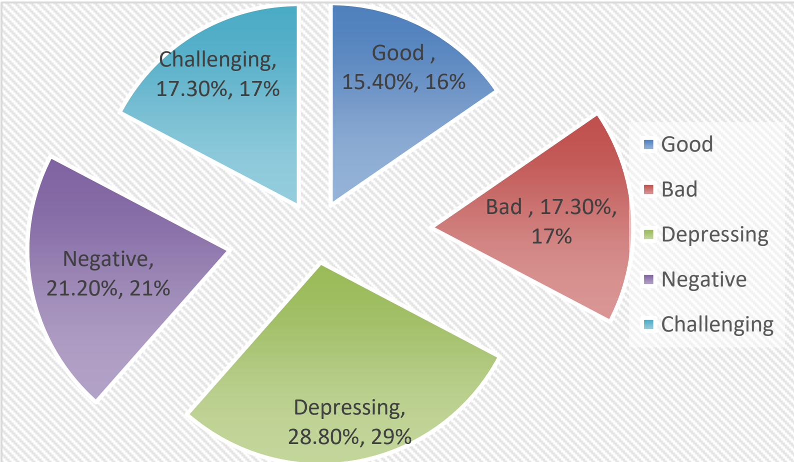

Figure 4: Occupation Status

Andrew-Speed, *et al*., (2003) states that decline in mine operations always has immediate and significant negative economic consequences in the community where the mine is operating. The resulting negative economic effects take the form of removal of some or all of the positive contributions made by the mine during its life. These are likely to include employment in the mine, spin-off economic activity, physical infrastructure and social services among others. Any reduction in these services which form basic components of life will not only affect economic strength of a community but will pose substantial risk to the decline of social aspects of a community. The common symptoms of a decline in these components range from unemployment, deteriorating infrastructure, failing social services and an increase in crime. Andrew-Speed, *et al.*, (2003) further states that during mine closure, three entities suffer economic loss; the mine company loses investment and future cash-flow, the local government loses tax revenue and workers lose their livelihood, be it residents or migrants. This trend shows that Luanshya is not spared from immediate shocks that mining towns are faced with particularly during mine closure.

5. Conclusion and Recommendations

From the literature reviewed it is evident that mine closures have a devastating effects on the surrounding mining communities as well as on the employees. The study found that most mining companies did not have any initiatives that can be undertaken in Luanshya district to promote community development and mitigate the social economic impacts of mine closure. If the mine workers are to be cushioned against the adverse impact of mine closure, mining companies should be proactive in providing various educational activities such as workshops in various fields and other opportunities such as scholarships for miners to upgrade their education. Therefore, it is of utmost importance that mining companies and the relevant stakeholders participate in careful and thorough planning for mine closures. As a way of mitigating the challenges associated with mine closure the following recommendations could be considered as possible remedies to the negative consequences associated with mine closure:

- Mining companies should develop a contingency plan to mitigate the potential socio-economic consequences of an unexpected mine closure. A contingency plan will assist in building resilience into the livelihood strategies of mineworkers and their dependents and it will create the ability for an organization to respond and meet immediate needs for sustenance in a mining community after a mine closure.
- Community participation should be promoted. Community members should be involved in all activities and planning to deal with an expected emergency. Community members must be able to voice their concerns and represent themselves and their marginalized groups on equal grounds with the local stakeholders (Twigg & Bottomley 2011).
- Mining communities should develop cooperatives goes into other business ventures and not solely be dependent on the mines
- The government should develop and enforce policies that will bound mine companies to develop the financial capacity and health of the communities they operate in. These policies will mitigate the negative effects of mine closures.

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Transition to circular economy for sustainable mining in Zambia: copper slag waste recycling

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Abstract

The extensive exploitation of mineral resources by the mining industry generates massive volumes of waste and has a significant detrimental impact on the natural environment. To alleviate environmental impacts and achieve sustainable mining, the circular economy model, which advocates for sustainable resource processing practices of "produce, use and recycle," should be explored. This study provides an overview of copper slag production in Zambia during the last two decades, as well as the environmental impacts and the potential for recycling to help the country transition to a circular economy. The findings in this study indicate that the copper slag annual production in Zambia has increased consistently from an average of 572,000 tons in 2000 to 1.8 million tons in 2020. The transition to a circular economy model can help the mining industry to generate additional economic value, reduce environmental impacts, and improve the energy efficiency while extracting maximum value from the copper slag waste.

Keywords: copper slag waste, circular economy.

1.0 Introduction

The exploitation of primary mineral resources generates significant amount of wastes. Over 100 billion tons of mining waste are generated annually from the primary production of mineral and metal commodities around the world (Rankin, 2015). The generation of this huge amount of mining waste has the potential to harm the environment in terms of resource depletion, high energy intensities, greenhouse gas emissions, water and soil pollution, and landscape impacts (Kuiper et al., 2019), necessitating long-term initiatives for reforming the mining industry to achieve a zero environmental footprint (Khorami et al., 2019). Copper slag is one of the mining wastes that is causing increasing concern due to the huge volumes produced every year worldwide (Phiri et al., 2021). Currently, Zambia produces 1.8 million tons of copper slag waste (Figure 1). The potential of slag to discharge hazardous elements into the environment has a direct bearing on its environmental effects (Parsons et al., 2001; Ettler et al., 2009; Piatak et al., 2014; Potysz et al., 2018; Phiri et al., 2021). Conversely, copper slag contains significant amounts of valuable metals such as copper, cobalt, silver, zinc, and iron, and reprocessing it using circular economy principles has the potential to mitigate negative environmental impacts and contribute to sustainable development.

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The circular economy model is a relatively new idea that can help the mining industry improve its sustainability performance (Lèbre et al., 2017), as well as increase the value of mining waste like copper slag. The concept is comprised of resource processing techniques centered on the principle of "produce, use, and recycle" (Lèbre et al., 2017; Nikoloski, 2020; Fort et al., 2020). The circular economy's immense potential for resource circularity and sustainable development has been widely recognised (Velenturf et al., 2019; Lanau and Liu, 2020). According to research, recycling mining waste according to the circular economy paradigm has the ability to keep additional value in products for as long as possible while also potentially alleviating the environmental legacy of mining activities (Smol et al., 2015). The mining industry's role in the transition to a circular economy based on non-renewable resource conservation has been investigated (Lèbre et al., 2017). Khorami et al. (2019) examined a novel approach for re-thinking mining wastes in order to achieve better environmental and circular economic goals. The study assessed the current frameworks on the management of mining waste and explored an integrative approach on "re-thinking" mining wastes across the social, environmental, technical, legal, regulatory, and economic domains. Copper slag waste is an important resource for a circular economy because it has the potential to deliver long-term economic and environmental benefits. In the current literature, there is no study on the application of circular economy to processing of copper slag waste, which is a significant gap that the research study addressed. The circular economy is a fundamental concept for sustainable mining, as it helps to solve concerns including depletion of high-grade ore, deteriorating economic viability, and increasing mining legacies by optimising extraction and lowering the quantity of valuable material in waste. This study aims to propose a strategy for sustainable management of copper slag waste in Zambia using circular economy model.

2.0 Copper slag production in Zambia

The mining of Zambia's most predominant mineral resource, copper, has been going on for more than a century, and it has played a key role in the country's economic, social, and political development. Despite efforts to diversify the economy, the copper mining industry in Zambia has continued to be a major driver of economic growth and development for a long time (Sikamo et al., 2016). However, the industry generates significant amount of copper slag during copper production. Copper slag is a waste produced during the pyrometallurgical extraction of metals from copper concentrates. It is estimated that for every ton of copper produced, 2.2 tons of slag is produced (Gorai et al., 2003). Globally, 37.7 million tons of copper slag is produced every year (Phiri et al., 2021). Zambia has an average annual copper slag production of 1.4 million tons, making it Africa's second largest producer after the Democratic Republic of Congo (DRC) and the world's seventh largest producer (Phiri et al., 2021). Copper slag production in Zambia has steadily increased from an average of 572,000 tons in 2000 to 1.8 million tons in 2020, totaling more than 28 million tons produced over the last two decades (Figure 1). The government of the Republic of Zambia has directed the mining industry to expand copper production from 830,000 tons per year to 3 million tons per year over the next ten years (Lusaka Times, 2022). With the trend shown in Figure 1, this directive by the government imply further increase in the generation of copper slag amounting to approximately 6.6 million tons per year. The production of copper in Zambia is based on the produce-use-dispose linear flow paradigm. For many years, land application has been Zambia's primary method of copper slag disposal. The disposal of these huge volumes of copper slag necessitates extensive expanses of land and has a significant negative effect on the soil and vegetation, which are the people's primary sources of livelihood. The traditional linear economy model has contributed immensely to the depletion of mineral resources and the generation of waste (Lèbre et al., 2017; Khorami et al., 2019; Fort et al., 2020). As a result, this form of the economy is unsustainable because of finite resources and harmful environmental consequences (Bonciu, 2014; Korhonen et al., 2018; Suarez et al., 2019). The predicted increase in copper production will lead to a corresponding increase in copper slag, which will exacerbate the environmental risks associated with copper slag waste under this traditional linear economy model. Thus, focusing research efforts on the circular economy and developing transition pathways for the mining industry to move toward more sustainable practices are beneficial.

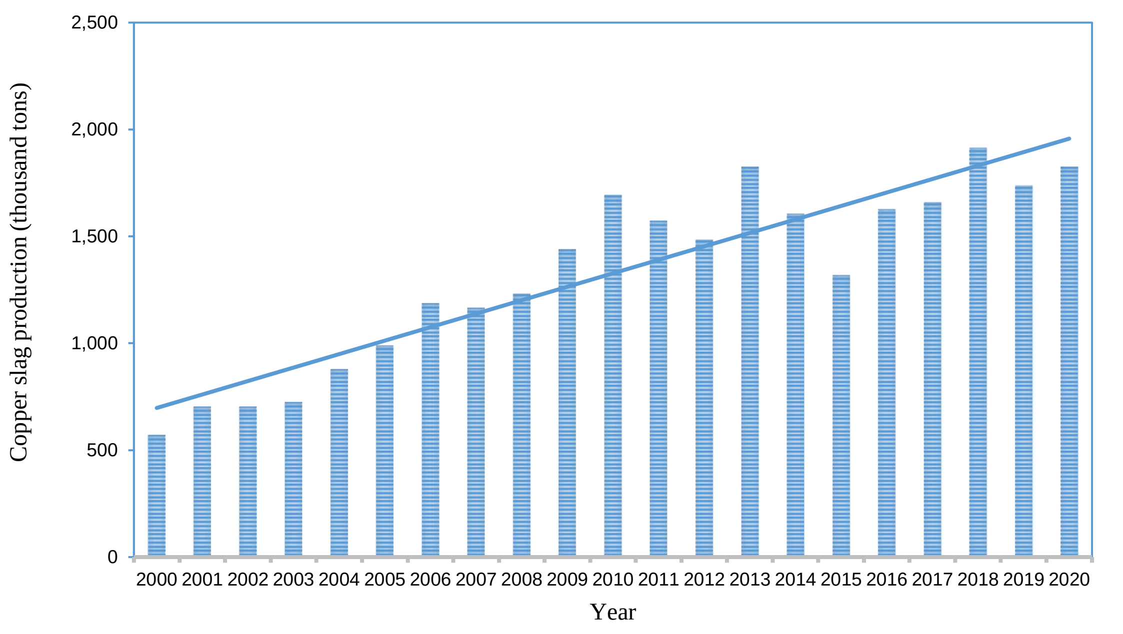

Figure 1: Copper slag annual production in Zambia for the period 2000 to 2020. Data Source: U.S. Geological Survey, (2001-2021).

3.0 Environmental Impacts of Copper Slag

The environmental threats associated with copper slag waste are a growing concern, especially the release of potentially harmful substances into the environment, which could lead to pollution of surface water, soil, and groundwater (Parsons et al., 2001; Ettler et al., 2009; Piatak et al., 2014). Pollution of the environment can harm human health, livestock, and wildlife biodiversity (Parsons et al., 2001; Ettler et al., 2009; Piatak et al., 2014; Potysz et al., 2018; Kambole et al., 2019), as well as have a negative impact on the welfare of the mining communities. The toxic heavy metals (Pd, Cd, As, Cu, and Zn) found in the copper slag can undergo the weathering process from the dump sites and form secondary phases (Phiri et al., 2021). The formation of secondary phases by slag weathering is a sign of the material's reactivity, which could potentially release harmful substances into the environment (Piatak et al., 2014). Ettler et al. (2003) stated in a similar study that analysing mineral phase alteration allows for the prediction of conditions favorable for metal mobilisation and immobilisation, as well as secondary phase creation. The presence of some metal-bearing phases of copper slag with a high susceptibility to alteration was found to potentially raise the likelihood of metal mobilisation from slags, according to the study (Ettler et al. 2003). Several studies have shown that the metal sulphides found in slag are the most susceptible to weathering conditions because they are easily altered, especially under oxidising conditions, which could increase the risk of metal mobilisation (Parsons et al., 2001; Ettler et al., 2009; Potysz et al., 2015). Sulphide minerals react with water and oxygen to form an acidic heavy metal laden leachate through the phenomenon called acid mine drainage (AMD) (Akcil and

Koldas, 2006). Slag leachate contamination of soil and water sources has been linked to a variety of ailments, including anemia, lung and stomach cancer, as well as irreversible skin and respiratory disorders in over-exposed people (Vestola et al., 2010). The leachate is not only poisonous, but it also causes an irreversible loss of metal content from the slag. This means that due to leachate formation, the quality of a waste dump as an abiotic resource is deteriorating over time (Lèbre et al., 2017).

With a long history of mining in Zambia, most communities near mines face a number of environmental and socio-economic concerns (Lindahl, 2014). As a result, mining in Zambia has remained contentious, and true sustainability has not yet been achieved. Although most mining companies have taken significant steps in recent years to mitigate the devastation effects of their operations in communities and areas of operation by developing comprehensive impact assessment studies and massive investments in infrastructure such as roads, hospitals, schools, electricity, and water supplies, this has not alleviated major concerns about air, soil, and water pollution, as well as other forms of environmental degradation (Aboka, 2018). Environmental regulations, a scarcity of disposal sites, and the high cost of waste treatment have all heightened interest in developing slag waste management strategies (Phiri et al., 2021). One of the strategies aimed to assist industry in preventing waste concerns is the circular economy. Given the seriousness of the mining industry's potential environmental impacts, circular economy mandates that mining sites employ several ways to manage waste problems and to best prevent major environmental disturbances. It also necessitates incorporating a number of highly effective environmental management tools into operations, such as audits, reviews, monitoring practices, an environmental management system, and reporting systems that will help the mining industry better anticipate waste problems and deal with them when they arise in a sustainable manner (Hilson et al., 2000). As a result, adopting circular economy as an environmental and economic strategy would be required for the mining industry in Zambia.

Recycling of Copper Slag Waste

Copper slag waste is considered a potential world resource for recycling because of the huge amounts produced annually, which contains significant amounts of valuable metals (Phiri et al., 2021). Several studies have investigated the recycling of copper smelting slag using approaches including flotation, hydrometallurgy, pyrometallurgy, and an integration of pyrometallurgy and hydrometallurgy (Pyro-hydrometallurgy). Converter and refining slags are mostly processed through recycling to the smelting furnace due to high metal content.

The flotation method for recovery of entrained metal compounds from copper slag has been explored utilising various collectors, frothers, modifiers, and depressants (Sarrafi et al., 2004; Das et al., 2010; Roy et al., 2015; Fan et al., 2017). However, the approach is only effective for recovering metallic copper and sulphide minerals, while other important metals such as cobalt remain in the slag or flotation slag tailings and are finally disposed off in waste landfills (Biswas and Davenport, 1994; Davenport et al., 2002; Deng and Ling, 2007; Meshram et al., 2017). This is due to the chemical combination of practically all cobalt with silica, iron, calcium, and aluminum oxides, making flotation separation extremely difficult (Dimitrijevic et al., 2016; Hara and Jha, 2016). Owing to these challenges, copper slag recycling using flotation approach has yet to find widespread industrial application. Although a few mining companies in Zambia, particularly small-scale mines, are reprocessing copper slag waste from dump sites using primarily conversional flotation methods, the waste product from these processes is dumped, causing even worse environmental degradation due to the reduced size of the slag after crushing and grinding. To ensure efficient metal extraction from copper slag, the entrapped matte and entrained metal grains should be large enough to be liberated during crushing and grinding. Thus, the cooling rates of copper slag following the smelting and converting processes are important considerations prior to milling and flotation operations for efficient metal recovery (Holland et al., 2019).

The hydrometallurgical approach via leaching is the most common method in low grade metal recovery processes because of its lower energy consumption and environmental advantages. The approach was investigated for metal extraction from copper slag utilising a variety of parameters including leaching system, solid/liquid ratio, temperature, extractant concentration, and leaching time. The atmospheric leaching using lixiviants such as acids, bases and salts have been explored. Sulphuric acid (H_2SO_4), alone or in combination with oxidants, has been used to process copper slag in a number of investigations (Anand et al., 1983; Sukla et al., 1986; Altundoğan et al., 2004; Boyrazli et al., 2006; Yang et al., 2010; Nadirov and Mussapyrova, 2019; Basir and Rabah, 1999; Banza et al., 2002). Sulphuric acid is a strong acid that is soluble in water at all concentrations and is an efficient lixiviant for the leaching of metal oxides. However, some studies have found that, while metal extraction efficiency is excellent (93–100%), extraction from silica rich slag requires a lot of sulphuric acid and results in silica gel suspended in a solution with high concentrations of iron (Deng and Ling, 2007; Yang et al., 2010; Potysz et al., 2015; Hara and Jha, 2016). This is because metals like cobalt and copper are dissolved in spinel oxide, ferrite, and silicates. The efficacy of the process is limited by its high sulphuric acid and lime consumption, as well as poor settling and filtration characteristics induced by the formation of iron hydroxide precipitates and silica gel (Yang et al., 2010; Hara and Jha, 2016). The use of bases and salts in the leaching of copper slag waste has been discovered to have several advantages and can minimise problems associated with the use of acids (Bulut, 2006; Carranza et al., 2009; Nadirov et al., 2017; Aracena et al., 2019).

The pyrometallurgical approach involves processes such as calcination, roasting, smelting, converting and fire refining. The extraction of metals from copper slag using carbothermic reduction at temperatures ranging from 1400 to 1800°C has been the focus of research employing this method (Jones et al., 1996; Yucel et al.,1992; Banda et al., 2002; Sanchez and Sudbury, 2013). Banda et al. (2002) explored carbothermic reduction of copper smelter slag under the influence of slag modifiers. When rutile (TiO_2) was used as a slag modifier, it was discovered that it produced a more selective recovery of cobalt when compared to fluorspar (CaF_2) and lime (CaO) modifiers. Sanchez and Sudbury (2013) investigated the recovery of copper by direct electrical reduction of magnetite with carbon. The carbon generates a gas film during the reduction process which produces bubbles and reacts with the oxides in the slag phase to form a metallic phase which can be further processed to produce blister copper. However, due to the high energy needs of the DC arc furnace, the pyrometallurgical strategy for recycling copper slag is not the most preferred choice (Mututubanya, 2013).

Pyro-hydrometallurgical approach involves copper slag roasting followed by water or acid leaching. The roasting of sulphides in the slag produces a calcine which is later processed using the hydrometallurgical process via leaching. Roasting copper slag with roasting chemicals such as sulphuric acid has been the subject of extensive research (Arslan and Arslan, 2002; Dimitrijevic et al., 2016; Deng and Ling, 2007), pyrite (FeS_2) (Tumen and Bailey, 1990), ferric sulphate ($Fe_2(SO_4)_2$) (Altundoğan and Tumen, 1997), graphite (Bulut, 2006) and ammonium sulphate ($(NH_4)_2SO_4$) (Sukla et al., 1986) to yield metal sulphates. The recovery of Cu, Co and Zn from copper smelter and converter slags by roasting with sulphuric acid was conducted (Arslan and Arslan, 2002). The effects of roasting duration, temperature, and acid:slag ratio were studied in this study. After two hours of roasting at 150 °C and using a 3:1 acid/slag ratio, metal extractions of 88% Cu, 87% Co, 93% Zn and 83% Fe were achieved. The study investigated the effects of roasting time, roasting temperature, and acid: slag ratio. The authors observed that increasing the roasting duration to four hours raised copper extraction to 95%. However, high iron content in the leach liquor makes it unsuitable for further processing. According to recent research, raising the sulphation temperature can minimise the amount of iron in the leach liquid (Dimitrijevic et al., 2016). The process comprised roasting the slag in the presence of sulphuric acid at a temperature of 250°C, with a maximum copper extraction efficiency of 94% and iron dissolution of 55%. Further experiments at a considerably higher temperature of 600°C lowered the iron extraction efficiency to about 6%, but the copper recovery also reduced to 79%.

A review of literature indicates that progress has been made on the reprocessing of copper slag using various approaches; however implementation of most of these processes to industrial scale still remains a daunting task. The major drawbacks associated with recycling of copper slag are its complexity, high energy demands and need for investments in equipment (Castro et al., 2007; Velenturf et al., 2019). Consequently, the copper slag processing has not been considered economically attractive enough, and many mining companies have settled down to copper production and marginalised secondary functions. However, copper slag is considered a world resource because it contains significant amounts of valuable metals (Cu, Co, Zn, Fe, Ag) (Phiri et al., 2021) with higher grades than the grades of these elements in the ore. Table 1 and 2 shows typical chemical composition of copper ores and copper smelting slag, respectively. It can be seen as an example that the grade of copper in the ore and slag are comparable. On the other hand, the grade of cobalt is higher in the slag than in the ore. Novel initiatives and efficient recovery of these metals in the copper slag using circular economy model will have great economic benefits.

Table 1: Typical chemical composition of copper ores in Zambia

Ore Type	**TCu**	**TCo**	**S**	**SiO_2**	**Fe**	**Al_2O_3**	**CaO**	**MgO**	**K_2O**	**MnO_2**
Silicious	0.1- 1.5	0.01 - 0.3	>0.01	50 - 70	1 - 3	3 - 10	0.2 - 2	1 - 4	5 - 8	0.15
Dolomitic	0.1 - 1.5	0.01 - 0.3	>0.01	15 - 30	5 - 12	5 - 7	0.1 - 20	0.1- 20	0.2 - 2	< 0.1

Table 2: Typical chemical composition of the Nkana slag dump in Zambia

Cu	**Co**	**S**	**SiO_2**	**Fe**	**Al_2O_3**	**CaO**	**MgO**	**K_2O**	**Cr**	**TiO_2**	**Pb**	**Zn**
0.8 - 1.5	0.4 - 0.9	0.1 - 0.3	30 - 40	20 - 30	6 - 12	8 - 15	3 - 6	2 - 5	0.1 - 0.2	0.4 - 0.8	<0.1	<0.1

Conversely, copper slag waste contains harmful elements which may have serious environmental repercussions if discarded. The declining public acceptance and more stringent environmental regulations are becoming a limiting factor of slag dumping. Thus, the transition to a more efficient circular economic model through increased recycling aspires to solve sustainability challenges on a higher level (Zhang et al., 2019). Undoubtedly, the overall benefits of recycling copper slag waste outweigh the disadvantages. New technology, product design, and recovery procedures can assist mining companies to develop viable circular economy strategies within their ecological context (Hobson, 2016).

Mineralogical examination carried out at the Copperbelt University has shown that copper in the slag exist in various forms; sulphide (Cu_2S, Cu_5FeS_4 and $CuFeS_2$), metallic form (Cu) copper oxide form (CuO, $Cu_2CO_3(OH)_2$ $Cu_3(CO_3)_2(OH)_2$, $Cu_2(CO_3)(OH)_2$) and calcium – aluminum – high iron - silicate. By comparison, about 90 % of the cobalt is chemically dissolved in the calcium – aluminum – high iron - silicate matrix while the remainder is in the oxide form (CoO) and chemically dissolved in copper sulphide. Therefore, simultaneous recovery of copper and cobalt from slag is very complex due to existence of several phases. Figure 2 presents the proposed flowsheet for recycling copper slag in Zambia. The milled slag is roasted with ammonium sulphate thereby sulphating copper, cobalt, iron, aluminium, magnesium and chromium. Copper may be recovered via electrowinning to form copper cathode. Iron may be separated from solution via solvent extraction and then subsequently crystallised to form iron sulphate which is a valuable product. Aluminium, magnesium and chromium may be recovered via precipitation which involves controlling pH. The solid residue material containing silica and calcium sulphate may be separated by physical process and then be ultilised in the construction and cement making processes, respectively.

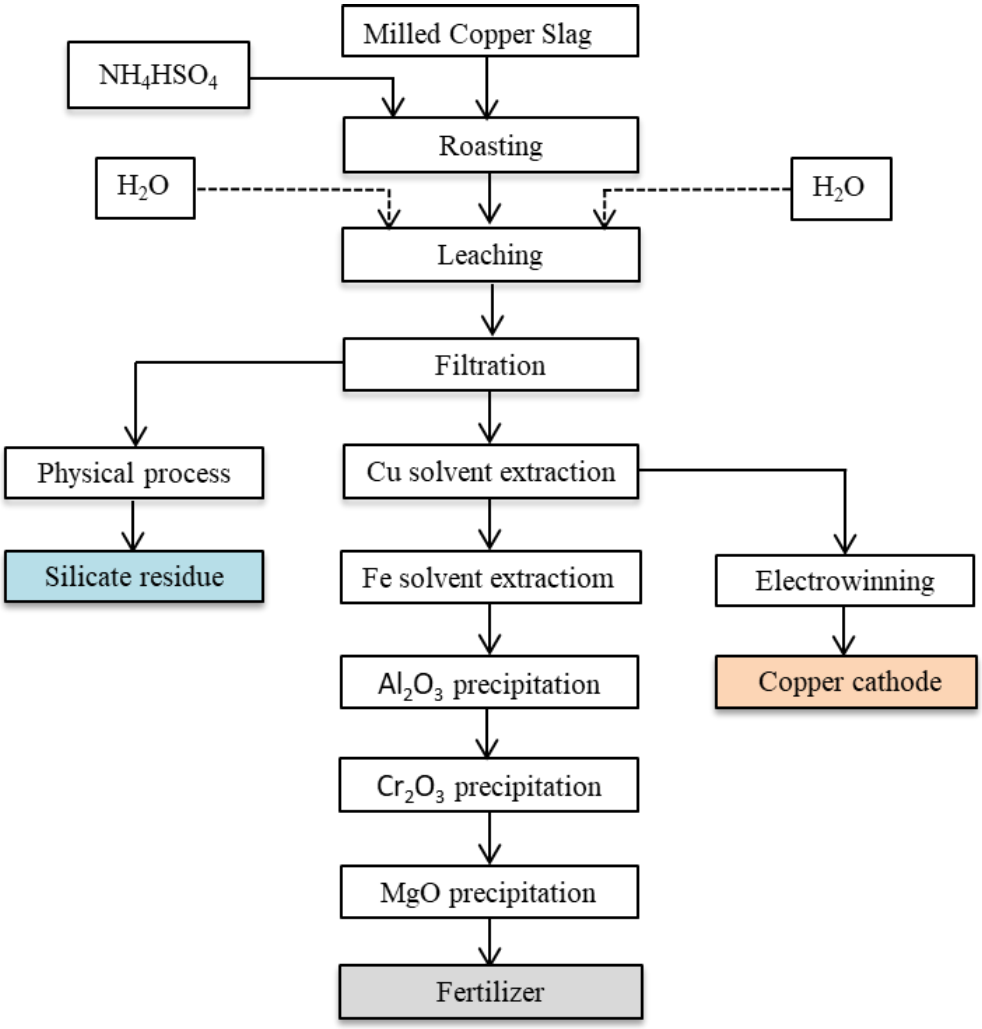

Figure 2: Proposed flowsheet for recycling copper slag in Zambia

4.0 The Circular Economy for Sustainable Mining

The mining industry, which is the world's largest producer of waste, is garnering attention as economic, social, and environmental indices of sustainable development improve. The knowledge of sustainable development in the context of mining has grown significantly since the landmark report 'Our Common Future' by the World Commission on Environment and Development (WCED), which defined sustainable development as "meeting the needs of the present without jeopardizing future generations' ability to meet their own needs," (WCED, 1987). This underlines the importance of intergenerational equity in terms of mining legacies, economic development, and legal requirements. Hilson et al. (2000), on the other hand, defined sustainable development as a combination of improved socioeconomic growth and development, and improved environmental protection and pollution prevention.

Sustainable development was first endorsed as a management and developmental strategy at the widely publicised United Nations Conference on Environment and Development (UNCED) in 1992 (Hilson et al., 2000). The concept has since become a key focus of planning, environmental protection, and remediation efforts around the world, and several academics and industrialists have developed policy frameworks, indicator sets, and management guidelines for use by governments and businesses in an attempt to operationalise the concept. The significance of sustainable development as a guiding principle in mining environmental management was proposed by Miller (1997). The author observed that sustainable development is extremely useful when creating environmental codes of practice. The mining industry can contribute to increased sustainability by preventing significant environmental problems from the outset and by implementing proactive environmental standards. What is often difficult to discern from these perspectives, however, is how mines may contribute to sustainable development and what steps a mine must take to improve its operations' sustainability. As a result, the debate over mining sustainability now includes a wide range of interpretations, and the majority of these significant mining sustainability articles have presented a global and comprehensive viewpoint. The purpose of this article is to explain how mines in Zambia can contribute to sustainable development through the circular economy, with a focus on copper slag waste recycling.

Since mining wastes have the potential to impact a diverse group of environmental entities, and are of interest to a wide range of stakeholder groups, there is ample opportunity for the mining industry to operate more sustainably. The mining industry can improve performance in both the environmental and socio-economic arenas, and contribute to sustainable development at the mine level through recycling of mining waste (Hilson et al., 2000). Specifically, a mine must minimise environmental impacts throughout its lifecycle, from exploration, through extraction and refining, to reclamation in order to contribute to sustainable development (Hilson et al., 2000; Khorami et al., 2019). The aim of the circular economy is to reduce the resources escaping from the circle so that the system functions in an optimal way (COM 398, 2014). This helps to keep resources within the economy when a product has reached the end of its life, so that they can be productively used again and hence create further value. Furthermore, the transition to a more circular economy requires full system change, and innovation in organisation, society, policies, technologies and finance methods (Smol et al., 2015). These elements speak to the aspirations of the circular economy and drive down impacts with residual waste management. Thus, it would help determine optimal scenarios for mining waste that would deliver overall societal benefits, notably including economic benefits for the industry and reducing the liabilities from mining legacies (Khorami et al., 2019).

The issue of more efficient use of waste is emphasised by the EU under 'A zero waste program for Europe (COM 398, 2014). 'Zero waste' is one of the most visionary concepts for solving waste problems and seems to be promising in the future waste management (Zaman and Lehmann, 2013). It assumes that transitioning to a more circular economy is critical to achieving the resource efficiency goals set out in the Europe 2020 Strategy for smart, sustainable, and inclusive growth (Smol et al., 2015). Investing in community development and recycling mining waste are two examples of positive mine legacies. Resources will last longer and achieve the circular economy's goals if reuse and recycling are increased. Increased and sustained resource efficiency performance can result in significant economic benefits. The circular economy is advocated as a method of economic growth that is in line with sustainable environmental and economic development (COM 398, 2014). While mineral and energy resources are obviously depleted and cannot be replenished, mining can help governments to mitigate impacts and generate income. The circular economy concept is being promoted by a number of national governments around the world, including China, Japan, the United Kingdom, Canada, France, Finland, the Netherlands, and Sweden, as well as several businesses. The push for a more sustainable society will result in better global standards and governance bodies (Khorami et al., 2018). Thus, applying circular economy thinking to mining waste in Zambia presents a major opportunity to reduce the liability and increase the value of waste. According to World Economic Forum (WEF) (2015), recycling should be made mandatory for private and commercial companies, while product design should allow for easy dismantling and metals extraction. These will cover the spectrum of industrial and environmental impacts of all stages of a product's life cycle (WEF, 2015). Better life-of-mine planning can reduce the amount of waste generated and most likely reduce overall project costs (Unger et al., 2017). Thus, a strong transition towards recycling and circularity is necessary for sustainable mining.

The Zambian government should encourage the mining industry and individual entrepreneurs to invest in circular economy technology. To encourage investment in the circular economy, the government should show its commitment by funding research and innovation, fostering skills development, and facilitating the commercialisation of innovative solutions. The EU, for example, created the Sustainable Process Industry through Resource and Energy Efficiency (SPIRE) and the Bio-Based Industries Joint Technology Initiative, both of which help to fulfill circular economy goals (COM 398, 2014). Under these programs all Member States have a consultation points where the industry and entrepreneurs can obtain information about current programs, supporting the development of green technologies. This has encouraged innovative enterprises in the EU to obtain the confidence and capacity to move to circular economy solutions (Smol et al., 2015). These programs can serve as knowledge platform and decision-support tools for Zambia and many other countries who have not adopted the circular economy on the management of mining waste.

5.0 Legal Requirements of the Circular Economy

Economic drivers and legal implications play a critical role in establishing new paradigms and allowing innovative approaches to be implemented (Khorami et al., 2018). Without a proper understanding of the economics as well as the legislative and regulatory context, technically feasible solutions that deliver better outcomes can fail. Mine management must not use environmental legislation as guidance since sustainability calls for proactive environmental management, hence a requirement to perform beyond regulatory demands (Hilson et al., 2000). Regulatory frameworks vary significantly throughout the world. For instance much of North America, Europe, and Australia, comprehensive environmental legislation has been in place for decades, but in a number of South American, African, and Asian countries, environmental laws are still in their infancy, and accompanying enforcement programs are far from effective (Hilson et al., 2000). The developing world is commonly a location for poorly managed mines, which, because of the "loose" regulatory environment, tend to employ a number of rudimentary, low-tech methods in mineral extraction and refining processes (Hilson et al., 2000). The mining legislations in Zambia, one of the developing nations, mainly present a technical approach, focusing on technological and safety issues without establishing a framework for sustainability mining. There is a lack of qualitative national waste management policies developed by the experts. There are number of laws and policies related with circular economy. For example, China enacted the "Cleaner Production Promotion Law", "Pollution Prevention and Control of Solid

Waste Law", and the "Circular Economy Promotion Law" between 2003 and 2009 (Su et al., 2013). Other countries must develop, enhance and implement these laws in order to transition to a circular economy. The laws should be dynamic in nature so that the developing countries like Zambia remains competitive with other major players on the global market (Sikamo et al., 2016). To achieve this, the mining industry must develop new business models and operate under new regulatory regimes which will encamps the management of copper slag waste in a way that maximises its value while minimising negative environmental impact.

6.0 Conclusions

Copper slag annual production in Zambia has steadily increased from an average of 572,000 tons in 2000 to 1.8 million tons in 2020, generating over 28 million tons in the last two decades. The disposal of these huge amounts of copper slag necessitates extensive areas of land and has a momentous adverse impact on the environment. Copper slag waste contains harmful elements that can pollute surface water, soil, and groundwater when released into the environment. The most practical step for the Zambian mines to contribute to sustainable development is to adopt circular economy as a corporate environmental strategy. Recycling is particularly important since copper slag contains substantial amounts of valuable metals. According to a survey of the literature, research has been done on the recycling of copper slag using various techniques, including flotation, hydrometallurgy, pyrometallurgy, and hydro-pyrometallurgy, however implementing of these processes to an industrial scale remains a challenging task. Reprocessing copper slag using circular economy aspirations has the potential to maximise its value while minimising negative environmental impact. The Zambian government should encourage the mining industry and individual entrepreneurs to invest in circular economy concept. To encourage investment in the circular economy, the government should show its commitment by funding research and innovation, fostering skills development, and facilitating the commercialisation of innovative solutions. The design and execution of new regulatory regimes that support circular economy thinking will require effective regulation. To achieve this, the mining industry will need to create new economic models and operate under new legal frameworks for the management of copper slag waste. Overall, recycling of copper slag using the circular economy principles is unquestionably the most promising option for sustainable mining in Zambia.

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A synopsis view of the COVID-19 challenges on the Zambian large scale copper mining industry

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Abstract

Zambian large scale copper mining sector has not been spared following the outbreak of COVID-19 in December, 2019 in Wuhan, China. From March to August, 2020, the country went into a partial lockdown which resulted in disruption of normal service delivery across various sectors of the economy. The government imposed several restrictions: ban on non-essential foreign travel, suspension of tourist visas, mandatory quarantine for travellers from high-risk countries, closure of learning institutions, suspension of some cross-border services and closure of non-essential businesses. However, all the large scale mines were allowed to operate at full capacity whilst following the COVID-19 guidelines. This paper highlights practical challenges faced by the large scale mines during COVID-19 outbreak. The study reviewed secondary data from all the large scale mines, government and the literature survey. Additionally, 60 questionnaires were administered using purposive sampling. Results of study indicate that, the social distancing guidelines implemented by the large scale mines led to the reduction of employees present physically and the placement of non-production essential workers on "working from home schedules" and some on forced leave. This working arrangement did result in disruption of some mining operations and temporal reduction in monthly production figures in the initial stages of implementation. However, overall annual copper production for 2020 showed significant increase to 882,061 tonnes, up 10.8% from 796,430 tonnes produced in 2019 despite COVID -19 restrictions. The increase in copper production was partly due to effective implementation of "work from home policy" and increased copper production at Sentinel and Kansashi mines who produced a combined record breaking of 486,190 tonnes. Furthermore**, t**he restrictions imposed in the country and beyond led to disruption in both local and international supply chains, depreciation of the Zambian Kwacha to a dollar from K13.08 on 2nd September, 2019 to K19.59 as of 2nd September, 2020.

Key words: Social distancing guidelines, COVID-19, mine restrictions, copper mining, Supply chain

1. Introduction

Zambia is ranked second in Africa and seventh in the World in copper production. In 2020, the country produced around 882,061 tonnes of copper. The mining sector contributed 9.9% of gross

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domestic production, 77.0% of exports, 27.8% of government revenue and 2.4% of employment (Zeiti, 2020).

On 18th March, 2020, Zambia recorded the first case of COVID-19 following the outbreak of the disease in Wuhan City, China in December 2019. COVID-19 was declared a Public Health Emergency of International Concern (PHEIC) by World Health Organisation (WHO) on the 30th of January, 2020. From March to August, 2020, Zambia went into a partial lock down which resulted in disruption of normal service delivery across various sectors of the economy. The government imposed several restrictions, including: a ban on non-essential foreign travel, suspension of tourist visas, mandatory quarantine for travellers from high-risk countries, closure of learning institutions, wearing of masks, suspension of some cross-border transportation services, closure of non-essential businesses such as bars, gyms, hotels, restaurants and cinemas (Osakwe, 2021). While these measures were necessary to contain the spread of the virus and prevent a health crisis, they had macroeconomic costs in the short and long term. Although no large scale copper mine was shut down during the partial lockdown period, they were still affected in one way or the other due to the adoption of new working arrangements aimed at reducing the spread of COVID-19. All the large scale mines were allowed to operate at full capacity whilst following the COVID-19 guidelines given by the Ministry of Health. Since then, the mines have continued their operations in an environment that has presented a lot of practical challenges such as implementing global restrictions that encourage social distancing, maintaining minimum staff, disruption of inventories and supply chain, drop in production output and loss of export markets, Flsmid (2020). This paper discusses how COVID -19 has impacted the mining operations, service delivery and supply chain in the large scale copper mining sector.

1.1 Social Distance

Social distancing is one of the most effective ways of COVID-19 prevention, WHO (2020). The Public Health Act Cap 295 of the Laws of Zambia and specifically statutory instruments (SI) 21, 22, and 62 of 2020 give legal framework on enforcement of public health measures when relating to COVID-19. In order to prevent the spread of COVID-19, the mines had to implement social distancing guidelines at the workplaces. The mines reduced the number of employees present physically at the mine sites by placing non-production essential workers on "working from home schedules". Tools and devices required for employees to work from homes such as laptops and Internet facilities for some employees had to be purchased while some non-essential workers were sent on forced leave. Since then, COVID-19 work rotations have been implemented in order to reduce the number of people physically present on the mines. This .has reduced the risk of work stoppage as a result of workers contracting Covid-19. In the event that workers contracts COVID-19, they were quickly quarantined for 14 days and the personnel working offsite was able to take over the work thereby preventing any stoppage and impact on production. This practice was done at all large scale mines especially in the support departments (finance, technical, and administration). However, employee absenteeism, increased administrative bottlenecks and reduced logistical services still remained major challenges caused by the pandemic (ZEITI, 2O20).

1.2 Disruption in mine operations and output

The COVID-19 pandemic has brought some operational disruptions in some large- scale mines. In April, 2020, Mopani copper mines Plc placed the mine under care and maintenance due to the escalation of COVID-19 cases. However, this was short-lived as the care and maintenance was rejected by the Zambian Government. Mopani copper mines plc was forced to rescind its decision. By 30th June 2020, about 64% of the copper mining companies reported a decrease above 10% in the level of their production (ZEITI, 2O20). Despite the unfavourable environment caused by the COVID-19, Zambia recorded a historical copper production of 882,061 tonnes in 2020, up by 10.8% from 796,430 tonnes produced in 2019 (Chamber of Mines, 2020). Since 2011, Zambia has shown a steady increase in production as shown in Figure 1.

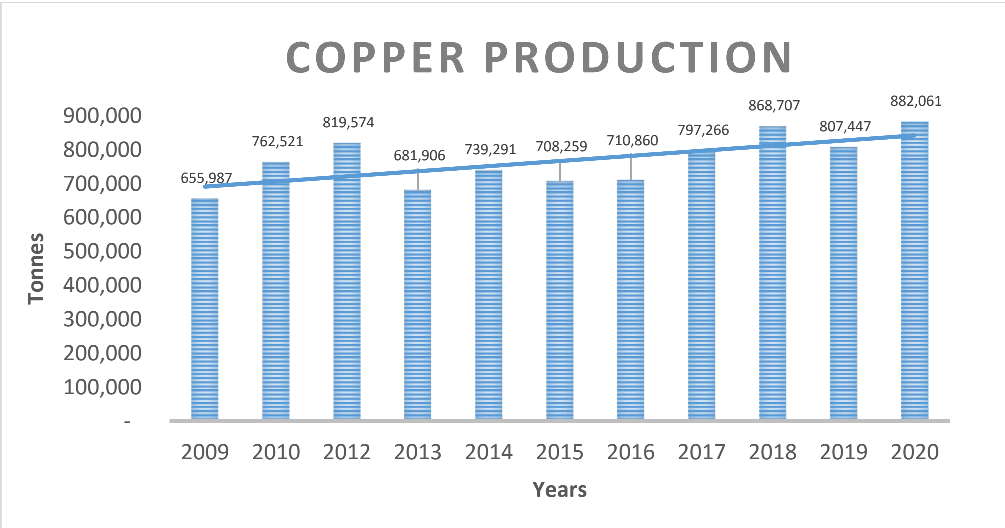

Fig. 1: Copper production trend (Chamber of Mines, 2020)

1.3 Trade and supply chain disruption

About 97.8 %of copper produced in Zambia is exported to other countries such as Switzerland and China(AFRODAD, 2016). As the pandemic started spreading worldwide, some nations started closing their boarders. All over the world, the COVID-19 pandemic has disrupted the political, economic, financial and social structures, Laing (2020). This has caused global economic recession. The lockdowns, social distancing and quarantine measures imposed to curb the spread of the virus in Zambia resulted in partial and, in some cases, full closure of factories and local supply chain disruptions, Osakwe (2021). The countries buying copper and other minerals like China, the United States of America, South Africa and many Europeans countries restricted imports due to slow down in industrial activities and commerce. The world shipping and air transportation almost came to a halt. Since, then global trade has not fully recovered. Additionally, travel restrictions have greatly affected the trading of minerals. The global restriction on movement has caused havoc on the mining supply chain, and hindered the export and sale of copper and other minerals, Chamber of Mines (2020). The COVID-19 has also caused supply chain uncertainties, due to shipping and road delays on import and export. Delays at the major shipping ports (Dar-es-salaam and South African) and travel restriction have impacted the supply chain. Mining like any other business manage low inventory in order to reduce costs. Very often, the level of inventory costs incurred in the enterprise are determined by the impact of external factors (prices of external logistics services including warehousing, transportation, services, interest rates on loans to finance inventories, Paweł etal (2014). In the wake of the COVID-19, this has made the effect of supply chain disruption even great. This has resulted in mines moving from having one single traditional supplier to engaging several suppliers (both local and International). Due to uncertainties in global supply, Zambian mines have been forced to increase their inventories especially on critical spares and chemicals. Though mines have worked towards improving the supply chain, the delays due to travel restrictions on boarders are still affecting delivery of essential goods and services. However, supply disruption due to COVID-19 have also caused a positive effect on the price of base metals (copper from US $6.077 in October 2019 to US$10,183 in March, 2022).

1.4 Uncertainties of financing

The relatively low copper prices following the onset of COVID-19, depreciation of the domestic currency, and the weakening of the macroeconomic environment as stated above resulted in most firms being reluctant to take new loans for investments. As a result there was a decline in growth of credit to the private sector from 8.3 percent in the second half of 2019 to 2 percent in the first half of 2020, BOZ (2020).

As COVID-19 continues to impact the Zambia’s economy, the mine financing sector has not been spared. The current high copper prices have cushioned the mines in production phase but not in the exploration and prospecting companies, Chamber of Mines (2020). The financing challenges in the prospecting and exploration sectors will likely cause a reduction in companies participating in exploration more especially by junior exploration companies due to difficulties in obtaining finance. This may lead, in future, to less discoveries of deposits. The prolonged lockdown imposed due to novel COVID-19 has substantially affected the micro and small-scale industries as well, which account for 30 percent of the GDP, Farhan Ahmed etal (2021). Banks and other sources of funds are mostly sceptical to fund a gemstone mine during this period as when the demand is likely to improve is unknown. In terms of overall mine financing in Zambia, COVID-19 has increased the financing requirement for mines due to the additional costs related to prevention measures. Mines had to spend unplanned resources in mitigating and safeguarding employees’ against COVID-19.

2.0 Materials and methods

The study reviewed secondary data from the Zambian large scale mines, Government agencies, journals and internet. Additionally, the study administered a questionnaire and used purposive sampling techniques to select 60 respondents from all the large scale mines. Slovins formula/calculator was used to derive the sample size. The calculation used a confidence level of 90% and margin of error of 5 % as shown below:

$$n = \frac{N}{1 + Ne^2} = \frac{70}{1 + 70(0.05)^2} = 60$$

Where: ***N*** = required population sampling and ***e*** = margin of error

3.0 Results and discussion

3.1Measures put in place to respond to COVID-19 challenges by the mines

Zambian mines like any other industry implemented the SI 90 and other safety measures to try to minimize and avert the spread of the COVID-19. This was done with the help of the district medical officers where mines are domiciled and the Mines Safety Department under the Ministry of Mines and Minerals Development. Most mines formed COVID-19 response units which came up with strategies of how to reduce the spread of COVID-19 and how production would continue if the worst case scenario happened (i.e., if the country had to go into a complete lockdown). The plans from the response units were submitted to the Ministry of Mines and Mineral Development. Additionally, the mines came up with accommodation space for production essential workers which could be used in case of a complete lockdown. Besides this, the mines reduced the sitting capacities in mines buses from the normal sitting capacity of 65 people to 30 people in order to comply with SI 90 and a one meter (1m) spacing. The buses had to be fumigated every trip and handwashing was made mandatory before boarding the buses. Washing of hands facilities were installed at all office blocks and point of entries to the mine site. The cage capacity was also reduced from 65 to 16 people and Mine captains were tasked to control crowding at the shaft cage. The wearing of masks on mines sites was made mandatory and disciplinary procedures for non-compliance to COVID-19 guidelines were implemented. The "No Mask, No Entry" campaign was rolled out on most of the mines. The number of people sharing offices was reduced and the "working from home" rotations were rolled out. The common rotations being one week on site and one week off site. Basic hygiene campaigns were rolled out by the Public Health Departments in the mines and COVID-19 community education outreach campaigns were also rolled out. Mines donated essential chemicals (disinfectants and hand sanitisers) and tools (fumigators and infra-red thermometers) to be used in the fight against the COVID-19 to government departments responsible for the fight against COVID -19 in the host communities. For example, Barrick Gold donated US $ 530,000 towards the fight against COVID-19 (Barrick, 2020) while FQM created a new ICU and a High Dependency Care Unity in Solwezi general hospital (FQM, 2020). Other large-scale mines also made substantial donations.

3.2 Questionnaire survey: Gender, education level and Job category of respondents

Tables 1, 2, 3 show gender, education level and job category of the respondents respectively. As can be seen from Table 1, 30% of respondents were females while 70 % were males. In terms of education level (Table 2), 37 respondents representing 61.7 % had university education while 4 respondents had secondary education.

Table 1: Gender distribution

Gender					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Female	18	30.0	30.0	30.0
	Male	42	70.0	70.0	100.0
	Total	60	100.0	100.0	

Table 2: Education levels attained by participants

Educational Level (years)					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Secondary	4	6.7	6.7	6.7
	College	19	31.7	31.7	38.3
	University	37	61.7	61.7	100.0
	Total	60	100.0	100.0	

Table 3: Employment category of participants

Employment Category					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Mining Engineer	10	16.7	16.7	16.7
	Mechanical Engineer	5	8.3	8.3	25.0
	Mechanical Engineer	9	15.0	15.0	40.0
	Electrical Engineer	3	5.0	5.0	45.0
	Mining Technician	4	6.7	6.7	51.7
	Clerical	6	10.0	10.0	61.7
	Human Resource	13	21.7	21.7	83.3
	Manager	10	16.7	16.7	100.0
	Total	60	100.0	100.0	

3.4 Responses on the challenges of COVID-19

Table 4 shows level of compliance to social distancing among the respondents. As can be seen from Table 4, all the respondents indicated that they were complying with social distancing guidelines. Figure 2 shows the number of respondents who were either retained at the mine sites or sent on forced leave. Twenty (20) respondents indicated that they were sent on forced leave while 40 respondents were not.

Table 4: Compliance to social distancing

Social Distancing					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	No	60	100.0	100.0	100.0

Table 5 and 6 show the impact of COVID-19 on the local supply of goods and services and the performance of local currency respectively. One (1) respondent representing 1.7% indicated that the impact of COVID-19 on the local supply of goods and services was good while 29 respondents representing 48.3% indicated that the impact of COVID-19 on the local supply was bad. Nineteen (19) respondents indicated that it was worse. Concerning, the performance of the local currency, fifty two (52) of the respondents representing 86.7% indicated that COVID-19 had led to the depreciation of the local currency while Six (6) respondents representing 10% indicated that COVID-19 had no impact on the depreciation of the local currency.

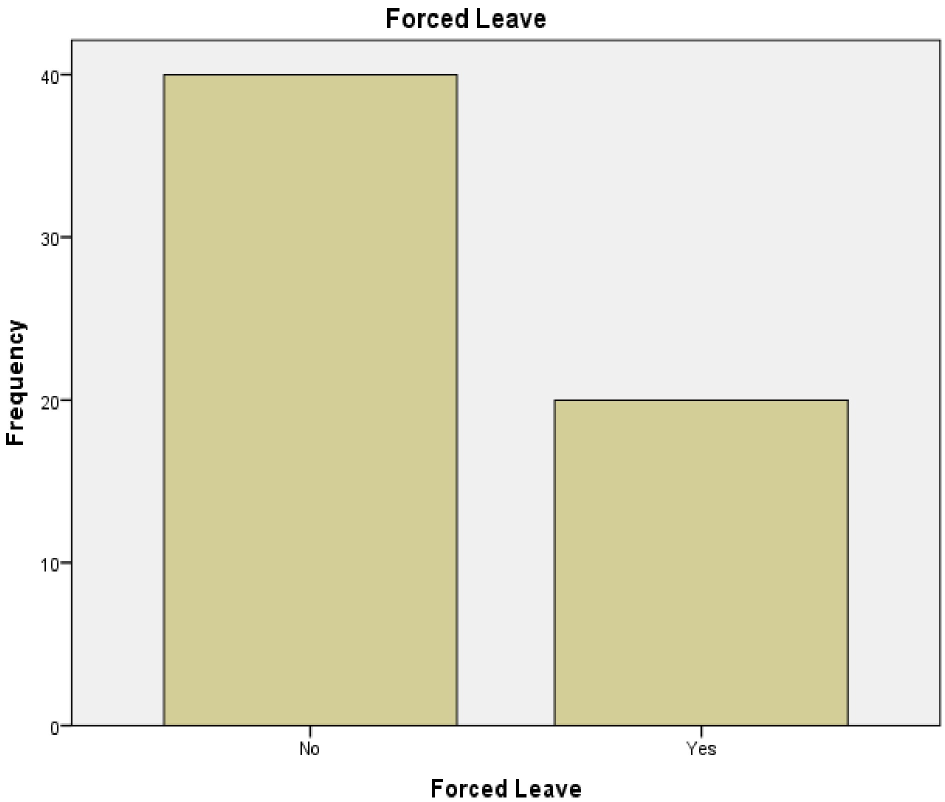

Fig.2: Number of respondents who were sent on forced leave

Table 5: Impact of COVID-19 on the local supply of goods and services

Effect on local supply					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid		9	15.0	15.0	15.0
	Good	1	1.7	1.7	16.7
	Bad	29	48.3	48.3	65.0
	Worse	19	31.7	31.7	96.7
	No effect	2	3.3	3.3	100.0
	Total	60	100.0	100.0	

Table 6 Impact of COVID-19 on the performance of the Zambian Kwacha

Effect on local Currency.					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	b	1	1.7	1.7	1.7
	None	6	10.0	10.0	11.7
	Depreciation	52	86.7	86.7	98.3
	Appreciation	1	1.7	1.7	100.0
	Total	60	100.0	100.0	

4. Conclusion

The outbreak of COVID-19 in Zambia has affected many sectors of the economy. Even though large scale copper mines were not allowed to shut down during the lockdown, the mines were still affected in that they were compelled to adopt new working procedures and arrangements aimed at reducing the spread of COVID-19.

In terms of production performance, the large-scale mines have relatively dealt well with the impact of COVID-19 due to effective response. The effects of social distancing have led to mines operating with minimal staff. As a result, all large scale-copper mines have remained operational and productive during the pandemic, despite having less people on site. However, business continuity has come at a cost due to additional costs associated with disruptions in the supply chain, implementation of new procedures, protocols and processes aimed at preventing the spread of COVID-19.

The restrictions imposed in the country and beyond led to disruption in both local and international supply chains which effectively made it difficult to procure parts and other intermediate inputs needed for production

Despite the restrictions imposed on the mines, the annual copper production for 2020 showed significant increase to 882,061 tonnes, up 10.8% from 796,430 tonnes produced in 2019.The increase in copper production despite COVID-19 and less people on the mining sites can be attributed to effective implementation of "work from home policy" and increase in production by Sentinel and Kansashi mines who produced a combined record breaking of 486,190 tonnes.

6. Recommendations

There is a need to continue expanding the health preventive measures, streamlining the supply chain and adopting more digital solutions in order to sustain mining operations and protect the workforce during and post COVID-19.

7. Limitation of study

This study covers the time when COVID-19 restrictions in Zambia started in 2020. This study did not cover the impact of macroeconomic variables (inflation, economic growth, balance of payment and unemployment) on the mining industry, thus providing sufficient scope for further research.

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Remote sensing applications in agriculture

Kachizya Mwale[1]

Abstract

Different objects based on their structural, chemical and physical properties reflect or emit different amounts of energy in different wavelength ranges of the Electromagnetic (E.M) spectrum. Different Remote Sensing (RS) techniques are applied in the assessing and evaluation of land cover in the context of agricultural activities of people. Some of the areas of application including; area estimation and monitoring, crop yield forecasting, crop nutrient deficiency detection, soil mapping, crop condition assessment, agricultural draught assessment. Multi spectral (MS) satellite images can be downloaded from European Space Agency's (ESA) Copernicus Open Access Hub part of the *Sentinel* program which is freely available were used in this case study. In optical remote sensing evaluation and analysis of high resolution Multi spectral (MS) images are hindered by atmospheric interferences, particularly distribution of cloud cover. Zambia is located in the subtropical region, for this reason cloud cover has a critical role in the regions around the tropics.

Keywords: Remote Sensing, Agriculture, Monitoring, Evaluation, Zambia

1. Introduction

Digital agriculture or precision agriculture (PA), concepts that are often used interchangeably, present the use of large data sources in conjunction with advanced crop and environmental analytical tools to help farmers adopt the right management practices at the right rates, times and places, with the goal of achieving both economic and environmental targets. In recent years, there has been growing interest in PA globally as a promising step towards meeting an unprecedented demand to produce more food and energy of higher qualities in a more sustainable manner by optimizing externalities. Remote sensing (RS) is one of the PA technologies that allows growers to collect, visualize, and evaluate crop and soil health conditions at various stages of production in a convenient and cost-effective manner. It can serve as an early indicator to detect potential problems, and provide opportunities to address these problems in a timely fashion. In Zambia in particular with an economy that needs substantial diversification, the agricultural sector has always been a viable alternative, and with digital agriculture, the profitability and efficient management of the sector could be increased significantly.

2. Study Area

The study area chosen due to the presence of large crop fields. It is located in the central part of the Republic of Zambia, which is the Lusaka province situated approximately 15.3657° S and 29.2321° E, which is located within the summer-rainfall belt of southern tropical Africa. Most of Zambia consists of flat plateau ranging from about 1,000 m to 1,500 m. At this altitude climate is mild with average winter temperatures of approximately 12°C and summer temperatures of around 30°C (Wolski, 1998). The rainfall decreases from north to south demarked by the 1,000 mm isohyet which corresponds approximately to the boundary separating the four northern

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provinces and the five southern provinces, with crops like cassava cultivated in the high rainfall regions and crops like maize cultivated in the medium to low rainfall regions of the country. Lusaka province is situated in the medium to low rainfall regions hence the crop mostly cultivated is maize. About 25% of Zambia's total land area is used for agriculture (Metternicht, 2006). Lusaka province on average has an area of about 21,900 km² and the total area of crops planted in 2014 was approximately (~82,600 hectares) which constituted 4.35% of the total area cultivated in Zambia (Allen, 2017).

3. Constraints on Agricultural Production

While most of the setbacks to agricultural production in Zambia are a result of market failures and the lack of public goods provision, the technical setbacks when addressed can be resolved by applying RS techniques in the monitoring of agricultural land use. Techniques and applications such as:

1. *Precision farming*: Information and technology-based agricultural management system to improve crop production efficiency by adjusting farming inputs to specific conditions within each area of a field.

2. *Meteorological monitoring*: Rainfall is of crucial importance for all life in Zambia not only because it is a resource for human and livestock but also because it is the major limiting factor to plant growth. Between 80 to 90% of agriculture in Zambia is rain-fed and as a result, rainfall determines the food supply for both human and livestock populations. Rainfall measurements have traditionally come from a network of rain gauges which in the past years have dwindled in number. Geo-stationary satellites such as the METEOSAT provide data at a resolution sufficient for monitoring of rainfall events at a much wider scale (iGETT-Remote Sensing, 2016).

Can be applied in addition other techniques aimed at improving the agricultural productivity.

4. Related Studies in Zambia Agriculture

Elements of groundwater study: A methodology is presented to comprehend with the geological formation of the Western part of Zambia, where large parts of the land surrounding the flood plains is cultivated for rice farming, the essence of which is the maximization of application of RS images in the process of groundwater modelling. Not only the initial set of data is derived on the basis of images interpretation, but the output of the model is also related to a different set of images. In this way, the conceptual assumptions of the model are verified or subjected to alteration. This iterative process (conducted with models at different scales) leads to derivation of zones of similar hydrogeological response (hydrotopes) which are based on both modelling output and RS images interpretation. These zones are finally the expressions of spatial distribution of parameters influencing the hydrogeology of the area (Kumar, 2015).

UN-Zambia-ESA Regional Workshop: Precision Agriculture (PA) carried out over certain target areas across Zambia. This workshop, carried out in a joint partnership with the United Nations (UN) and ESA divided the target areas into management zones with techniques: continuous sensors to map crop yielding and intensive soil mapping were carried out. Figure 1 is an image representing this mapping exercise. Variable rate technology, traditional land surveys (in order to ensure precision), wireless sensors networks and GIS were technologies used in enabling the delivery of this workshop (National Soil Maps).

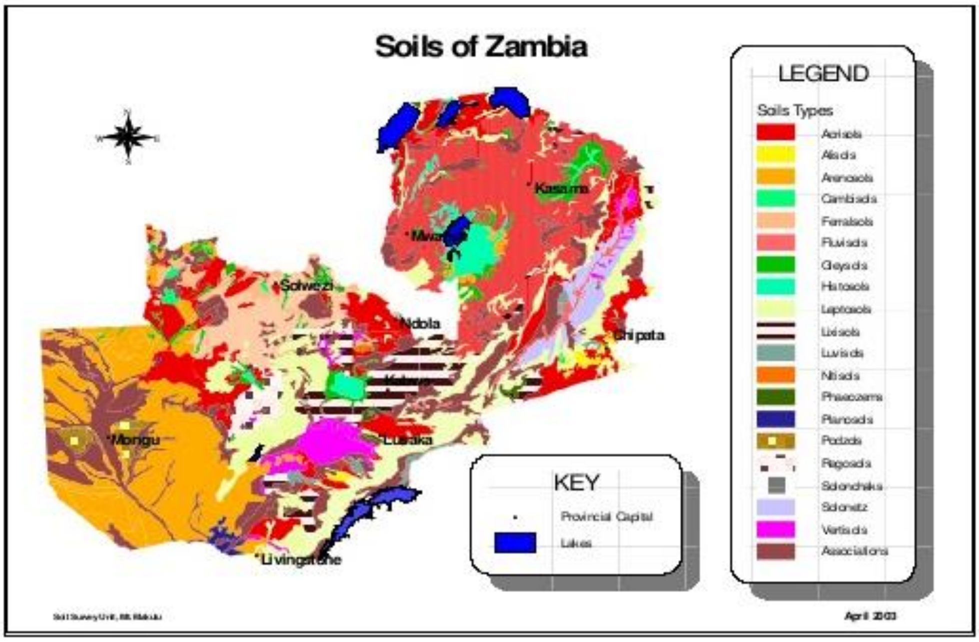

Figure 1 Soil Map of Zambia.

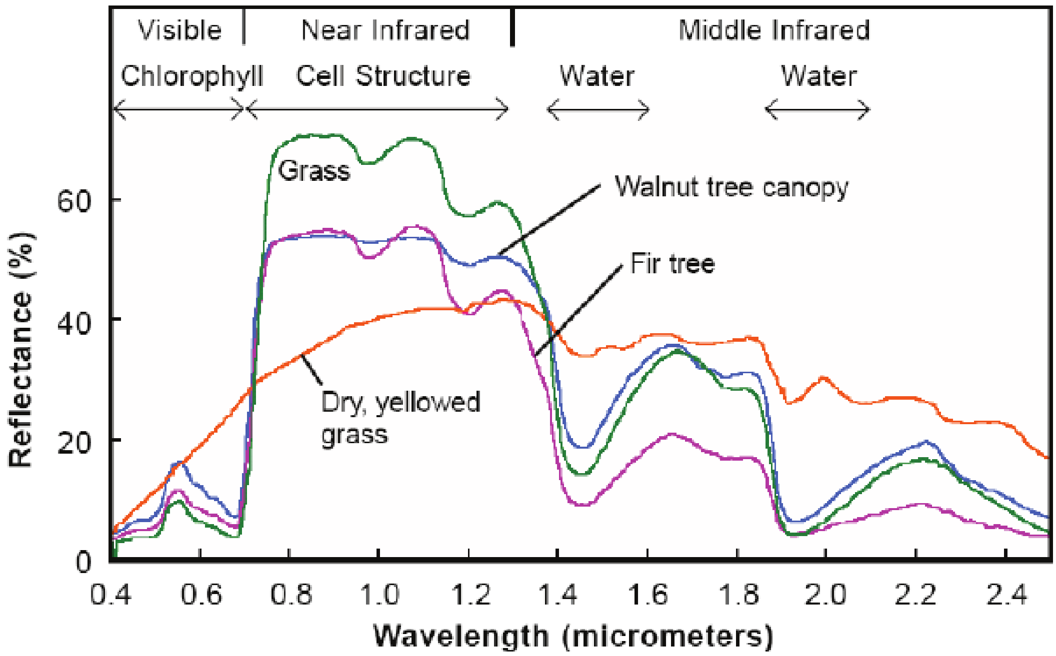

Figure 2. NDVI Reflectance spectra of different types of green vegetation compared to a spectral signature for senescent leaves (Source: Smith, 2001a)

After the launch of the first Sentinel-2A sensor in 2015, Figure 3, continuity of land cover monitoring has been established with a global coverage every 10 days. This was enhanced to 5 days and even 2-3 days in mid-latitudes after the launch of Sentinel-2B in 2017.

Figure 3: Sentinel-2A (10m) (Source: ESA 2016)

In this study, the Sentinel-2A satellite provided data with high spatial resolution (10m x 10m) and the NDVI was calculated from the S2-band 4 (665nm) located in the RED and S2-band 8 (842nm) located in the NIR of the spectral domain.

5. Conclusion

The increasing importance of the role that remote sensing plays in the improvement of agricultural production efficiency and the monitoring of crop has been clearly demonstrated. The growing realization of the effectiveness of RS in agriculture has in turn increased the amount of research and analysis of how to further improve the methods and techniques used in RS applications in the field. For example, for most crops large production increases (between 45 and 70%) are possible of improving the yield gap to 100% of possible attainable yields (Ray,

2010). . Investments in key agricultural growth drivers that can benefit all people, especially the underfunded farmers. Investments such as agricultural research and development, with focus on Remote Sensing and how it can improve the management and crop yield quantities with low cost and efficient techniques and improve economic recovery in a changing world.

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Production of gypsum by reacting rock lime with sulphuric acid

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Abstract

The objective of this project was to conduct a laboratory scale tests to produce gypsum by reacting calcium carbonate with sulphuric acid using agitation as well as heap leach methods at Mopani Copper Mines (MCM) Plc. Gypsum is a critical ingredient in the cement manufacturing process to control setting rates of cement. In Zambia, after depletion of the naturally occurring mineral, gypsum was traditionally supplied by Chambishi Metals Plc but the closure of the company resulted in a critical shortage, forcing the cement producers to import gypsum at a high cost. This shortage of cheaper locally produced gypsum provides Mopani Copper Mines an opportunity to produce and supply gypsum from its locally produced acid. In addition, the price of acid is demand driven, therefore, Mopani could benefit from the sale of gypsum during the times when there is low demand of acid. The test work to produce gypsum therefore involved optimization of the critical process parameters and extrapolation of findings to plant scale. Process parameters such as temperature, pH, particle size, residence time, slurry density and initial acid concentration were optimized and a process flowsheet was developed. The optimum results were as follows: pH range 4.5-5.5 and a residence time of 10 minutes by using concentrated sulphuric acid and rock lime of 86% calcium carbonate purity. The optimum rock lime particle size range was found to be 60-75% passing 75um, at 15% solids for agitation method and -18mm for heap leach method. Heap leach is the cheapest method in the production of gypsum however, the high acid consumption and costs for a dilution plant outweighs the milling and agitation costs involved in the agitation process.

Keywords: Gypsum production, sulphuric acid, heap leach, parameter optimization.

1.0Introduction

Gypsum also known as selenite occurs naturally as a hydrated calcium sulphate and is commonly associated with halite, anhydrite, Sulphur, calcite and dolomite (Ghrefat & Hawari, 2010), however it can also be synthesized as a by-product of other processes. In addition, gypsum can also be produced by reacting rock lime ($CaCO_3$) with sulphuric acid (H_2SO_4) in a Continuous Stirred-Tank Reactor (CSTR) at industrial level. The chemical reaction equation between sulphuric acid and the rock lime suggests a feasible exothermic reaction (Yangok, 2017). The chemical reaction is presented in equation 1.

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$$CaCO_{3\,(s)} + H_2SO_{4(l)} + H_2O_{(l)} \longrightarrow CaSO_4.2H_2O_{(s)} + CO_{2\,(g)} \quad (1)$$
(ΔH = -21,874.6 kcal/kmol)
(ΔG = -27,310.1 kcal/kmol)

In Zambia, after exhausting the naturally occurring gypsum, gypsum was then traditionally supplied by Chambishi Metals Plc. The closure of Chambishi Metals Plc resulted in a critical shortage of gypsum, thereby forcing the cement producers to import at a higher cost. This shortage of cheaper locally produced gypsum provides MCM an opportunity to produce and supply gypsum from its locally produced acid. In addition, the price of acid is demand driven, therefore, MCM could benefit from the sale of gypsum during the times when there is low demand for acid. It would also promote the market for limestone at Ndola Lime Company thereby increasing the company's revenue base.

There has been an increase in the number of cement companies in Zambia which include Dangote, Lafarge, Sinoma and Zambezi Portland which have facilitated a ready market for the gypsum. For example, Lafarge Cement Plc consumes about 40,000 tons/year of gypsum at a grade of 85% and 15% moisture for the production of cement. Dangote Cement Plc, on the other hand, has an average annual consumption of 20,000 tons. Zambia's imports of Gypsum, Anhydrite, Plasters (Consisting of Calcined Gypsum or Calcium Sulphate) from South Africa was worth about US$160,080 in the year 2020 according to the United Nations COMTRADE database on international trade.

Gypsum has a wide range of applications globally. It is widely used in construction, agricultural industries (Ghrefat & Hawari, 2010) and the mining industry. It can also be used as a bone void filler in surgery (Lazary & Varga, 2010). Gypsum is mainly used in the cement industries as an additive that retards the setting of cement. China and USA are the main producers of gypsum globally and about 61% is directed to the production of cement (Rowland, 2017). The future of the gypsum global market forecasts to increase from $2.2 billion in 2018 to $3.4 billion by 2028. The annual growth rate from 2018 to 2023 is anticipated at 4.0% and likely to increase to 8.2% for 2023-2028 period (Fowler, et al., 2020).

Gypsum can be produced by the stoichiometric ratio reaction of calcium hydroxide and sulphuric acid (Rossete, et al., 2006). Maree and Du Plessis (1993) proposed the use of 2 back mix reactors in the neutralization of sulphuric acid with either calcium carbonate or calcium hydroxide in the production of gypsum. It was suggested that the neutralization can also be done in stationary limestone beds which can be operated by either vertical or horizontal fluid flow. The use of limestone as a raw material in the production of gypsum is the most economical because it is cheap and readily available. The rate of reaction is affected by the concentration of calcium carbonate in the limestone and its particle size (Maree & Du Plessis, 1993).

The objective of this project was to conduct laboratory scale tests to produce gypsum by reacting calcium carbonate with sulphuric acid using agitation as well as heap leach methods at MCM. This project involved optimization of the critical process parameters such as:

- Temperature
- pH
- Rock lime

- Particle size
- Residence time
- Slurry density
- Initial acid concentration.

2.0 Methodology

2.1 Materials

Lime rock sample, concentrated sulphuric acid and water

2.2 Sample preparation

Lime rock from MCM smelter stock pile was crushed using a Boyd crusher (18mm product size) and the product's particle size was further reduced using a Pulverizer. The sample was then screened on 250,150, 125 and 75microns sieve size to determine the particle size distribution. 26.67mm and 18.85mm screens were included for the heap leach sample.

2.3 Experimental procedure

The experimental set-up consisted of the following:

- 250mL Erlenmeyer flask as the reaction vessel
- Water bath for temperature control
- Agitator for stirring
- Hanna pH probe for pH measurement
- Thermometer for temperature measurement
- A Boyd crusher for particle size reduction of the lime rock
- A Pulverizer and Splitter
- 75microns sieve for screening
- Beakers and Measuring Cylinders
- A fabricated heap leach reaction vessel.

2.3 Sequential steps

- A 200g pulverized sample of lime rock (75% passing 75 microns) was mixed with water to form slurry in a flask.
- The flask was then placed in an agitated water bath followed by the addition of sulphuric acid.
- The effects of temperature, pH and residence time were investigated.
- These experiments were repeated 5 times for each set of conditions.

The experiments that involved heap leach setup were done similarly. Gypsum formed was filtered using a vacuum filter then dried and mass recorded.

The experiments were conducted at different pH values ranging from pH3.0 -7.0 by varying the volume of sulphuric acid addition, whilst maintaining all other parameters constant.

Another set of experiments were conducted at 20%, 30%, 40%, and 50% solid concentration.

Similarly, experiments were conducted at different residence time, particle size distribution and initial acid concentration. The lime rock samples of different particle size were soaked in sulphuric acid at different residence times.

The %yield was calculated based on laboratory assays using equation 2. Assays were analysed using Atomic Spectrometry (AS) for %Ca and %S; CaSO_4 was calculated using a factor.

$$\%Yield = \frac{Actual\ mass\ of\ gypcum\ formed\ after\ the\ reaction}{Stoichiometric\ mass\ of\ gypsum} \times 100 \qquad (2)$$

Elemental analysis was also performed on the lime rock sample that was used for the experiments using the Atomic Spectrometry, XRF and bulk mineralogy using the Scanning electron microscope to determine the impurities and initial %CaCO_3 in the sample. The % calcium carbonate in the rock lime on average was 86% and the other impurities included SiO_2, Fe, Cu, Al_2O_3, MgO, S and CaO.

3.0 Results and Discussion

The effects of various parameters on the yield and purity of gypsum produced from the reaction of lime rock with sulphuric acid are discussed in the sections that follow.

3.1 Effect of pH

There was no specific correlation between the pH and the %yield overall. However, it was observed that for pH values of above 5, the %yield was above 90% as shown in Fig 1. At lower pH values, the % yield decreased which implied that there was excess acid which resulted in the formation of other products from reaction of impurities. A pH of 5 indicated a complete neutralization of the rock lime sample which initially was on average at the pH above 8.

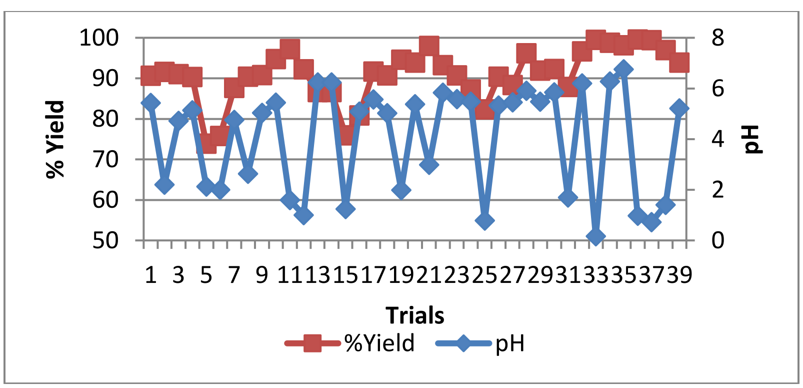

Fig. 1: Overall pH variations with % yield

The control experiment for the stoichiometric reaction of pure calcium carbonate was also conducted and it was found that at a pH value of 6.5, the neutralization was complete.

It was found that at a pH value of below 6, the % yield was above 90% for all reaction conditions. However, there was a decrease in %yield at lower pH values due to the formation of other products due to excess acid. In this study, the optimum pH range was found to range between 4.5 and 5.5 which does not significantly deviate from what Yangok (2017) who had proposed as pH of 4.0-5.5. This is however not in agreement with (Bard, 2006) who proposed a much wider range of pH 2.0-7.0.

3.2 Effect of slurry density

The product gypsum is formed by precipitation, implying that there is an increase in solid weight for the product. The higher the acid concentration, the finer the particles formed. The white gypsum crystals form a paste as the reaction is proceeding which prevent effective agitation as indicated by Fig 3. The relationship between slurry density and % yield is shown in Fig 2. Lower % solids facilitate effective agitation which promotes maximum acid utilization, resulting in higher yields.

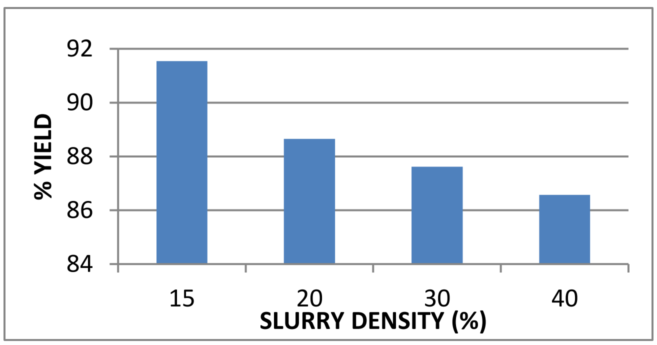

Fig. 2: Effect of slurry density

Fig. 3: Agitation of samples

15% Slurry density was found to be the optimum for agitation test due to effective agitation, resulting in maximum acid utilization as opposed to higher %solids which yields low grade gypsum due to poor agitation. However, the optimum slurry density is a compromise between reactor capacity and %yields. A very low slurry density implies that a very large reactor volume would be required to treat the target tonnage which consequently increases the capital cost. On the other hand, lower slurry densities facilitate effective agitation which promotes maximum acid utilization, resulting in higher yields. This is in agreement with Bard, (2006), who proposed that the concentration of the solids should be less than 30% due to decrease in the fluidity of the slurry. Decrease in fluidity may also increase equipment down time due to pump, agitator and pipeline failure, thus adding to maintenance costs. Lower % solids also reduces power consumption on the agitator and the pump as well as improving pH control by facilitating proper instrument utilization.

3.3 Effect of residence time

Residence time is the amount of time the reactants spend in the reactor, which implies that, the higher the residence time, the higher the conversion of reactants into products, consequently resulting into higher %

yield. The % yield was directly proportional to the residence time as indicated in Fig 4. At 10 minutes residence time and above, the %yield was above 90%, this is in agreement with Yangok, (2017) who proposed 10 minutes residence time for gypsum production. The maximum yield recorded was 98% at 30 minutes residence time. However, optimum residence time is a compromise between the production rate and the % yield.

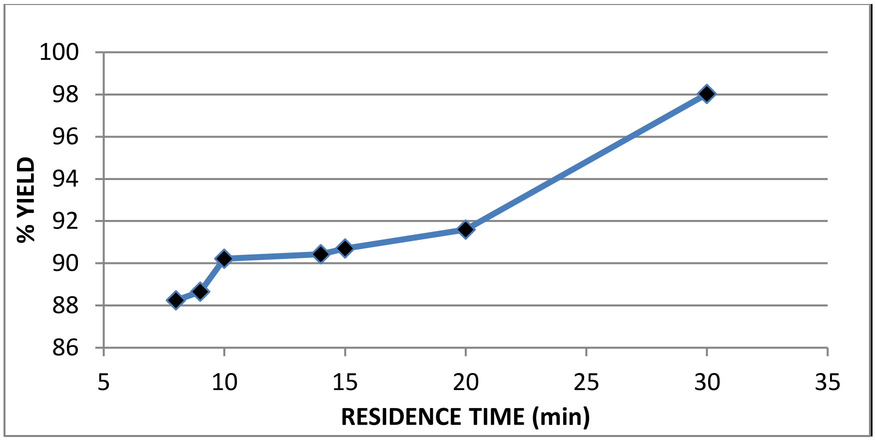

Fig. 4: Effect of residence time on %yield

For this study 10 minutes residence time at 90% yield was the optimum for production of gypsum in order to maximize production and equipment utilization.

3.4 Acid concentration

There were no significant effects of the initial % acid concentration on % yield as indicated in Fig 5. This was because % yields at the same residence time for 30%, 50% and 99% acid concentration all ranged between 90-92% (same range % yield for all 3 tests conducted at each initial acid concentration except for 70% which could be an outlier).

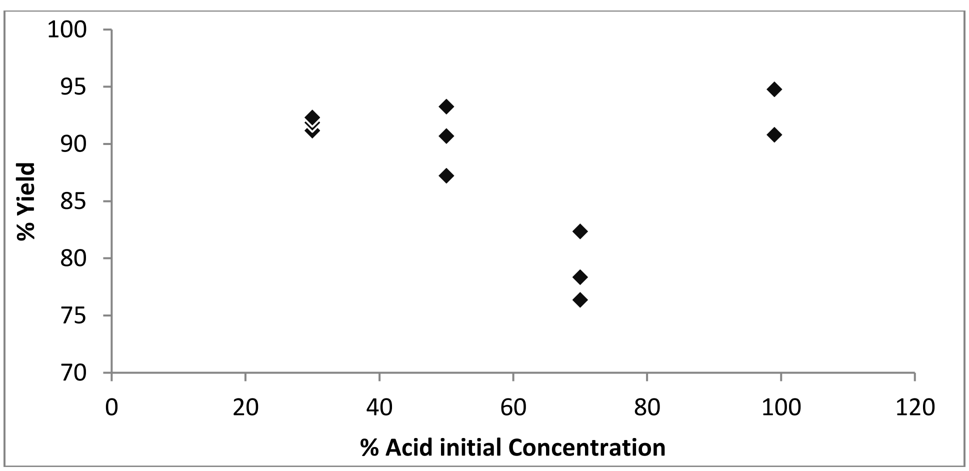

Fig. 5: Effect of initial acid concentration on %yield

3.5 Acid consumption

Acid consumption is lower for diluted acid than the concentrated acid because there is no significant difference in volume of acid used for 50%, 70% and 99% as shown in Fig 6. The volume of acid for 50% concentration is expected to double the amount used for 99% concentration for the same pH.

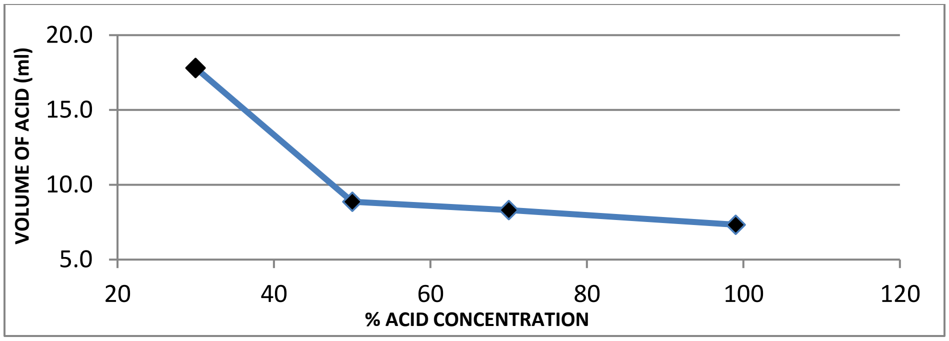

Fig. 6: Effect of acid consumption

The initial acid concentration had no effects on the %yield and the acid consumption for diluted acid was low. The reaction was less vigorous for the diluted acid than for the concentrated which could improve personnel safety and decrease the wear rate for the equipment. This agrees with (Yangok, 2017) who suggested that 50% sulphuric acid be used for the reaction. However, Mopani smelter produces concentrated acid and acid dilution is an exothermic reaction. This will require special equipment for dilution which adds to the capital cost for the operation and adds to personnel's safety vulnerability. Diluted acid on the other hand is a better option for the heap leach due to high acid consumption for the process. The milling and agitation costs are outweighed by the high acid consumption for the heap leach and the extra costs for the acid dilution plant.

The precipitation reaction for the production of gypsum follows the shrinking core model. The calcium sulphate coats the unreacted calcium carbonate particle which prevents further reaction as shown in Fig 7. This implies that particle size plays a major role for the reaction kinetics and for this study 60% passing 75microns for agitation test works was used but for plant scale production, coarser particle size should be used to minimize the milling costs. For heap leach, a particle size passing 18mm sieve for different acid volumes had higher % yield (50%) than the +18mm particle size with % yield of 8.6%. The optimum particle size for the agitation test works is in agreement with what Maree & Du Plesis (1993) and Yangok, (2017) who proposed (60-70% passing 200 mesh).

Fig. 7: Calcium sulphate coating the unreacted calcium carbonate particle

3.6 Proposed flowsheet

The production of gypsum requires crushing and milling in order to achieve the optimum particle size**.** A continuous stirred tank reactor (CSTR) is required for the reaction on plant scale and thereafter liquid solid separation which could be achieved by filtration since the product densities are high enough to skip thickeners. There may be need to provide a drier after filtration depending on customer requirement.

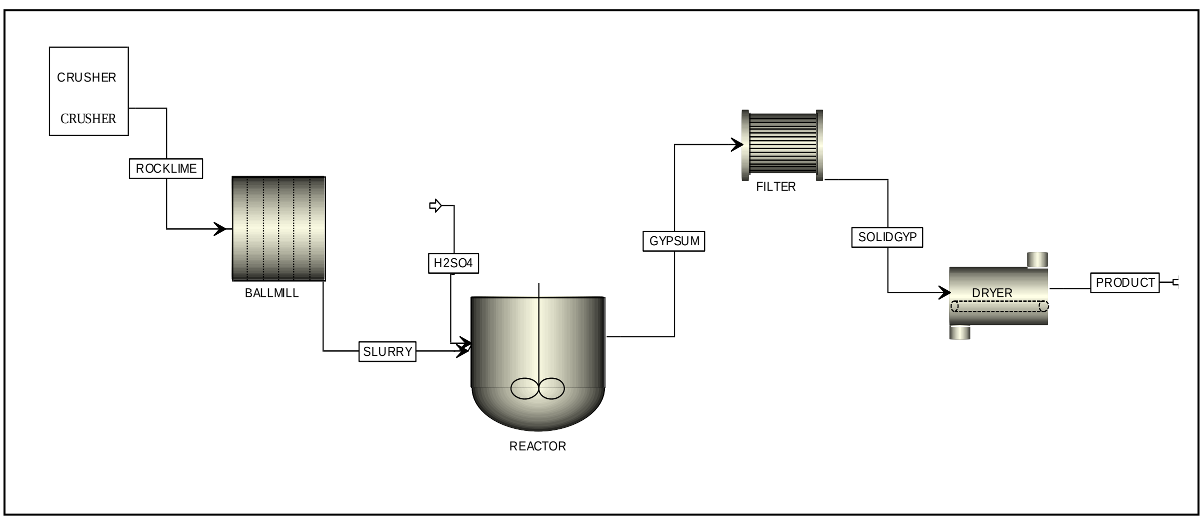

Fig. 8: Proposed process flowsheet for the production of gypsum

4.0 Conclusion and Recommendation

From the successful laboratory test work results, there is an opportunity for Mopani to produce gypsum at a large scale using agitation method at a pH 4.5-5.5, 15% solids, 10 minutes residence time and concentrated sulphuric acid.

The following recommendations are made:

a. A cost benefit analysis is required to determine the viability of the project.
b. Further work should be done on the acid concentrations (40%, 60%, 70% and 90%) to investigate the effects of initial acid concentration on the % yields.
c. Further work to be done on the viability of the heap leach method in terms of particle size, irrigation rates, acid consumption, and suitability of equipment for dilution.
d. Comparison of operating at 15% solids gypsum operating higher densities, which will require high power motor agitation equipment.

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Design of cost-effective house-hold water treatment system (HWTS): A case study of Makululu Settlement

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Abstract:

In this study, two Household Water Treatment Systems (HWTS) were designed using locally available materials which included a filtration chamber consisting of mainly a bucket, fine sand, course sand and activated charcoal. Filter media thicknesses were adjusted between the two treatment systems and their effectiveness to treat water to a portable state assessed. Parameters assessed included turbidity, total dissolved solids, pH, fecal coliforms, and total coliforms. The designed systems improved the water quality of the tested samples. The turbidity levels of the water samples before filtration ranged from 2.2 to 5.6. The average turbidity obtained after filtration ranged from 0.3 to 0.5 NTU for system one and 1.6 to 2.3 NTU for system two. Total Dissolved solids (TDS) ranged from 394 to 424 mg/L before filtration. The average TDS obtained after filtration ranged from 223 to 234 mg/L for system one and 240 to 256 mg/L for system two. The pH levels of raw water samples before filtration ranged from 7.3 to 7.7. The average pH obtained after filtration ranged from 6.8 to 6.9 for system one and 7.1 to 6.91 for system two. System one removed 99.1% to 100% of bacterial coliforms while system two removed 94.2% to 96.4% of these bacteria. The outcome of this investigation demonstrated that water filter system 1 with a fine sand bed of 150mm can be an effective and sustainable HWTS for Makululu Settlement, as it removed the total and faecal coliform concentration from tested water samples, it can be manufactured using locally available materials, and is easy to operate and to maintain. Alternatively, water filter system 2 can be utilized as a pre-treatment filter for the other HWTS.

Keywords: Filtration, Coliforms, informal settlement and turbidity.

1.0 Introduction

Over the past decades, an increase in water demand has been observed worldwide due to many factors that include population growth, agricultural activities, industrialization, hydropower generation and environmental water requirements. Poor water, sanitation and hygiene are the main causes of infections like cholera and diarrhea, and inadequate water, sanitation and hygiene services continue to be the leading cause of death of children under the age of five in sub-Saharan Africa (Gleick, 1996). In an attempt to improve household water quality, the House-hold Water Treatment System (HWTS) is one of the techniques being applied and is one of the fundamental and most mainstream water treatment alternatives, because of its viability, straightforwardness of activity, simplicity of development, and potential for utilizing neighborhood materials. HWTS's are systems that treat water in batches and deliver water to a tap, such as a kitchen or bathroom sink or an auxiliary faucet mounted next to a tap. These systems are composed of a number of treatment stages such as sedimentation, filtration and safe storage. The study was conducted in Makululu Compound, Kabwe Town which is situated in the Central Province of Zambia. It lies

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along the Great North Road, about 139 kilometers north east of Lusaka. Geographically, the area is situated near the Lukanga swamp hence it's flood prone.

Makululu Settlement contains four wards specifically; Makululu, Chililalila, Zambezi, and Moomba. Makululu has an assessed housing unit of 6,641. The 2010 statistics puts the number of inhabitants in Makululu ward at 3,328, Chililalila ward (5,489), Zambezi ward (8,230) and Moomba (11,038), giving the settlement an all-out populace of 28,585. (CSO, 2011). Makululu has limited water treatment facilities and poor sanitation services. The current sanitation services in Makululu contains a total number of 6111 pit latrines and 36 VIP toilets. On the other hand, Makululu has the following water sources: - 75 community Boreholes, 43 protected wells, 610 unprotected wells, 20 stand taps and 25 Kiosk (Makululu Health Centre Records, 2021). Due to lack of access to safe drinking water and sanitation provision, Makululu Settlement is prone to water borne diseases which include cholera, diarrhea and dysentery (Phiri, 2016). The settlement is perpetually prone to urban flooding caused by several factors. First, it is an informal settlement and receives limited support from the government in terms of provision of safe water and sanitation services, waste collection, and unblocking of drainage channels all culminating into flooding nearly every year (Gilbert and Gugler, 1992). The effects of this flooding include water related hazards of cholera, typhoid and diarrhea disease outbreaks and destruction of housing and other infrastructure. Hence, the main purpose of this research was to design two types of water filters that are easy to operate, affordable to low-cost households like the ones in Makululu Settlement, and capable of producing drinking water that complies with the *Zambia Bureau of Standards (ZS:276) Drinking Water Quality-Specification* (ZABS, 1994). In this study, indicator coliform bacteria (faecal coliforms and Total coliforms), which are used to detect the faecal contamination levels in drinking water, were considered as microbial pollutants. The two HWTS were evaluated for efficiency in removing target bacterial pathogens and turbidity were compared to determine the most efficient filter that could remove the target bacteria in contaminated water.

2.0 Literature Review.

A bucket filter and a Ceramic candle filter are one of the devices that are currently being used in various developing countries around the world as cost-effective systems for treating microbially contaminated water sources in order to produce drinking water of an acceptable quality for domestic purposes (Sobsey *et al.,* 2008). The Bucket Filter device was constructed from two 25 L buckets stacked on top of each other. A 20 mm hole was drilled 5 cm from the base of the bottom bucket, into which a tap was fixed for the collection of filtered water. The filter media, consisting of a 20 cm layer of fine sand (0.3 mm) and a 5 cm layer of gravel (5 mm), were packed into the top bucket. The filtering process in the BF takes place as follows: Contaminated water is poured into the upper bucket, passes through the filter media (fine sand), and the treated water accumulates in the lower bucket through the perforations in the base of the top bucket. Filtration occurs through the thick layer of fine sand while the gravel prevents the fine sand from getting into the collection vessel through the perforations (CAWST, 2008), While a ceramic candle filter (a hollow, dome-shaped cylinder, 10 cm high with a diameter of 10 cm) was obtained from Headstream Water Holdings (South Africa). It was wedged between two 25 L buckets by screwing the candle to the bottom of the upper bucket through the lid of the lower bucket, and a spigot was inserted 5 cm from the base of the lower bucket. The candle filter element was covered with a thick cloth to reduce the turbidity of the contaminated water and to trap debris (leaves and insects). Contaminated water is poured into the upper bucket and is filtered through the microspores (0.2 microns) of the dome-shaped candle filter. The filtered water accumulates in the lower bucket, where it is temporarily stored until use. (Boison *et al.,* 2010). Therefore HWTS is one of the viable solution for treating water in Makululu Settlement.

3.0 Materials & Methods.

3.1 Materials

The following materials were used to come up with the water filtration systems.

- The filter chamber (1.5L) was loaded with the consisted of the following:
  - ✓ Fine sand (0.2-1.2mm) responsible for catching particles such as dirt, grit and made the water look clean
  - ✓ Coarse sand (2-4mm) responsible for trapping large particles and prevents the fine sand from getting into the collection vessel through the perforations.
  - ✓ Activated Charcoal (5-8mm) responsible for removing bad smells, bacteria, pollutants and allergens from water. (Note: Activated Charcoal was bought from the Local market Chemist) which were loaded in a 1.5L containers.
- A 10L collection bucket for clean water
- 20L container which contained contaminated water
- CPVC glue which was used to unite individual components like PVC pipes ½”
- PVC Elbows ½”
- 2 PVC Couplings ½”, and a Reducer
- 1 hand held Geographical Position System (GPS) used to collect coordinate points

3.2 Method.

A total of twelve by 500mls sterile sampling water bottles from laboratory were used to collect water samples from the four wards of Makululu settlement. One sample was collected from the water taps supplied by Lukanga water and Sewerage Company from each of the four wards. In addition 2 samples were taken from the hand dug well in all the four wards. Water samples were collected aseptically with sterile sampling bottles. These bottles were sterilized using wash solution with distilled water by a lab technician, in order to prevent contamination and infection from the external environment. The samples were transported within 3 hours of collection in a cool box containing ice packs to Lukanga Water and Sewerage Company laboratory in Kabwe for analysis. The parameters to be analyzed included; Total coliform (cfu/100ml), and faecal coliform (cfu/100ml), pH, Total Dissolved Solids (mg/l), and Turbidity (NTU). After the examination, feacal pollution of water was determined through separation of indicator organisms, total coliforms, and afterward faecal coliforms, through Multiple-Tube Fermentation (MTF) technique Probability tables (McCrady tables) were utilized to decide the Most Probable Number (MPN) estimates of the coliform organisms per 100 ml of water. Analysis of data was generally descriptive, including assurance of frequencies. Further, Distances between pit latrines and wells was measured using the Geographical Position System (GPS) device to ascertain the proximity between pit latrines to the closest hand dug well. The coordinate points were also picked from each house in order to geographically locate the houses for collecting water samples for the second and third time.

4.0 Description of Water filters.

The components of the water filters included a 20L plastic vessel filled with contaminated water, a 1.5L container filtration chamber packed with filter media with a pipe that allows the filter to maintain a 2.5 cm layer of water above the sand surface to prevent it from drying out. The dimensions of the water filtration chamber comprise a height of 225 mm and a width of 120 mm. The filtration chamber was packed with 25mm gravel, 25 mm coarse sand, 25 mm activated charcoal, and a fine sand media layer of 150 mm high. A 10L collection bucket is connected to the filtration chamber above it. The first modification made to the design in this study was the use of a 20 L plastic container (height 36 cm and width 28 cm) and a 1.5L filtration chamber. The size of the filter was scaled down to ensure that the filter would not take up too much space in a small rural home like the ones found in the Makululu compound. The difference between the two designs was in the height of the layer of fine sand and the height of the layer of activated charcoal. The first design has a layer height of fine sand of 150mm and 25 mm activated charcoal and the second design has a layer of 125 mm of fine sand and 5 cm of activated charcoal.

5.0 Results and Discussion

A total of 5 parameters: pH, turbidity, total dissolved solids (TDS), Faecal and total coliforms were used for this study. The selection of these parameters to predict bacteria contamination was based on several factors; prior knowledge of the explanatory variables relationships with coliform bacteria and previous findings in literature concerning factors that influence microbiological organisms as well as based on their data availability and significance. Total coliforms and faecal coliforms were the focus variables of this study (Aram, 2021).

However, total dissolved solids (TDS), Potential hydrogen (PH), Turbidity, Faecal coliforms and total coliforms had been determined using twelve different samples from different sources in Moomba, Makululu, Chililalila and Zambezi ward. The aim of this study was to reduce the determined TDS, pH, Turbidity, Faecal coliforms and total coliforms in twelve water samples collected in these four wards using the new designed HWTS. The samples collected in Moomba Ward were namely Tap1 which was the sample from tap water supplied by Lukanga water and it acted as our control, Furthermore samples from Well 1 and Well 2 (well 1, Well 2 and Well 3 in Makululu, Chililalila and Zambezi wards). Firstly, before the HWTS was used all the twelve samples were taken to Lukanga Water and Sewerage Company laboratory and later Mulungushi University Natural Sciences laboratory (NS) after filtration for testing. Based on the two institutions laboratory results, the tap water sample had the Turbidity of 0.21 NTU, 7.6 PH, TDS of 238mg/l and 0 total coliforms whilst well 1 had Turbidity 5.6 NTU, 7.3 PH, TDS of 424 mg/l and total coliforms of 250 cfu/100mls and Well 2 had 7.2 PH, Turbidity of 2.2 NTU, TDS of 94 mg/l and total coliforms of 52 cfu/100mls. (Refer to table 5.1 below). Based on this data that had been collected, showed that sample well 1 and Well 2 contained higher amount of total coliforms 250 cfu/100mls for well 1 and 52 cfu/100mls well 2 and also the Turbidity for well 1 was 5.6 NTU which is above the standard and had a bad scent proving that the sources of this may have come from pit latrine since they were located few meters from the shallow wells and they were not protected (refer to table 5.1 through table 5.4). The high number of total coliforms in both wells and high turbidity impacted the health of the wells and clarity of the water decreased and made water less aesthetically pleasing and unsafe for use. Secondly, the twelve samples collected from all the four wards were subjected to two filtration system 1 and system 2 (refer to table 5.1 through table 5.4). Based on the data collected (table 5.2) showed that the Turbidity, Faecal coliforms and total coliforms tremendously reduced from the total coliforms of 250cfu/100mls to 0 cfu/100mls, 5.6 turbidity to 0.3NTU in Well 1 and 2.2 turbidity to 0.8 NTU, total coliforms of 52 to 0 in well 2 using system 1. Based on the results collected in table 5.3 for Chililalila, the Turbidity reduced from 5.6 to 0.4 NTU, 250 to 11 cfu/100mls for total coliforms in Well 1 and 2.2 to 1.4 NTU turbidity, 52 to 12cfu/100mls total coliforms in Well 2 (refer to table 5.3 and 5.1) using system 2. In contrast, the data results collected in Makululu ward showed the drastic reduction in the determined values of all the five parameters. In system 1, the Turbidity reduced from 4.5 to 0.7 NTU of 7.8 to 6.6NTU, from 364 mg/l TDS to 242mg/l, 250cfu/100mls total coliforms to 0 cfu/100mls and faecal coliforms to 0cfu/100mls in Well 1 whilst in system 2 total coliforms, Faecal coliforms and Turbidity reduced to 4 cfu/100mls, 9 cfu/100mls and 1.3NTU respectively (table 5.4).

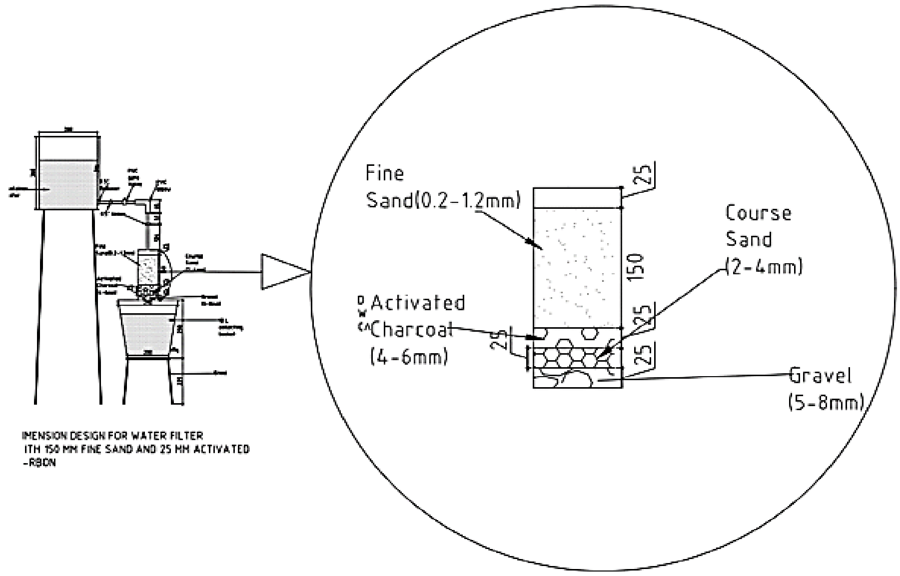

Figure 1: Water filter with 150mm sand

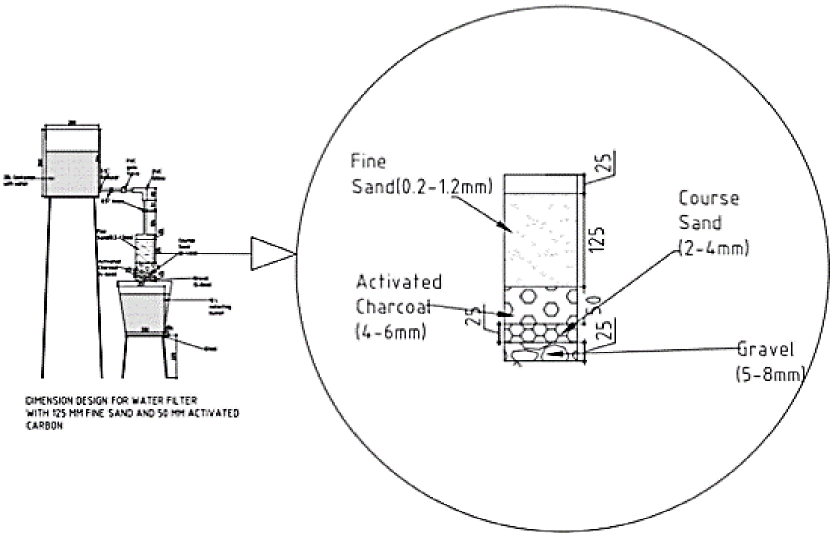

Figure 2: Water filter with 125mm sand bed

Table 5-1: Water Quality Analysis for Moomba Ward

Parameter	Water Quality Testing before filtration			Water Quality Testing after filtration with 150mm thick fine sand device.			Water Quality Testing after filtration with 125mm thick fine sand device.			ZABS Guidelines
	MOOMBA WARD FEBRUARY 2021			MOOMBA WARD MAY, 2021			MOOMBA WARD JUNE, 2021			
	SAMPLES FROM									
Physical parameters	**Tap 1**	**Well 1**	**Well 2**	**Tap 1**	**Well 1**	**Well 2**	**Tap 1**	**Well 1**	**Well 2**	
PH	7.64	7.37	7.72	7.64	6.87	6.9	7.64	7.4	7.8	6.5-8.0
Turbidity (NTU)	0.21	5.64	2.2	0.21	0.3	0.8	0.21	0.8	1.4	5
Total Dissolved Solids (mg/l)	238	424	394	238	223	234	238	240	256	1000
Bacteriological Results										
Total Coliforms (cfu/100mls)	0	>250	52	0	0	0	0	11	12	0
Feacal Coliforms (cfu/100mls)	0	>250	35	0	0	0	0	9	17	0
Distance between pit latrine and well points (Meters)	N/A	13	14	N/A	13	14	N/A	13	14	50

Table 5-2: Water Quality Analysis for Makululu

Parameter	Water Quality Testing before filtration			Water Quality Testing after filtration with 150mm thick fine sand device.			Water Quality Testing after filtration with 125mm thick fine sand device.			ZABS Guidelines
	MAKULULU WARD FEBRUARY, 2021			MAKULULU WARD MAY, 2021			MAKULULU WARD JUNE, 2021			
	SAMPLES FROM									
Physical parameters	**Well 1**	**Well 2**	**Well 3**	**Well 1**	**Well 2**	**Well 3**	**Well 1**	**Well 2**	**Well 3**	
PH	6.78	7.18	7.6	6.6	6.5	7	6.6	6.8	7.3	6.5-8.0
Turbidity (NTU)	8.45	4.5	2.87	0.7	0.23	0.41	1.3	2.5	0.87	5
Total Dissolved Solids (mg/l)	364	498	287	242	232	243	255	265	262	1000
Bacteriological Results										
Total Coliforms (cfu/100mls)	>250	>250	>250	0	0	0	4	6	7	0
Feacal Coliforms (cfu/100mls)	9	>251	21	0	0	0	5	11	2	0

Distance between pit latrine and well points (Meters)	12	18	14	12	18	14	12	18	14	50

Table 5-3: Water Quality Analysis for Chililalila

Parameter	Water Quality Testing before filtration			Water Quality Testing after filtration with 150mm thick fine sand device.			Water Quality Testing after filtration with 125mm thick fine sand device.			ZABS Guidelines
	CHILILALILA WARD MARCH, 2021			CHILILALILA WARD MAY, 2021			CHILILALILA WARD JUNE, 2021			
	SAMPLES FROM									
Physical parameters	**Well 1**	**Well 2**	**Well 3**	**Well 1**	**Well 2**	**Well 3**	**Well 1**	**Well 2**	**Well 3**	
PH	7.9	7.6	7.3	7.4	7.5	6.8	7.49	7.08	7.12	6.5-8.0
Turbidity (NTU)	12	5.33	8.23	0.21	0.3	0.39	0.12	0.23	0.41	5
Total Dissolved Solids (mg/l)	331	250	485	224	231	213	234	247	231	1000
Bacteriological Results										
Total Coliforms (cfu/100mls)	>250	>250	>250	0	0	0	3	7	5	0
Feacal Coliforms (cfu/100mls)	19	>253	35	0	0	0	4	5	3	0
Distance between pit latrine and well points (Meters)	15	14	17	15	14	17	15	14	17	50

Table 5-4: Water Quality Analysis for Zambezi

Parameter	Water Quality Testing before filtration			Water Quality Testing after filtration with 150mm thick fine sand device.			Water Quality Testing after filtration with 125mm thick fine sand device.			ZABS Guidelines
	ZAMBEZI WARD MARCH 2021			ZAMBEZI WARD MAY, 2021			ZAMBEZI WARD JUNE, 2021			
	SAMPLES FROM									
Physical parameters	**Well 1**	**Well 2**	**Well 3**	**Well 1**	**Well 2**	**Well 3**	**Well 1**	**Well 2**	**Well 3**	
PH	6.45	7.4	7.3	6.6	6.5	7.8	6.45	7.24	7.21	6.5-8.0
Turbidity (NTU)	1.35	8	1.15	0.17	0.29	0.8	1.35	4.5	1.15	5
Total Dissolved Solids (mg/l)	235	271	240	241	228	256	247	269	263	1000
Bacteriological Results										
Total Coliforms (cfu/100mls)	17	>250	>250	0	0	0	12	5	8	0
Feacal Coliforms (cfu/100mls)	20	52	21	0	0	0	2	13	3	0
Distance between pit latrine and well points (Meters)	18	11	22	18	11	22	18	11	22	50

On the other hand, Data collected in Chililalila ward had distinct outcomes. ln system 1, the Turbidity reduced from 12 to 0.21NTU, from >250 cfu/100mls total coliforms to 0 , 19cfu/100mls Faecal coliforms to 0 and pH of 7.49 to 7.2 in Well 1 while in system 2 total coliforms, Faecal coliforms and Turbidity reduced to 3cfu/100mls, 4 cfu/100mls and 0.12 NTU respectively. Also, In Zambezi ward, the results collected showed the reduction of values determined reduced in both systems. In system 1, Turbidity reduced from 1.35 to 0.17 NTU, from 17 cfu/100mls total coliforms to 0cfu/100mls, Faecal coliforms to 0 cfu/100mls and pH of 6.9 to 6.6 in Well 1 while in system 2, total coliforms, Faecal coliforms and Turbidity reduced to 12cfu/100mls, 2cfu/100mls and 1.35NTU respectively. Comparing results from system 1 and system 2. The reduced number of total coliforms, faecal coliforms and Turbidity of sample taken from filtrate of samples from wells of these wards proved the efficiency of the low cost effective HWTS in water purification, however, system 1 performed way much better than system 2 (Refer to table 5.1 through table 5.4) due to the difference in the heights of the fine sand beds; system l had 150 mm fine sand bed with 25mm activated charcoal while system 2 had 125 mm fine sand bed. The study suggests that the thicker the fine sand bed height the better the filtration process hence increasing the height of the sand bed could have completely removed the faecal coliforms present in these samples. Therefore, HWTS is the cost effective viable solution for treating contaminated water in Makululu settlement.

6. Conclusion

The design of two low-cost household water treatment systems were successfully constructed using locally available materials and proved to have removed and reduced the values of the total coliforms, Faecal coliforms, Turbidity, TDS and pH determined. The performance of the water filter system 1 with a fine sand bed of 150 mm was the most efficient, as it produced drinking water that complies with the recommended limits set by the Zambia Bureau of Standards (ZABS) ZS 276 *Drinking Water Quality-Specification* in terms of turbidity and indicator coliform bacteria, regardless of the type of water source. Water filter system two also reduced the values of turbidity and bacteria considerably, but would require additional stages to improve the effectiveness in treating total and fecal coliforms. Alternatively, system 2 can be utilized as a pre-treatment filter for the other HWTS. This performance was due to the difference in the heights of the fine sand bed of 125mm as the study suggested that the thicker the fine sand bed height the better the filtration process. This proved the efficiency of the water filtration HWTS on the water purification process. Therefore, implementation of HWTS is an effective responses to emerging groundwater contamination problems (wells) and suggest broad avenues for future water works in Makululu settlement.

7. Recommendation

- Future researchers should focus on designing a filter component that will eliminate faecal and total coliforms without requiring repeated use of the filters in order to meet recommended standards.

- Future research be conducted on the social acceptability of these devices, as it is crucial that they

  Should not only be efficient and affordable, but also culturally acceptable to ensure that their use

  Is sustainable.

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Impact of Urbanization on surface runoff using remote sensing and GIS technology: A case study of Lusaka District.

Mwale Yobe[1]; Goodson Masheka[2]; Muumbe Lweendo[3]

Abstract

The accurate assessment of the hydrological impact urbanization has on surface runoff is of great importance in resilient urban planning strategies and water resource management. It was from this background that a study was undertaken in Lusaka District of Zambia. The objective of the study was to assess the effects of urbanization on surface runoff using Geographic Information System and Remote sensing as well as SCS CN (Soil Conservation Services Curve Number) model for Lusaka district. This involved classification of land use/land cover maps from Landsat TM/EMT+ imageries for (1984, 1994, 2004, 2013 and 2020) using an integrated approach of remote sensing and Geographical information System (GIS) techniques. Firstly, four (4) land use classes (built-up area, vegetation, water body and barren land) were defined. Supervised classification (maximum likelihood pixel-based classification) technique was used to pick training sites for the 4 land use classes by identifying representative features on the ground using different spectral band combinations. The land use/ land cover maps were produced with an overall accuracy between 93.22 % to 99.19 %. Surface runoff simulation was analyzed using SCS CN model to aid in investigating the variations in surface runoff with the change in land use / land cover for Lusaka district. The SCS CN model takes into account soil type, precipitation data, land use, soil moisture condition, size and shape of watershed. Lusaka district soil map was assessed and classified the soil under hydrological soil group (HSG) C. The weighted curve number for each land use class was calculated using the HSG, CN corresponding to the land use class and area. The study showed a noticeable increase in the percentage of urban areas (built-up area class) from 28.7 % in 1984 to 68.7 % in 2020 respectively. SCS CN model showed an increase in surface runoff correlating to the increase in urban areas having recorded a minimum of 385.02(mm) in 1994 and a maximum of 1082.59(mm) runoff recorded in 2020.

Keywords: Land use / land cover (**LULC**), Soil Conservation Services Curve Number (**SCS-CN**), Geographical Information System (**GIS**), Hydrological Soil Group (**HSG**), Runoff.

1 Introduction

In recent decades, with the steady and accelerated growth of urban population, urbanization has become an important urban environmental and ecological issue, especially in most developing

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countries (Yang et al., 2003). Therefore, accurately mapping LULC changes in urbanized areas and evaluating their impact on surface runoff and river quality is very important for urban planning and land/water management decision makers (Yang et al., 2003). Patil et al (2008) stated that as population density and development continue trending upward, storm water runoff from increased impervious surfaces presents challenges on a local and global scale. Surface runoff estimation is a very important hydrological variable in water resource application. Occurrence and the amount of runoff are dependent on intensity, duration and distribution of rainfall (Tailor et al., 2016). Sindhu et al., (2013) used the SCS CN model to know the variations of surface runoff potential with different LULC and the different soil conditions present.

The objective of the study was to assess the effects of urbanization on surface runoff using Geographic Information System and Remote sensing as well as SCS CN model for Lusaka district

1.1 Background

Lusaka city is located in Lusaka province and is the capital city of Zambia. Its central geographical coordinates are 15° 24′ 24” S and 28° 17′ 13” E as shown in figure 1.

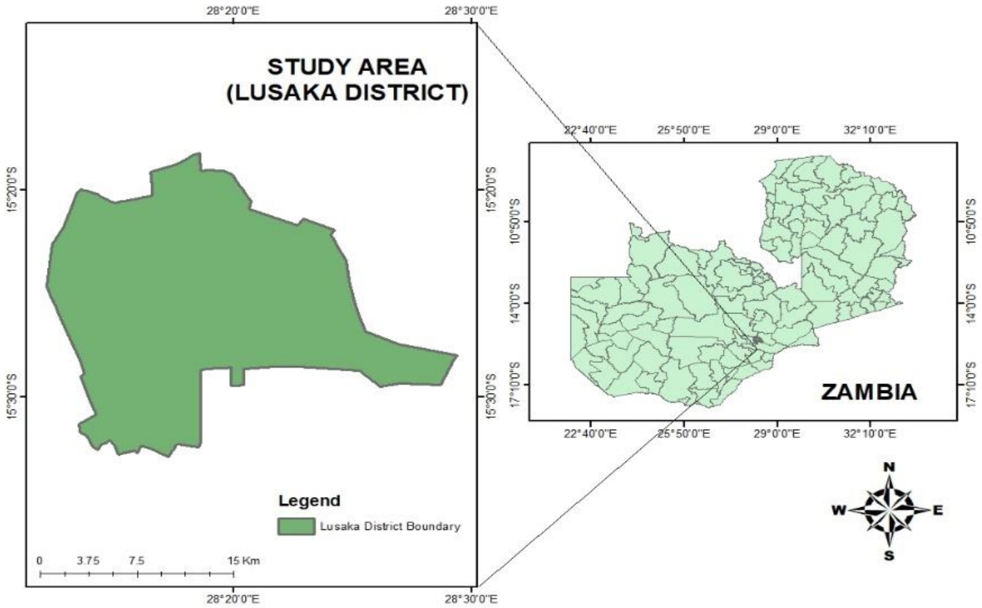

Fig. 1: Study Area (Lusaka District)

The city has an administrative area of approximately 412 km² and is one of the fastest growing cities in southern Africa (Simwanda and Murayama, 2017). Lusaka is the political, cultural and economic center of the country and the home of the central government. Therefore, many institutional, commercial and industrial activities are concentrated in Lusaka. The city has a population of about 2 million 1 and dominates Zambia's urban system. (Simwanda and Murayama, 2017). According to the Central statistical office report (2010), stated that 79% of the urban population resided in Lusaka district and the other is shared among the other districts in Lusaka province.

2 Material and methods

The methodology chosen for this study is shown in the flow chart in Figure 2.

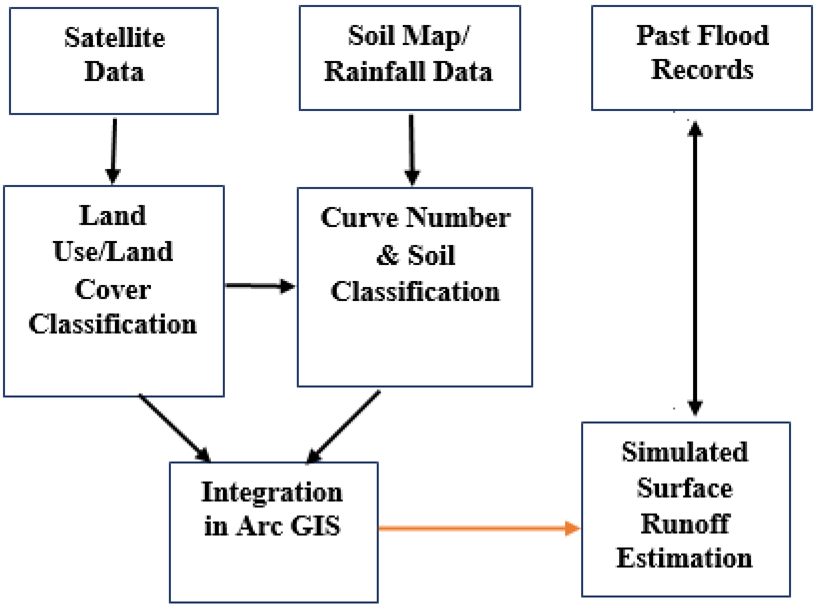

Fig. 2: Methodology flow chart

2.1 Land Use /Land cover Classification (Supervised Classification)

In this study, supervised maximum likelihood pixel-based classification technique to process the various Landsat 5, 7 and 8 imageries were applied and processed using ArcGIS software. A band composite file for each map was compiled for each of the Landsat imagery, a delineated boundary shape file for Lusaka district was used to mask out the study area from the band composite layer. A false colour composite band for each respective Landsat imagery type was applied to the masked study area to aid in identifying each land use type. Training sample sites were selected for each of the four (4) land use classes (built-up area, barren land, vegetation and water body) by identifying representative features on the ground using different spectral band combinations. Ten (10) to thirty (30) training sample sites were picked for each of the land use class to help improve the accuracy of the classification. However, misclassifications were observed among Land use classes due to spectral confusions originated from complex and heterogeneous nature of the study area. However, errors were mitigated by reclassifying the maps and ensuring each maps had error matrix accuracy above 90%, thereby improving on the overall accuracy of each land use classifications as recommended by Simwanda and Murayama, 2017.

2.1.1 Accuracy Assessment

To assess the overall accuracy of the classified map the error matrix accuracy assessment method was used for the study area. 30 to 100 random points were picked for each land use class in during the process. Randomizations of the points selected for each land use class ensured reduced biasness. All random points represented true ground data. Using the google earth time scale, maps for 1984, 1994, 2004, 2013 and 2020 were obtained to accommodate in the selection of ground data. The following were the overall accuracy levels for each of the classified maps; 97.169%, 99.19% ,98.41%, 93.22% and 97.328% in 1984, 1994, 2004, 2013 and 2020 respectively.

2.2 Surface Runoff analysis (SCS CN Model)

The SCS curve number model is an efficient method for determining the approximate amount of rainfall event in a specific area (Handbook of Hydrology., 1972). The SCS curve number method is based on the water balance equation and on 2 hypotheses, (1) Ratio of actual direct runoff to the potential runoff is equal to the ratio of the infiltration to the potential infiltration and (2) the amount of initial abstraction in some fraction of the potential infiltration (Handbook of Hydrology., 1972).

i. $S = (25400/CN) - 254$
ii. $Q = (P - 0.2S)^2 / (P + 0.8S)$ where $P > Ia$ otherwise $Q = 0$
iii. $CN = (\sum (NCi \times Ai)) / A$
iv. $Ia = 0.2\,S$

Where;

CN = Weighted curve Number

CNi = Curve number from 1 to any no. N

Ai = Area with Curve number

A = Total area of water shed

Q = actual direct runoff (mm)

P = Total storm rainfall cumulative (mm)

Ia = Initial abstraction

2.2.1 Soil Classification

Soils are classified into four hydrological classes A, B, C and D based on infiltration, slope and other characteristics.

Hydrological Soil	Type of soil	Runoff Potential	Final Infiltration Rate (mm/hr)	Remarks
Group A	Deep, well-drained sands and gravels	Low	>7.5	High rate of water transmission
Group B	Moderately deep, well-drained with moderately fine to coarse textures	Moderate	3.8-7.5	Moderate rate of water transmission
Group C	Clay loams, shallow sandy loam, soils with moderately fine to fine textures	Moderately high	1.3-3.8	Moderate rate of water transmission
Group D	Clay soils that swell significantly when wet, heavy plastic and soils with a permanent high water table	High	<1.3	Low rate of water transmission

Fig. 3: USDA-SCS Hydrologic Soil Group

From the soil map analyzed, Lusaka district soils are classified as clay to candy clay loam which fell under hydrological soil group C as shown in figure 3.

2.2.2 Antecedent moisture condition AMC

AMC refers to the moisture content present in the soil at the beginning of the rainfall event under consideration. AMC-I soils are dry, AMC -II Average Conditions, AMC – III Sufficient rainfall has occurred within 5 days. The assumption used, AMC -II was chosen to simulate runoff flow on average conditions (Handbook of Hydrology., 1972).

2.2.3 Land cover condition

This describes surface conditions of the watershed. Poor having less than 50% ground cover, fair 50% ground cover and Heavy, for more than 50% ground cover. Fair ground cover conditions were selected for the model analysis.

2.2.4 Rainfall Data

Table 1 below shows the rainfall data for 1984, 1994, 2004, 2013 and 2020 obtained from the Zambia Meteorological Department.

Table 1: Rainfall Data

Time Period	Rainfall Received(mm)
1984	759.99
1994	564.92
2004	848.11
2013	729.5
2020	1147.77

3 Results and Discussion

3.1 Land use / Land cover classification

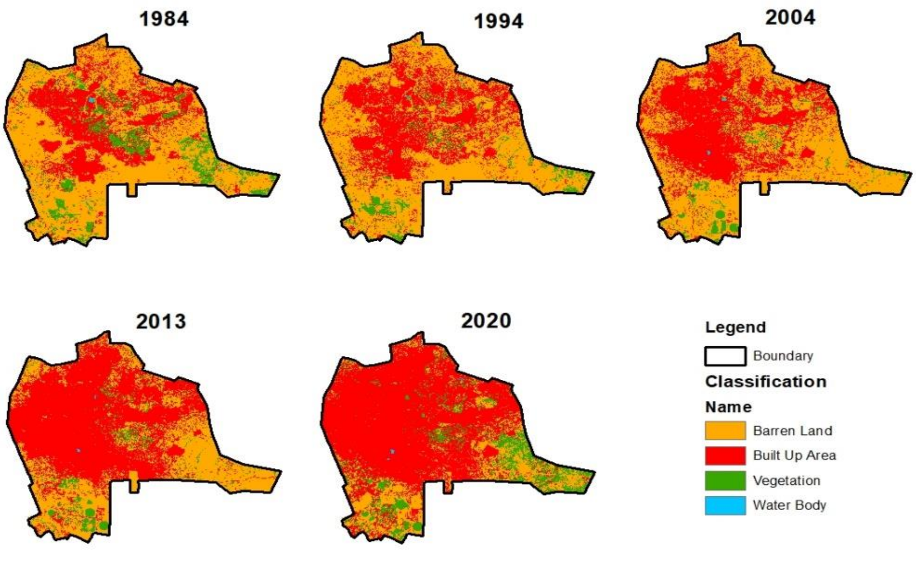

Fig. 4: Land use / Land cover classification (1984, 1994, 2004, 2013 & 2020).

Figure 4 shows the classified maps for 1984, 1994, 2004, 2013 and 2020 which were generated using GIS and Remote sensing techniques.

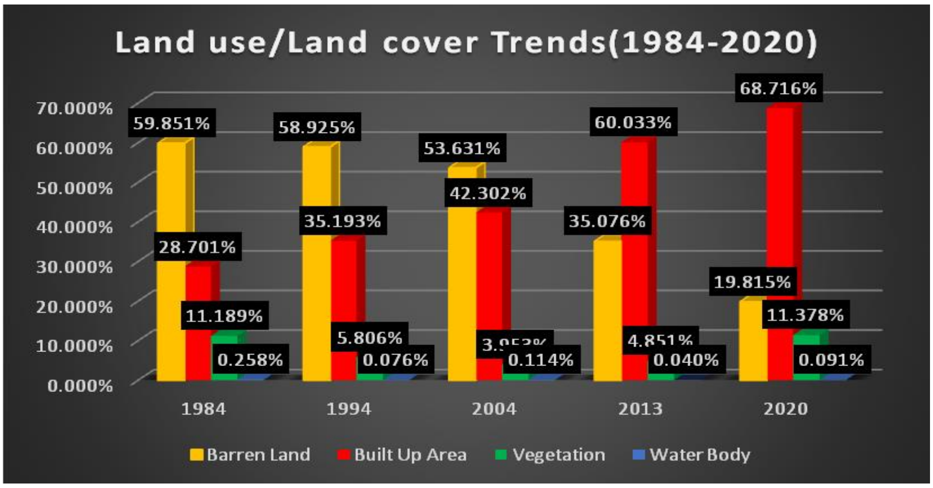

Fig. 4: Land use / Land cover trend analysis (1984, 1994, 2004, 2013 & 2020)

Figure 4 shows the change in the percentage of the four (4) land use classes (built up area, barren land, vegetation and water body) for 1984, 1994, 2013, and 2020. It was concluded that there was a significant increase in the percentage of urban areas (built-up area) from 28.701% to 35.193% to 42.302% to 60.033% to 68.716% in 1984, 1994, 2004, 2013 and 2020 respectively. On the other hand, barren land saw a drastic drop from 59.851% in 1984 to 19.815% in 2020. While vegetation and water body experienced fluctuations over the years.

3.2 Calculations of weighted curve numbers

Table 2 shows the calculation of weighted curve numbers for the four (4) different land use classes (built up area, water body, vegetation and barren land) for 1984, 1994, 2004, 2013 and 2020. This analysis was based on the CN attributed to each land use class which was obtained from the Hydrologic soil cover complexes manual. Additional determining criteria used included AMC-II and fair ground cover conditions.

Table 2: Calculations of weighted curve numbers

No.	**Land use class**	**HSG**	**CN**	**Area (km^2)**	**% Area**	**Area*CN**	**Weighted CN**
				1984			
1	Built Up Area	**C**	94	120.160	28.701	27042.37	**84.742**
2	Water body	**C**	100	1.081	0.258	38.11325	
3	Vegetation	**C**	86	46.845	11.189	4096.507	
4	Barren Land	**C**	80	250.572	59.851	6636.497	
				1994			
1	Built Up Area	**C**	94	147.335	35.193	13849.57	**85.289**
2	Water body	**C**	100	0.319	0.076	31.902	
3	Vegetation	**C**	86	24.305	5.806	2090.265	

No.	Land use class	HSG	CN	Area (km^2)	% Area	Area*CN	Weighted CN
4	Barren Land	**C**	80	246.691	58.925	19735.31	
2004							
1	Built Up Area	**C**	94	177.097	42.302	16647.12	**86.181**
2	Water body	**C**	100	0.478	0.114	47.85	
3	Vegetation	**C**	86	16.55	3.953	1423.302	
4	Barren Land	**C**	80	224.526	53.631	17962.1	
2013							
1	Built Up Area	**C**	94	251.332	60.033	23625.29	**88.704**
2	Water body	**C**	100	0.168	0.04	16.83	
3	Vegetation	**C**	86	20.307	4.851	1746.476	
4	Barren Land	**C**	80	146.85	35.076	11748.06	
2020							
1	Built Up Area	**C**	94	287.684	68.716	27042.37	**90.321**
2	Water body	**C**	100	0.381	0.091	38.113	
3	Vegetation	**C**	86	47.6338	11.378	4096.507	
4	Barren Land	**C**	80	82.956	19.815	6636.497	

Table 3 below shows the simulated runoff (mm) generated from the SCS CN model corresponding to the amount of rainfall (mm) received and the percentage of surface runoff generated. The results generated from the model were graphically represented in figure 5.

Table 3: Annual Rainfall and SCS CN Model Runoff simulation

Year	CN	S(mm)	Ia(mm)	P(mm)	Q(mm)	%Runoff
1984	84.742	45.733	9.146	623.2	571.491	91.703%
1994	85.289	43.811	8.762	433.5	385.023	88.817%
2004	86.181	40.728	8.145	1138.8	1091.343	95.833%
2013	88.704	32.345	6.469	785.6	748.075	95.223%
2020	90.321	27.219	5.443	1114.6	1082.590	97.128%

Figure 5 shows the rainfall recorded and the simulated runoff observed for each respective time period. The peak runoff points recorded from the runoff simulation model were compared to past records of flood events (2005, 2009, 2017 & 2020) in the district which corresponded to the observed results from the SCS CN model.

4 Conclusion

The results obtained from the simulated runoff model (SCS CN Model) showed correlation of increased surface runoff to increased urbanization which also corresponded to observed ground flood data in the district. A minimum of 385.023 mm simulated runoff with a percentage runoff of 88.817% was recorded in 1994 which sequentially increased by 8.3% to 97.128% in 2020 with a runoff record of 1082.590 mm.

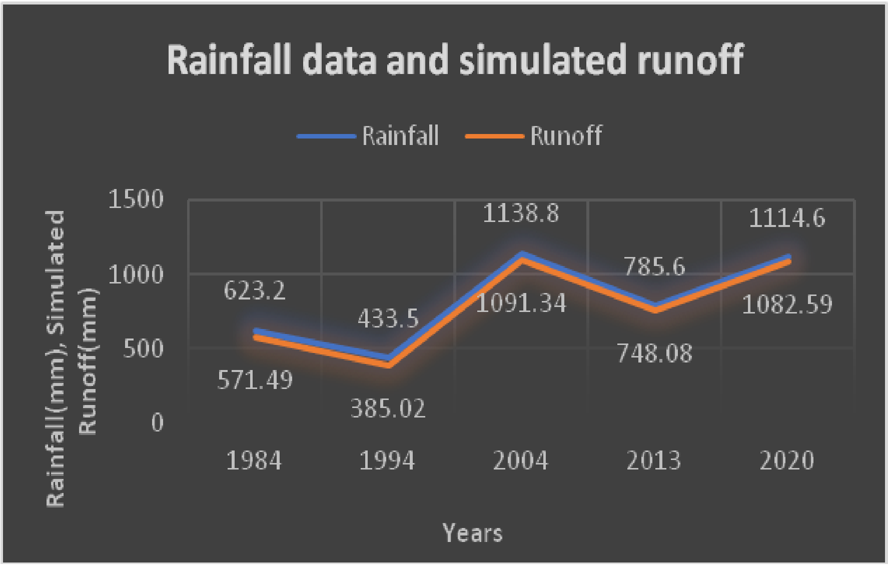

Fig. 5: Rainfall data and simulated runoff

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Estimation of charging points for electric vehicles along Lusaka - Ndola Road

Henry Mulenga[1] and Mwiya Balimu[2]

Abstract

The world is electrifying the road transportation sector hence there is a need for any African country to prepare for the electric car revolution that is happening globally. The will to fight climate change and the promotion of green energy for sustainable development has led big economic powers such as China and the European Union to electrify road transportation. These countries have also called for a complete ban on the sale of fossil fuel vehicles by 2030 and completely phasing them out by 2050. Despite all this, there is minimal preparation and investment in electric vehicle infrastructure Zambia.

The aim of the study was to examine how the introduction of electric vehicles on Zambian roads would impact the Zambian road infrastructure. The methodology used involved the determination of the minimum distance between fast charges (MDFC) on the case study road between Lusaka to Ndola. The minimum distance was then used to establish the necessary charging infrastructure points on the case study area using software packages like google earth.

It was established from this research that a minimum of four (04) strategically located charging stations would have to be installed on the road between Lusaka and Ndola in order to allow smooth travelling with reduced range anxiety for electric vehicles that have a range that is as low as 132 kilometres.

It was therefore concluded that strategically positioned fast chargers would enable the charging time of an electric vehicle to be comparable to the fuelling time in conventional internal combustion vehicles and also for the travelling time of an electric vehicle to be comparable to conventional combustion vehicles. Incentives put in place by governments to encourage the general public to adopt electric vehicles together with the advancements in battery technology and charging infrastructure has resulted in increased electric vehicle adoption globally.

Keywords: Transportation, infrastructure, electric, vehicle, climate

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1. Introduction

1.1 Background

Transport underpins our society. It connects people, cities, countries and economies, fostering societal growth and employment. However, transport also damages the climate, the environment and human health (Vooren, 2014). To reduce these impacts, the world is moving towards a more sustainable circular economy and decarbonized transport system. According to the European Environmental Agency (2014), transportation contributes about 24 percent of global carbon emissions and road transport is the main contributor to carbon dioxide emission because it contributes 71 percent of the carbon emissions (Vooren, 2014). To mitigate climate change and improve air quality in cities worldwide, several countries such as the members of the European Union are reducing carbon emissions by reducing the dependency on fossil fuels and promoting renewable energy sources (European Union, 2020). The significant progress that has been made in electric motors, power electronics, battery technologies and the will to fight climate change has fuelled the electric vehicle revolution. Several countries have therefore called for a complete ban on the sale of new petrol and diesel vehicles such as cars and vans from 2030 and completely phasing them out by the year 2050 (Jagadeesh, 2020). According to the Zambian National Transportation Policy (Ministry of Transport and Communications, 2019), it is estimated that 46 percent of Zambians live in urban areas. The policy states that most of the urban population depends on public transport for their daily transit, but the service is of relatively low quality and is more expensive compared to other countries in the region (Ministry of Transport and Communications, 2019). As a result, cities in Zambia have experienced increased usage of private motor vehicles leading to traffic congestion and road safety concerns. Further, the country is likely to increase carbon emissions further as the population increases to 27 million by 2035 because of its dependence on the vast estimated road transportation system of 67,671km if deliberate policies are not put in place to mitigate and regulate the road transportation sector to stop relying on fossil fuels and shift to greener sources of energy such as electric vehicles (Ministry of Transport and Communications, 2019).

1.2 Problem Statement

The world is swiftly modifying the road infrastructure in order to support electric vehicle transportation driven mostly by its low carbon footprint and a fast-evolving battery energy technology. For example, Kenya has no choice but to commence preparations for electric vehicles (EVs), as petrol/diesel vehicles will cease production around 2030 (George, 2021). The need for any sub-Saharan country such as Zambia to prepare for the electric car revolution in terms of infrastructure, policy and institutions has never been greater.

Currently, the National Transportation Policy of 2019 has no mention of electric cars but it clearly states the need to promote environmentally friendly transportation services (Ministry of Transport and Communications, 2019). However, there is little or no preparation in Zambia for electric cars in terms of policies, institutions and infrastructure.

1.3 Aim

To investigate the main infrastructural requirements for electric vehicles usage in Zambia.

1.3.1 Objectives

- To establish infrastructure requirements for electric vehicles
- To determine the factors necessary to find the minimum distance between chargers.
- To model the requirements for a given stretch

1.4 Significance of Study

Currently there is little or no preparation going on for the introduction of electric vehicles in Zambia despite major economic powers like the European Union and Britain announcing the banning of the manufacturing of diesel/petrol (fossil fuels) powered vehicles by the year 2030 and completely phasing them out by the year 2050 (Jagadeesh, 2020). Assessing the impact electric vehicle infrastructure will have on Zambian roads will help Zambia to prepare and plan adequately on how the electric vehicle infrastructure can be set up in Zambia and also to be aware of the changes it will bring on the road infrastructure. This knowledge will assist policy makers to make the right long-term investment in infrastructure.

1.5 Scope and Area of Study of Research

For the purpose of the study, the research was limited to:

- Road signage and charging stations for electric vehicle infrastructure in particular for a fast charging capable personal electric vehicle cars; and
- A 317 kilometres stretch of part of the T2 & T3 trunk Roads from Lusaka to Ndola as a case study

2. Methodology

In order to establish infrastructure requirements for electric vehicles and to model the requirements for a given stretch, it was noted from literature that there is a need to determine minimum distance between fast chargers (MDFC). Fast charging, sometimes referred to off-board charging, works by delivering direct current to the vehicle (EEA, 2016). This is because the alternating current to direct current converter is located in the charging equipment, instead of inside the vehicle as for the other levels (EEA, 2016). Fast charging is hence defined as a charging station that provides at least 43 kilowatt (kW) of power (Wolbertus and van den Hoed, 2020), this charging station should be able to charge a 225 kW maximum charging capacity Porsche Taycan 4s to up to approximately 30 percent in 5.5 minutes when the charger is providing 100kW of power (Porsche, 2020) or charge a 50 kW maximum charging capacity Chevrolet Spark to over 80 percent in less than 30 minutes when the charger is providing 50kW of power (EV COMPARE, 2015). A quantitative method was used to obtain data that was used to determine the MDFC, the procedure described and used in this paper can be adopted and applied in any other country.

Information necessary to determine MDFC was based on the type of charging systems for electric vehicles available on the market i.e. whether these vehicles have fast charging capability and the battery capacity available on the vehicle. The procedure that was used in this research to determine the minimum distance between fast chargers (MDFC) is from the research paper by Colmenar-Santos et al. 2014.

Questionnaires were used to obtain data necessary to determine the MDFC such as driver behaviour and the simultaneity factor of the modelled stretch.

Google Maps and Google Earth were used to represent the fast chargers location across the modelled stretch. The use of these software packages helped in having a visual representation of the infrastructure across the modelled stretch.

2.1 Factors Necessary to Calculate the MDFC

It was established from literature the minimum distance between fast chargers puts into consideration the following factors:

2.1.1 Minimum Range

The minimum range of an electric vehicle is an important input when determining the distance between fast charging point points for long distance travelling. The minimum available range that was used in this paper was obtained from literature (Colmenar-Santos et al, 2014, p. 8).

2.1.2 Weather Conditions

The weather conditions are critical to the case study when determining the minimum distance between fast chargers. This is because the battery power supply duration of an electric vehicle is highly affected by the air conditioning usage by the motorist based on the prevailing weather conditions. The weather conditions value that was used in this paper was obtained using the procedure described in literature (Colmenar-Santos et al, 2014, p. 10) using the highest and lowest temperatures reported in Zambia of 33.1^{o}C and 9.22^{o}C respectively (World Bank, 2021).

2.1.3 Speed Flexibility Margin

The flexibility margin includes the road and traffic conditions, the driving style and charging patterns. Therefore, the flexibility margin considers the range reduction due to highway speed and driving behaviour. The speed flexibility margin that was used in this paper was obtained using the procedure described in literature (Colmenar-Santos et al, 2014 p. 11) using the maximum allowable speed in the country of 120 kilometres per hour as stated in statutory instrument number 007 of 2020 of the laws of Zambia (GRZ, 2020)

2.1.4 Simultaneity Factor

The Simultaneity factor "*k*", considers the coincidence of weather conditions and flexibility margin. If behavioural factors defer electric vehicle driving when weather conditions are cold or most highway trips are when weather conditions are more appropriate (for example city to coast trips in summer), the simultaneity factor will have a reduced value. The aggressive driving style factor together with simultaneity factor was obtained using the procedure described in literature (Colmenar-Santos et al, 2014) using the data obtained through questionnaires

2.2 Case Study Description

The case study road is a relatively busy stretch because it connects two very economically active provinces, the Copperbelt and Lusaka Provinces. It is also a stretch of high economic value to the

Southern African Development Community (SADC) and the Common Market for Eastern and Southern Africa (COMESA) (Zawya, 2019) as it connects Zimbabwe, South Africa, Namibia, Malawi and Tanzania. The selected road of 317 kilometres according to Google Earth has a maximum slope of 6.1 percent and minimum slope of -4.5 percent and an average slope of 1.5 percent and -1.5 percent hence it is a relatively flat route (Google Earth, 2021).

3. Results

Table 1 shows all the necessary factors necessary to determine the MDFC obtained using the procedures described in the methodology. The model electric vehicle that was used in this paper is the 50 kW maximum charging capacity Chevrolet Spark.

Table 1: Summary of Factors for MDFC Determination

FACTOR	OBTAINED VALUE
Minimum available Range (R_m)	132km
Weather Conditions (M_w)	20 percent
Speed flexibility margin (M_f) ✓ Aggressive driving style factor ✓ High traffic factor ✓ Non full charging pattern	25 percent 5 percent - Not Applicable
Simultaneity factor (k)	0.9

3.1 Calculation of MDFC

Equation 1 and factors in Table 1 were used to calculate the MDFC, the computations are illustrated below;

$$MDFC = R_m \times (1 - (M_w + k \times M_f)) \quad \text{.................Equation 1}$$

$$MDFC = 132km \times (1 - (0.20 + 0.9 \times 0.30))$$

$$MDFC = 132km \times 0.55$$

MDFC = 69.96 km

Which is approximately 70 kilometres

3.2 Summary of Charging Station Locations

Using the calculated MDFC of 70km, Table 2 shows the summary of the fast charging station locations as collected from Google Earth. It gives a detailed description of where the chargers should be located along the selected stretch, which is part of the T2 and T3 trunk roads from Lusaka to Ndola.

Table 2: Summary of Fast Charging Station Locations

	Latitude	Longitude	Description of location
Starting Point	15°23'16.63"s	28°19'28.85"e	UNZA Bus stop was chosen because of quick access to electricity and security and convenience that comes from being in proximity to east park mall
First Charger	14°52'39.53"s	28° 3'35.26"e	Landless Corner. This location was chosen because of quick access to electricity and security that comes from being in proximity to a police station
Second Charger	14°26'29.68"s	28°26'52.54"e	This location was chosen because of quick access to electricity and security and convenience that comes from being in proximity to Kabwe Hungry Lion
Third Charger	13°53'34.30"s	28°39'26.82"e	This location was chosen because of quick access to electricity and security and convenience that comes from being in proximity to Lukanda market in Kapiri Mposhi
Fourth Charger	13°16'51.36"s	28°40'57.34"e	This location was chosen because of quick access to electricity and security that comes from being located Kafulafuta Weigh Bridge
Destination	12°59'30.01"s	28°38'58.43"e	This location was chosen because of quick access to electricity and security that comes from being located at Chreso University Ndola Campus

3.3 Traffic Signs

From literature, it is stated that countries need to develop their own electric vehicle charging stations, road signage or borrow signage from another country if they do not develop their own, including signs for dedicated charging stations at parking locations (public and/or private) (Clean Fuels Consulting, 2012).

Since Zambian road signs are similar to the United Kingdom, electric vehicle signage for the United Kingdom is proposed to be adopted for Zambia. Some of the charging station signs currently in use in the UK are shown in Figure 1.

4. DISCUSSION

The main infrastructural requirements for electric vehicles usage in Zambia are;

4.1 Charging Stations

It was established from literature that fast charging technology is the best charging infrastructure for long distance travelling. This is because fast charging technology has made it possible for the charging time of an electric vehicle to be comparable to the fuelling time in a conventional internal combustion vehicle. This can be seen in a Porsche Taycan 4s which is able to charge to up to 100 kilometres of range in 5.5 minutes when the charger is providing 100kW of power (Porsche, 2020) and this is relatively comparable to the average fill up time of fuel which takes approximately 2 minutes (API, 2021).

4.2 Positioning of Realigned infrastructure

The minimum distance on the case study stretch from Lusaka to Ndola road between fast chargers is 70 kilometres. A minimum of four fast chargers would need to be installed on the Lusaka to

Ndola trunk road in order to reduce range and to allow smooth travelling for electric vehicles that have range that is as low as 132 kilometres.

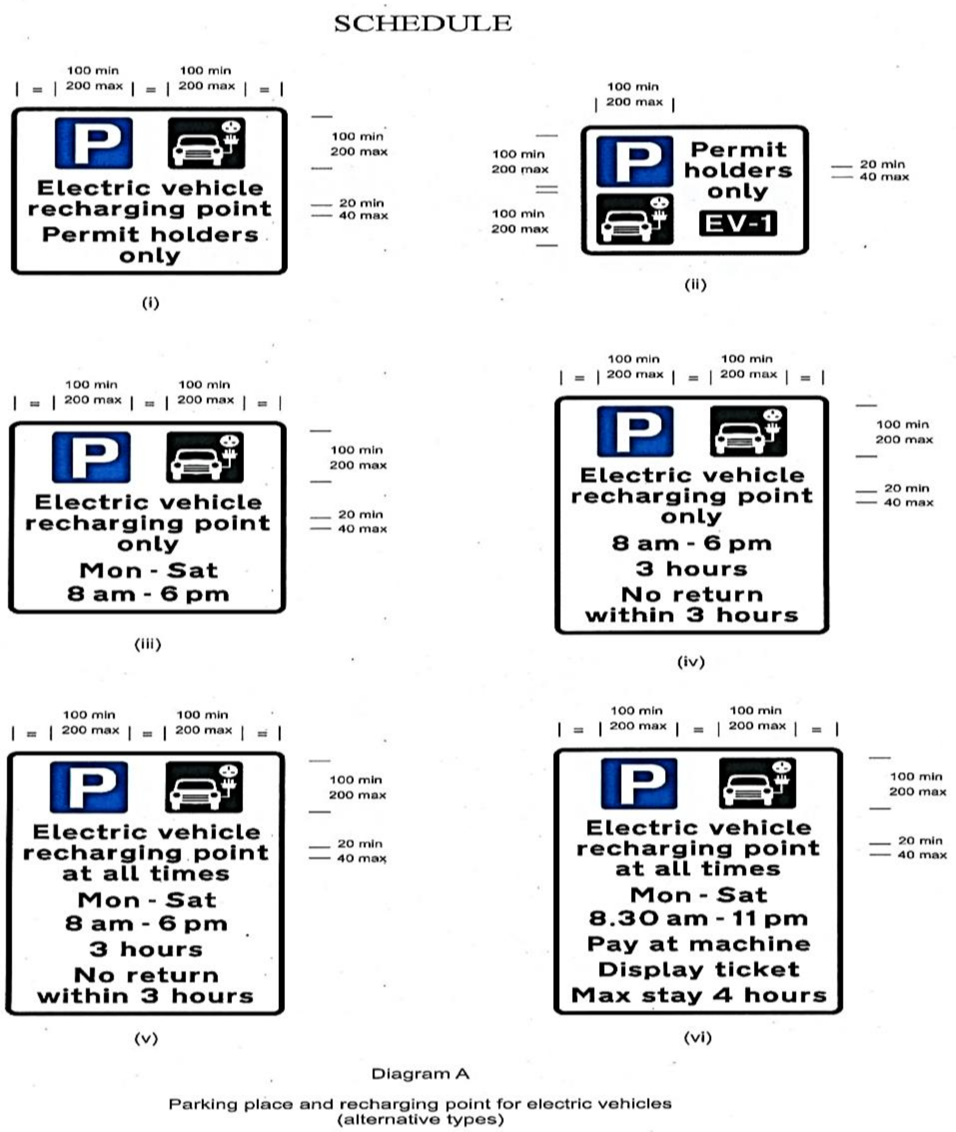

Fig. 1: Parking place and recharge point for EV (Regional, 2012))

4.3 Road Signs

Most countries would need to develop their own EV road signage or adopt signage from another country for dedicated charging stations at parking locations for both public and private use. Hence since the Zambian road signage infrastructure is similar to the United Kingdom, the electric vehicle road signage from the United Kingdom was recommended for adoption.

5. CONCLUSION

Fast charging technology together with properly placed fast chargers will allow a personal motor vehicle to travel from Lusaka to Ndola with no range anxiety. It was seen in this research that in a worst case scenario of an electric vehicle with a short range of 132 kilometres and fast charging capability of 30 minutes together with the worst weather and road conditions can only add an extra 1 hour to the travel time in which the vehicle will need to charge twice. But for more advanced electric vehicles with a range of approximately 400 kilometres and fast charging capability of charging up to approximately 30 percent in 5 minutes, the travel time is indistinguishable to conversational vehicles even under the worst weather and road conditions. This will lead to increased electric vehicle adoption by Zambians just like it has been in developed nations, but this will require government or the private sector investment in electric vehicle infrastructure and proper government policies and incentives.

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Green Hydrogen Production

Hassan Diakite Phiri[1]

Abstract

Hydrogen fuel is projected to be a future of sustainable storage of renewable energy and is mainly classified as per production path used in separating it from other elements i.e. green, blue, grey and turquoise hydrogen. However, hydrogen gas can be used in its pure state, stored for future use or transformed to other compounds for end use. Hydrogen produces water when combusted as a fuel. With increasing effects of climate change, global warming and world's shift to sustainable use of clean energy, this paper reviews the different green hydrogen production methods, uses of renewable energy to produce green hydrogen, economic sustainability of green hydrogen and the future of green hydrogen production in Africa.

Keywords: Hydrogen production, renewable energy, hydrogen economic sustainability, future of hydrogen

1.0 Introduction

Hydrogen gas is an odourless, colourless and highly combustible gas. It is the most available chemical element in the universe, mostly constituted in liquid form as water and hydrocarbon. On earth, it rarely exists as a gas hence needs to be separated from other elements. Predominantly, Hydrogen gas has been used in many production processes such as petroleum refining, ammonia production and other metal refining processes. However, hydrogen can also be used as a fuel to produce electricity using a designed hydrogen fuel cell device.

Hydrogen production technologies vary depending on the energy source and the type of production process used. Generally, production technologies used for bulk production of hydrogen gas are reforming of the natural gas, gasification of coal and petroleum coke and reforming of heavy oils (Acar & Dincer, 2019). But due to increased costs because of decreasing availability of oil reserves and global climate change penalties for carbon emissions and greenhouse gases from combusting fossil fuels, hydrogen produced by electrolysis of water using renewable energy has more advantages in the need deliver clean energy and address concerns that affects climate and global warming, electrolysis technology does not emit any greenhouse gas which is an agent of climate change and global warming. Although hydrogen production by electrolysis of water has significant advantages, its application is limited to small scale production as it is not economical currently. Conceptual hydrogen production by electrolysis of water is more sustainable for energy production and distribution in a small town or a small energy system such as communication system and small off grid electricity production.

After hydrogen gas has been produced, it can be either stored in cylinders or transported by tanker trucks and pipelines as a gas or liquid (Abdalla & Nisfindy, 2018).Globally, Hydrogen gas production by electrolysis using a renewable energy source to split the water molecules into

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hydrogen and oxygen molecules has been of interest for researchers over the past decades. There has been massive investment in research and development of new technologies that looks at improving the production, storage and operation efficiency of hydrogen gas. Mostly, the renewable energy source of electricity in the electrolysis process to split water into hydrogen and oxygen is either solar energy or wind or both renewable sources of energy can be utilised as one grid and used to produce hydrogen gas. This type of energy hybrid system reduces the dependency on using other energy source like hydroelectric or fossil fuels (Acar & Dincer, 2019). Hydrogen production can be classified as per method of production used. However, hydrogen produced by electrolysis is classified as green hydrogen because it does not produce any greenhouse gases. Fig. 1 shows the conceptual illustration of energy production of electrolysis of water using a renewable source such as solar or wind.

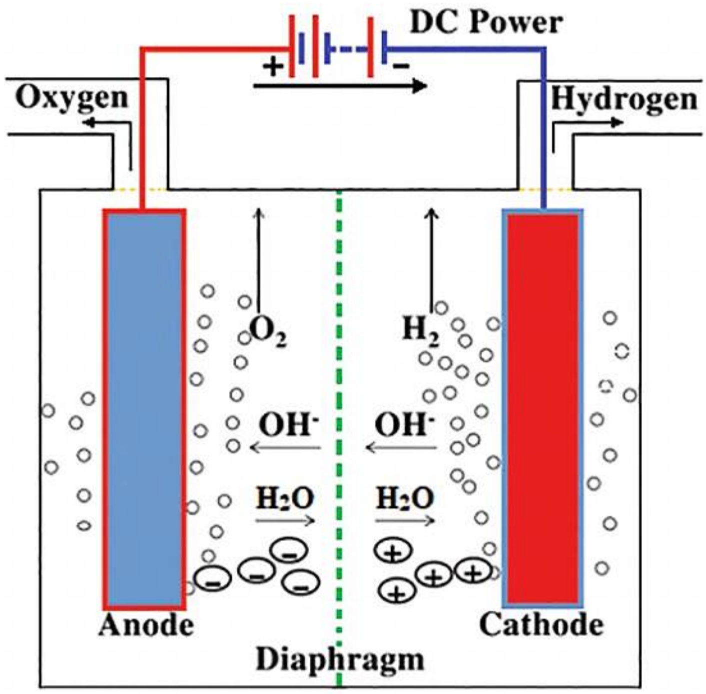

Fig. 1: Hydrogen Production by Electrolysis. (Kaur & Pal, 2016)

2.0 Hydrogen production

Electrolysis of water is the process of splitting water molecules into hydrogen and oxygen molecules by using an externally applied energy source, direct current DC source. Typically, an electrolyser chamber consist of two electrode metals, annoyed and cathode, an electrolyte solution and a DC power supply source. In figure 2, a DC is applied to maintain electricity balance which makes electrons flow from a negative terminal (anode) of the Direct current source to the positive charge electrode(cathode) where hydrogen ions consume electrons to form hydrogen gas (Rasid & Nsheem, 2015). To keep the electric current in balance, hydroxide ions must move to the Anode electrode through the electrolyte solution. The electrolyte solution also provides additional ions for the electrolysis of water. However, the direct current power source can either be solar or wind energy and during the process of electrolysis of water, hydrogen ions move towards the cathode, consume electrons to produce hydrogen gas while hydroxide ions provided by the electrolyte solution, move to the anode and combine with oxygen ions to form half oxygen ions. The chemical equations below highlight a summary of chemical equations at the cathode and anode electrodes respectively (Dawood & anda, 2020).

Reaction at the Cathode;

$$2H^{+} + 2e^{-} = H_2 \tag{1}$$

Reaction at the anode;

$$2H_2O = O_2 + 4H^{+} + 4e^{-} \tag{2}$$

The hydrogen produced by electrolysis needs to be compressed and stored in a cylinder while the oxygen is released to the environment. At room temperature, the electrolysis effect is very small with an approximation of 10000 moles per litre. This is because water is a very poor conductor of electricity and to overcome the poor conductivity of water, the electrolyte (water) can either be made as an alkaline medium or a basic medium so that current can easily flow. Examples of acid or base medium used to improve the conductivity of water are alkaline electrolytes such as potassium hydroxide (KOH), sodium hydroxide (NaOH) and sulphuric acid (H_2SO_4). The medium spilt into negative and positive ions in water solution and easily conduct electricity by flowing from one end of the electrode to another (Rasid & Nsheem, 2015).

3.0 Classification of Water Electrolysis Methods

The classification of water electrolysis methods depends on the different electrolyte used in the electrolysis cells and this classification can be divided into three main categories namely;

3.1 Alkaline Electrolysis

Alkaline is one of the oldest purging techniques which can be incorporated with renewable source of energy like solar wind. It is a zero-carbon emission technique where an electrolyser separates the water molecules into hydrogen and oxygen gas. The operating conditions of an alkaline electrolysis technique are listed in Table 1. This solution electrolyte is usually mixed with water to increase the conductivity of water and provide extra hydroxide ions when splitting water into hydrogen and oxygen gas (Rasid & Nsheem, 2015). This technology is the one oldest and most established with almost 70 percent efficiency. Additionally, alkaline electrolysis technology is environmentally friendly with lower operation costs and easy to run. Corrosion of electrodes due to aqueous electrolyte need high energy to separate water and low current density are the major drawbacks associated with an alkaline electrolysis system.

Table 1: Alkaline Operating Conditions

Concentration	Temperature (K)	Pressure (MPa)
20-40% wt.	343-363	3

3.2 Polymer Exchange membrane electrolysis (PEM)

This is a technique that uses a polymer exchange membrane which acts as a solid electrolyte. At the anode, during the operation of the electrolysis, Oxygen decomposes into protons and molecular oxygen and is removed from the chamber by water circulating through the electrolysis chamber. Fig. 2 summarises the operation of the PEM Electrolysis technique. Due to electric effect, the protons to move to the cathode where they are reduced to hydrogen molecules and hydrogen gas is collected at the other side of the polymer membrane. The characteristics in choosing the polymer used depends on its ability to withstand high temperature and resist swelling after some time of operation. (Rasid & Nsheem, 2015). PEM electrolysis has high pure hydrogen gas Collected, zero carbon emission, low maintenance costs and higher safety. However, the major drawbacks experience by the PEM electrolysis technology is high initial capital investment and partial commercialisation of this technique.

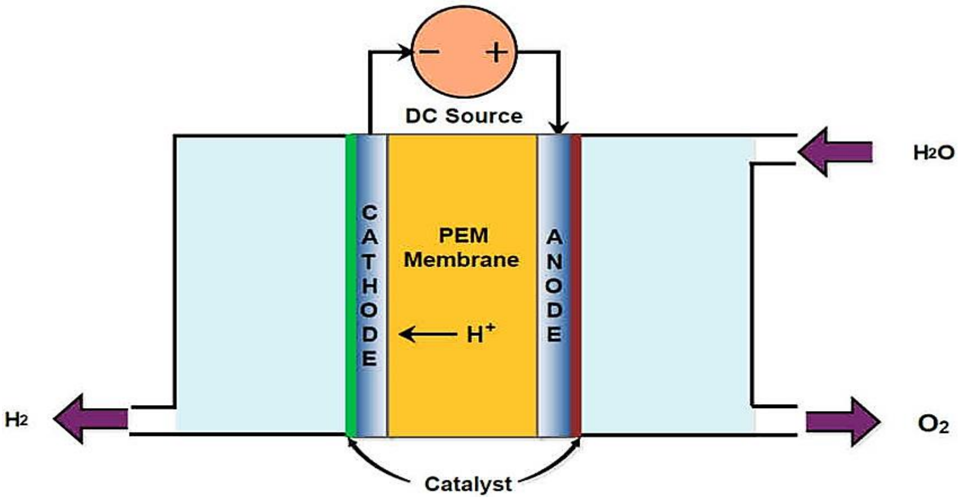

Fig.2: The PEM Electrolysis Technique (Kaur & Pal, 2016)

3.3 Steam Electrolysis

Steam electrolysis is an electrolysis technique that has high efficiency when compared to alkaline and PEM electrolysis. Water is heated to higher temperatures such that water vapour is reduced to hydrogen gas and water vapour. At high temperature, water conductivity and electrochemical reaction increase at the electrodes hence the separation of water is faster and the collection of hydrogen gas is more. Supplementary waste heat processes such as solar geothermal can be incorporated to reduce the consumption of the source of energy used in this technique (Rasid & Nsheem, 2015). Fig.3 illustrates the operation of a Steam electrolyzer. Steam electrolysis has high efficiency and high operation pressure which makes hydrogen storage easy but has high maintenance costs, high operation costs, high electricity consumption and the technology not yet commercialised.

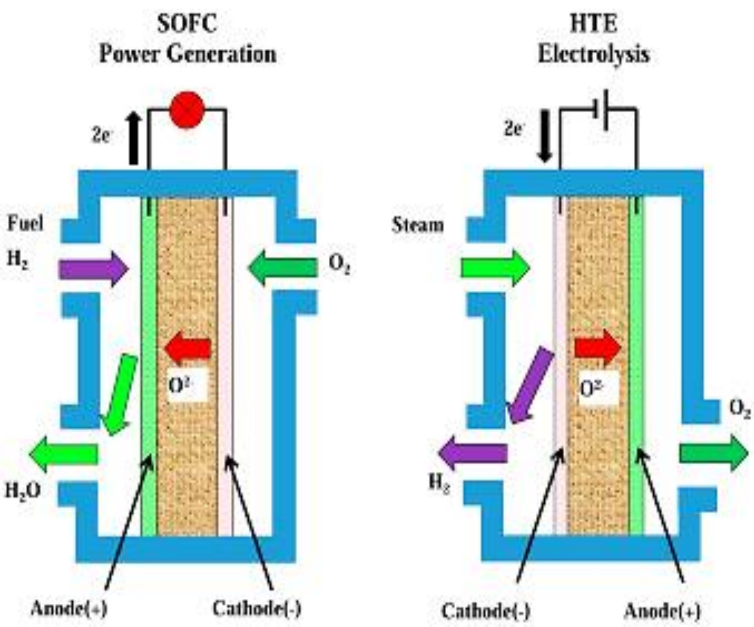

Fig. 3: Steam Electrolyser (Kaur & Pal, 2016)

4.0 Economic Sustainability of Green Hydrogen Fuel

Solar produced green hydrogen gas using electrolysis of water is a global strategy to reduce on carbon emissions and dependency on traditional fossil fuels. However more research is being carried out to improve efficiency and the cost of production of green hydrogen gas. Predominantly hydrogen gas has been produced by traditional fossil fuel which contributes to climate change and global warming owing to the carbon emissions from these processes. Hydrogen generated by traditional fossil fuels has an average cost of about USD 2.55/kg for hydrogen production compared to an average value of USD 3.68 / kg for hydrogen produced by PV solar electrolysis of water (Chang, 2020). However, the projection in future predicts a significant reduction in the cost of hydrogen production (Saba, et al., 2018). This is due to the reduction of prices of solar equipment, high learning rate of the solar electrolysis technology and improved electrolyser efficiency due to massive investments in solar electrolysis hydrogen efficiency research. Additional factors that affect the cost of hydrogen production include location, as areas with high irradiances and more sunlight hours have reduced cost of hydrogen production.

A stand-alone PV solar hydrogen production electrolyser system has limiting capacity factor for remote location but tends to be cheaper than high power grid Connections. As Per Monte- Carlo Model flow diagram (Fig. 4) of technical and economic calculations of cost of hydrogen production, input factors like weather data, solar data, variable parameters and economic parameters provided an average price of hydrogen cost of production between USD 3.25 per kg and USD 3.97 per kg for a city of Townsville, Australia (Saba, et al., 2018). Furthermore, Hydrogen cost of production can be significantly reduced by improving analysis on variable parameters like electrolyser efficiency and optimum PV solar size. Compared to diesel, 1KG hydrogen cost between USD 3 per kg to USD 6 per kg Equal to 33.6KWh while diesel costs about 0.851 per kg equal to 12 to 14 KWh. To model the two electrolyser technologies, a Monte Carlo analysis was done for both, with the same input uncertainty ranges. The simulation showed AE has lower costs of hydrogen production.

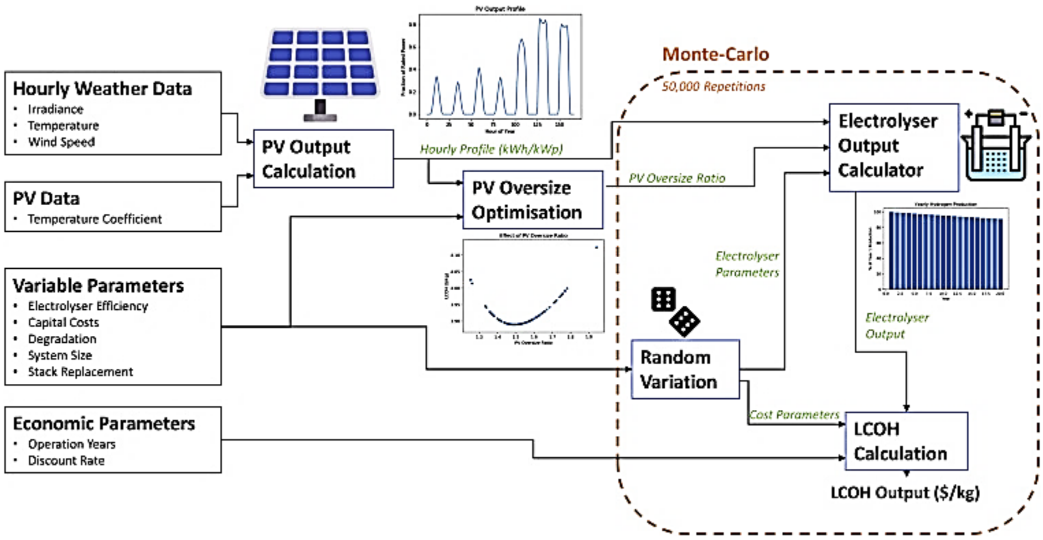

Fig. 4: As per Monte- Carlo Model flow diagram of technical and economic calculations of cost of hydrogen production (Saba, et al., 2018)

To determine the parameters that most affect the cost difference between PEM and AE, an uncertainty analysis (like the Key Drivers to cost of hydrogen production model by Monte Carlo) was completed for the differing variables. This showed that the two most important parameters were the capital cost difference and the energy consumption difference. Many studies predict that

PEM technology will have lower specific energy consumption than AE, with an improved electricity usage of up to USD3–4 kWh per kg H_2 (Chang, 2020).

The current cost of polymer exchange electrolyser (PEM) is reported higher than alkaline electrolysers (AE), this cost gap continues to decrease with time and more research and it is estimated that the cost of PEM electrolysers will be lower than alkaline electrolysers. PEM Electrolysers have higher efficiency and are more load flexible and suitable for valuable renewable energy source like solar or wind.

5.0 Future of Green Hydrogen Production in Africa

With an increasingly high demand to shift to clean energy production methods and reduced cost of renewable energy materials for solar and wind, Africa has the potential to becoming a hub to supply clean energy to the world particularly hydrogen fuel. (Chang, 2020) Africa has abundance of renewable resources which are early movers of green hydrogen production and have significant implications on the economy of Africa. Zambia has significantly improved with more scholars undertaking more research on the development of technologies of production of green hydrogen gas and more innovation by scholars to develop electrolyser prototypes. A group of researchers in Zambia by the name of Sheagle technology is currently undertaking an improved hydrogen production electrolyser research. Progress has been made in South Africa by the South African hydrogen space with the first government lead hydrogen road map under development and green hydrogen. Community initiative highlights South Africa is potential for hydrogen production to the global community. (Abdalla & Nisfindy, 2018).

6.0 Conclusion

Green hydrogen production has substantial economic benefits when utilized on a commercial scale and addresses the adverse effects of global warming and climate change. PEM electrolysis is the most promising, efficient and latest water electrolysis method of production and continues to attract the attention of researchers around the globe in order to make green hydrogen a cheap and sustainable fuel compared to fossil fuels. However, more attention should also be centered on improving the storage and safety of green hydrogen.

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