2023 ENGINEERING INSTITUTION OF ZAMBIA SYMPOSIUM

INVESTIGATING GROUNDWATER IN PERI-URBAN AREAS: A CASE STUDY OF CHIPATA COMPOUND IN KITWE CITY, ZAMBIA

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Avani Victoria Falls Resort, Livingstone, Zambia

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1.0 INTRODUCTION

- Groundwater is the water found underground in the cracks and spaces in soil and most rocks. It is one of the major sources of fresh water in the world (Brassington, 2007; Heath, 1983; Subramanya, 2010; Thomas *et al*, 1998).
- According to Vision 2030 (2006), Zambia aims to provide secure access to safe potable water sources and improved sanitation facilities to 100 percent of the population in both urban and rural areas.
- This can be achieved if monitoring of groundwater resources is taken into consideration as most peri-urban and rural settlements depend on groundwater.
- Petersen and Hubbart (2020) recommend more field-based studies in diverse physiographical regions and over larger spatial extents to provide information regarding factors influencing faecal coliform concentrations in secondary habitat (like groundwater aquifers)

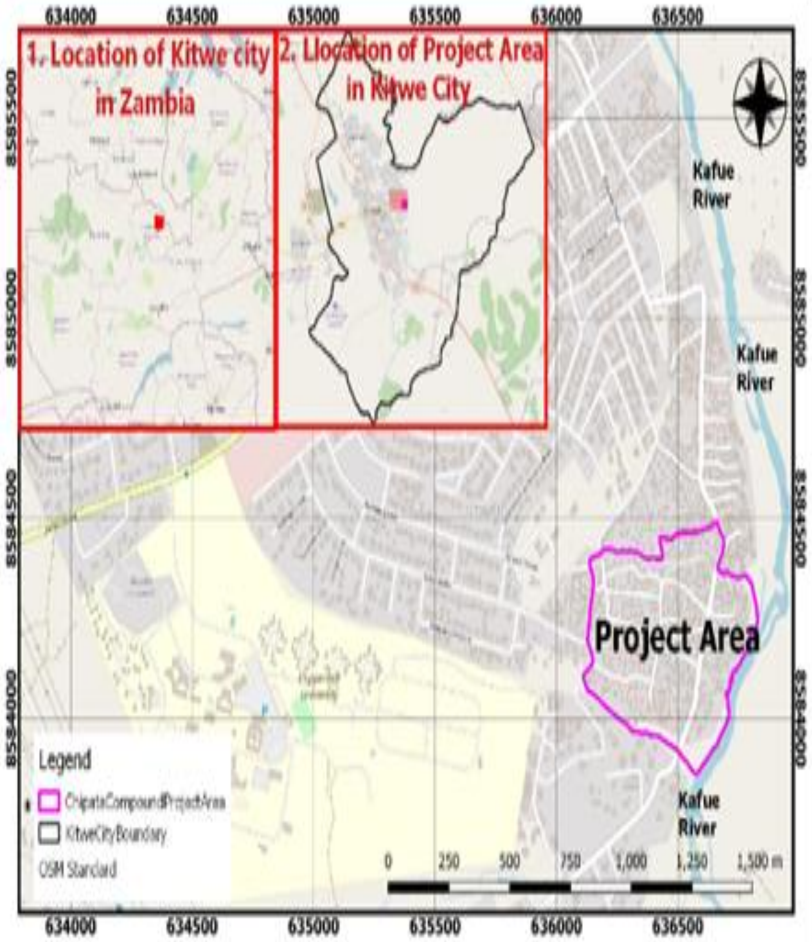
1.0 INTRODUCTION

- The traditional and most common way of obtaining groundwater in peri-urban areas of most developing countries is through Hand dug wells (Water AID, 2013)
- Globally at least 1.7 billion people use a drinking water source contaminated with faeces (WHO, 2022). Microbial contamination of drinking water as a result of contamination with faecal matter possess the greatest risk to drinking water safety.
- Due to the nature of the activities around and in close proximity to the hand dug wells, contaminants easily find their way into the groundwater. For this reason, there is need for constant monitoring and studying the underground water quality in peri-urban areas.
- World Health Organization (WHO) recommends positioning pit latrines at least two meters above the groundwater table and maintaining a 30-meter distance from any water source during construction. Adhering to these guidelines is crucial, especially in areas lacking local geological knowledge (WHO, 2018).

2.0 MATERIALS AND METHODS

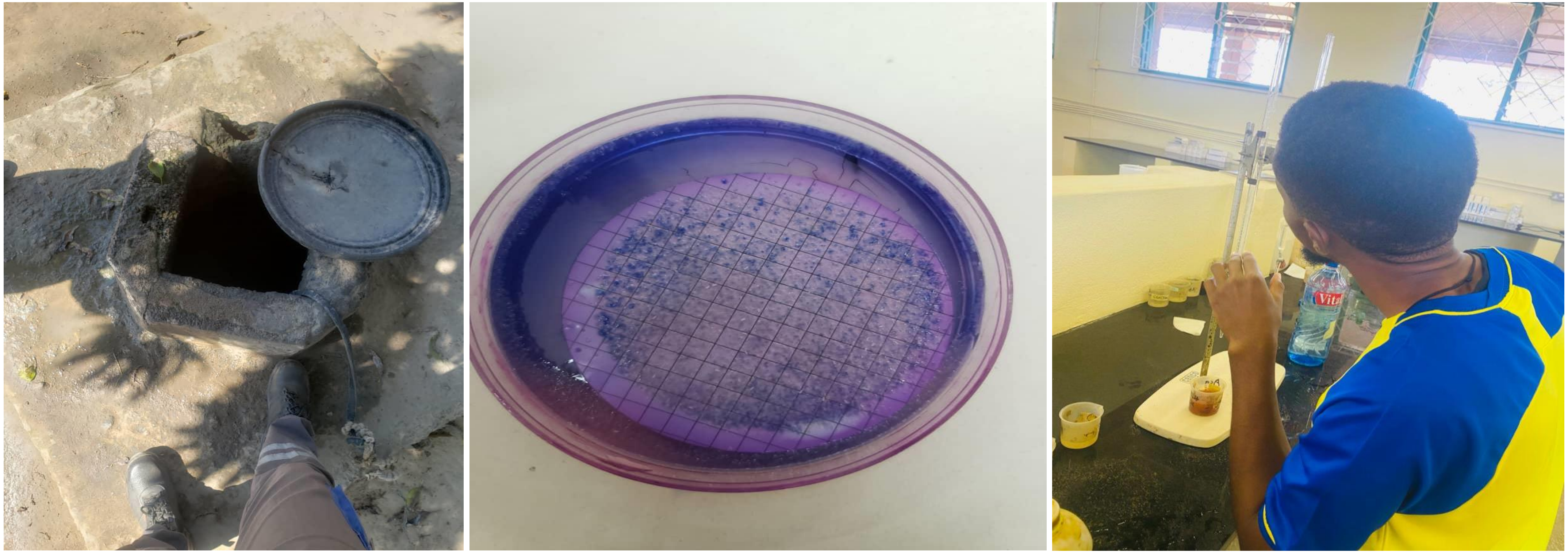
2.1 STUDY AREA

- The study area which is located in Chipata Compound, about 1.5km North-East of Copperbelt University main campus, spans over an area of about **30ha** (293,347m^2) and consists of over 90 hand dug wells and over 100 pit-latrines. Chipata compound is a peri-urban area located in Kitwe, a city with population of **661,901** in Zambia (ZamStats, 2022)



2.2 DATA COLLECTION

- A total of 100 hand dug wells and 104 pit latrines were located in the study area. Thirty (30) wells were selected for water level observations and fourteen (14) wells were selected for water quality tests.



- Water quality testing from the 14 hand dug wells was carried out twice every month from February to June 2023.

2.2 DATA COLLECTION

- Water quality tests were conducted in the Copperbelt University Environmental Engineering Laboratory and standard laboratory methods were used in accordance with the American Public Health Association (APHA. 2017).
- The water parameters analyzed were Total Dissolved Solids, Total Suspended Solids, Electrical Conductivity, Turbidity, Total Chlorides, Nitrates, Sulphates and pH, Total Coliforms and Faecal Coliforms
- Groundwater levels were observed twice a week for 8 months from the 17th of December 2022 to the 16thof July 2023
- using the groundwater levels and elevations of each well, the groundwater potential head was calculated.
- The porosity of the soil was determined by collecting soil samples from the field using core rings

2.3 DATA ANALYSIS

- Groundwater was assessed for drinking water suitability against ZABS standards (ZABS, 2001) by comparing measured parameters with the required Standards of drinking water.
- Further, possible contributing factors to contamination such as distance to pit latrine, depth of water table and groundwater flow direction were analyzed so as establish their effects on groundwater pollution.
- Temporal Variation of Water table for Observation Wells were compared with WHO (2018) recommended Depth of Pit Latrines.
- A correlation analysis was done in MS Excel to establish whether or not the distance from well to pit latrine had a bearing on groundwater quality.
- Spatial analyses were executed in Q-GIS. Groundwater potential heads (Total Hydraulic Heads) were calculated by deducting depth of water table from the elevation head of the wells.

2.3 DATA ANALYSIS

- Groundwater Potential Head contours and Pollutant Concentration contours were generated in QGIS using Inverse Distance Weighted (IDW) Interpolation.
- From the contours flow direction was established at 90^{o} of the contours of groundwater potential heads(Flow lines are orthogonal contour lines)
- The average recharge and discharge rate were evaluated based on the Groundwater Potential Head hydrograph concentration limb and recession limb
- Velocity of groundwater was computed using the equation below:

$$v = \frac{K}{n}\frac{dh}{dl} \qquad (1)$$

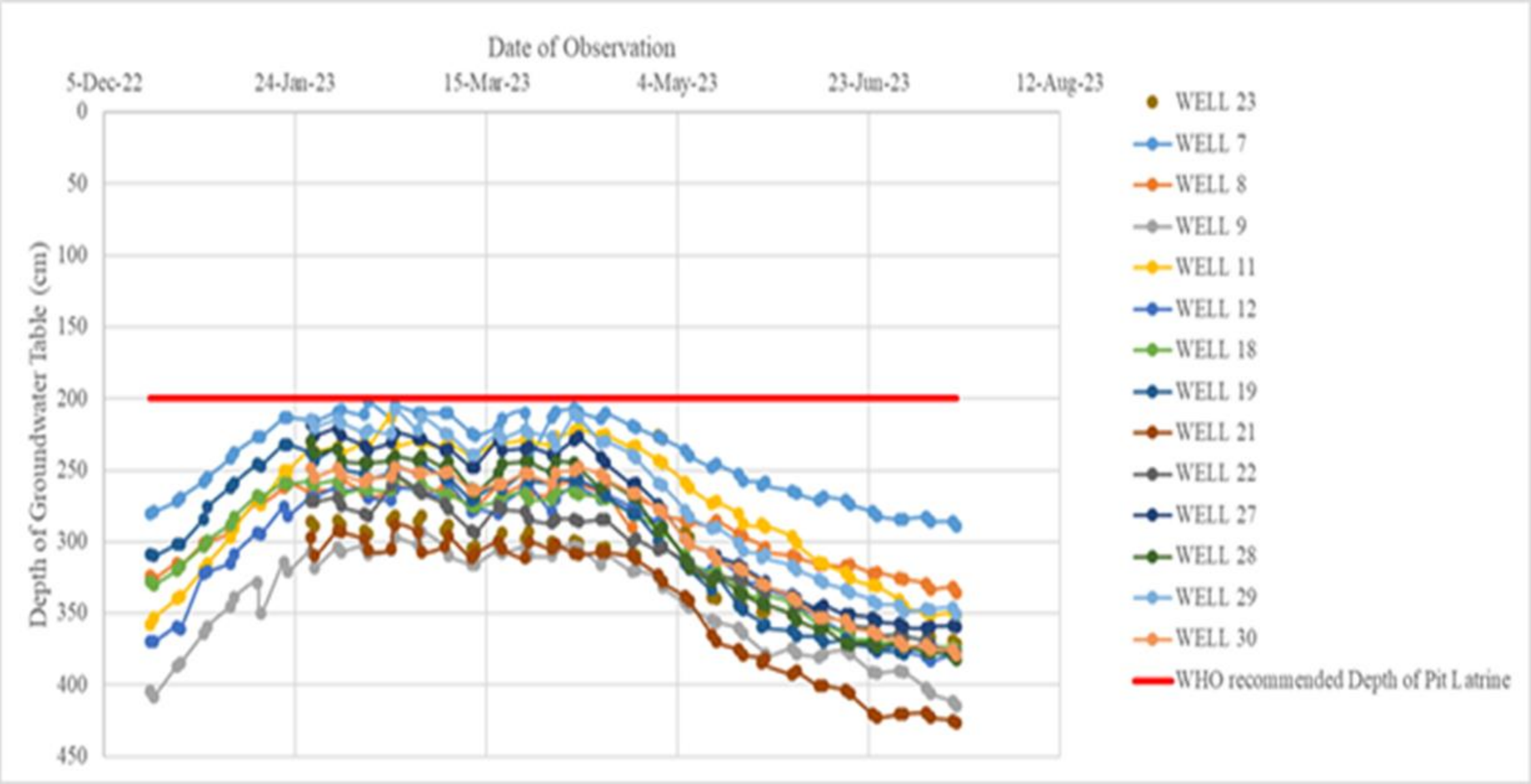
Where,

- $v = velocity\ of\ groundwater,\ n = porocity, K = \ Hydraulic\ conductivity$ Time was computed using equation 2:

$$Travel\ time\ (day) = \frac{Displacement\ (m)}{velocity\ (m/day)}$$

3.0 RESULTS AND DISCUSSION

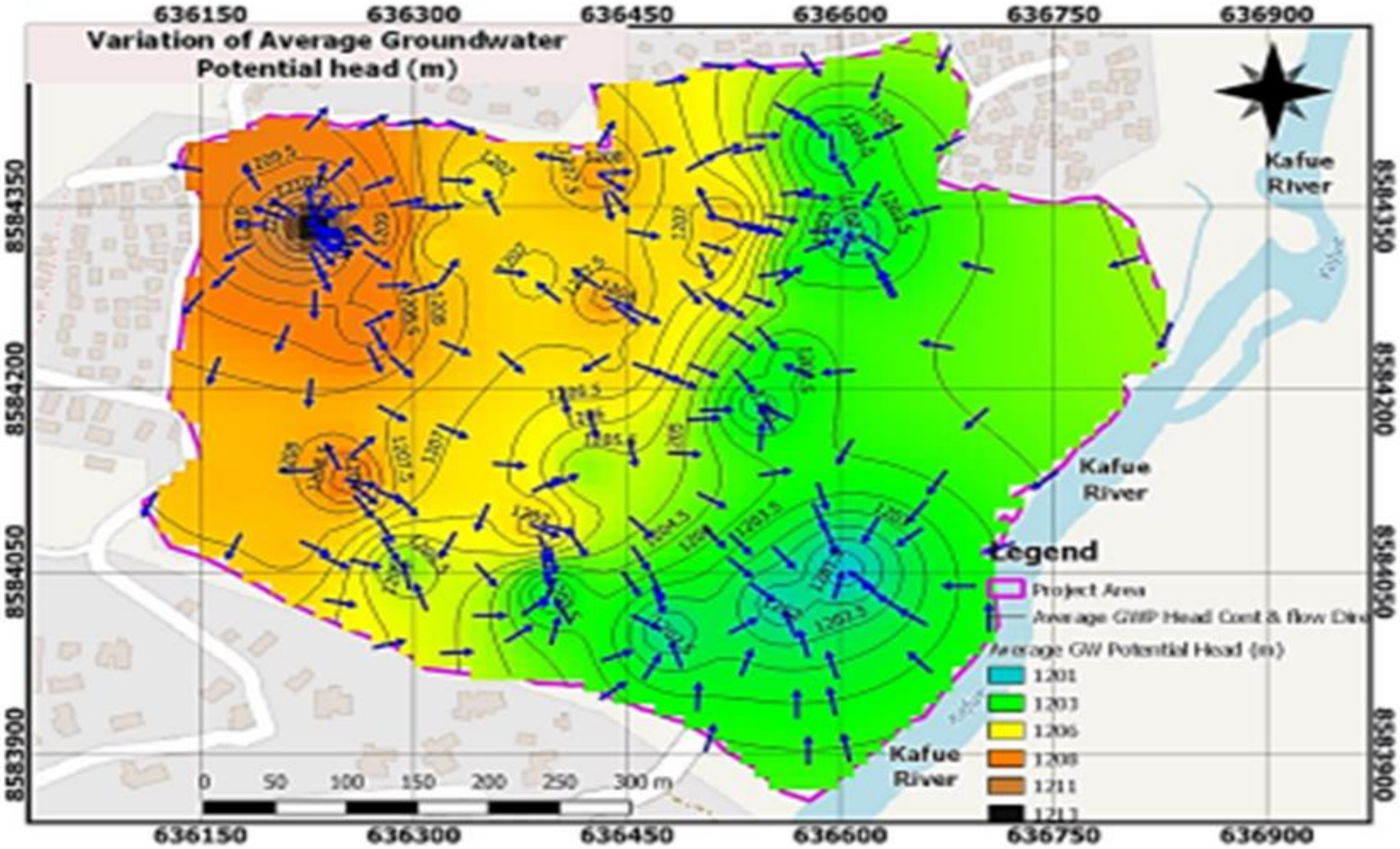
- Only Pit Latrine close to 14 observation wells are safe from being submerged by groundwater table. For these wells the water table is always below the depth of the pit latrines.



- Recharge rate:0.017m/d
- Discharge rate:0.011m/day

3.0 RESULTS AND DISCUSSION

- Groundwater flow analysis using minimum, average and maximum Groundwater Potential Head reveal that groundwater predominantly flows from Kafue River to the project area
- The figure below shows Spatial distribution of Average Groundwater Potential Heads and Groundwater Flow Direction



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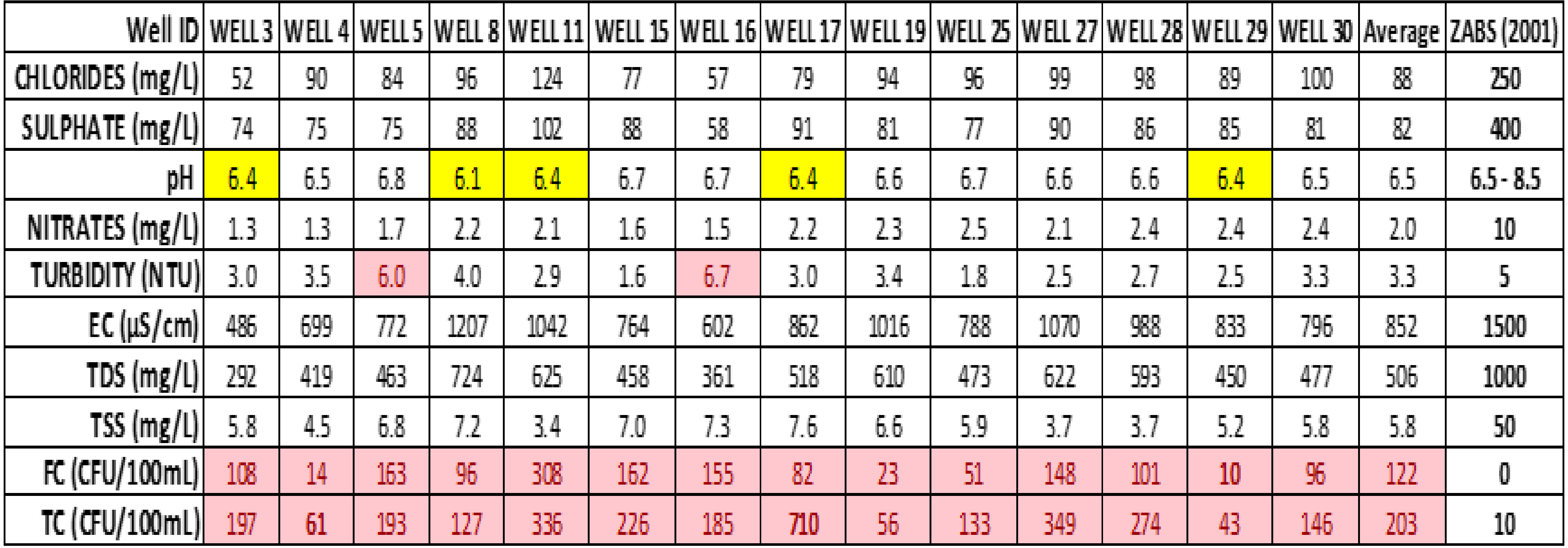
3.0 RESULTS AND DISCUSSION

- Laboratory results of the water samples shown in the table below, indicate all observation wells were contaminated with Faecal Coliforms (FC) and Total Coliforms (TC). Well 5 and 16 indicated poor turbidity. Wells 3, 8, 11, 17 and 29 recorded pH less than 6.5.

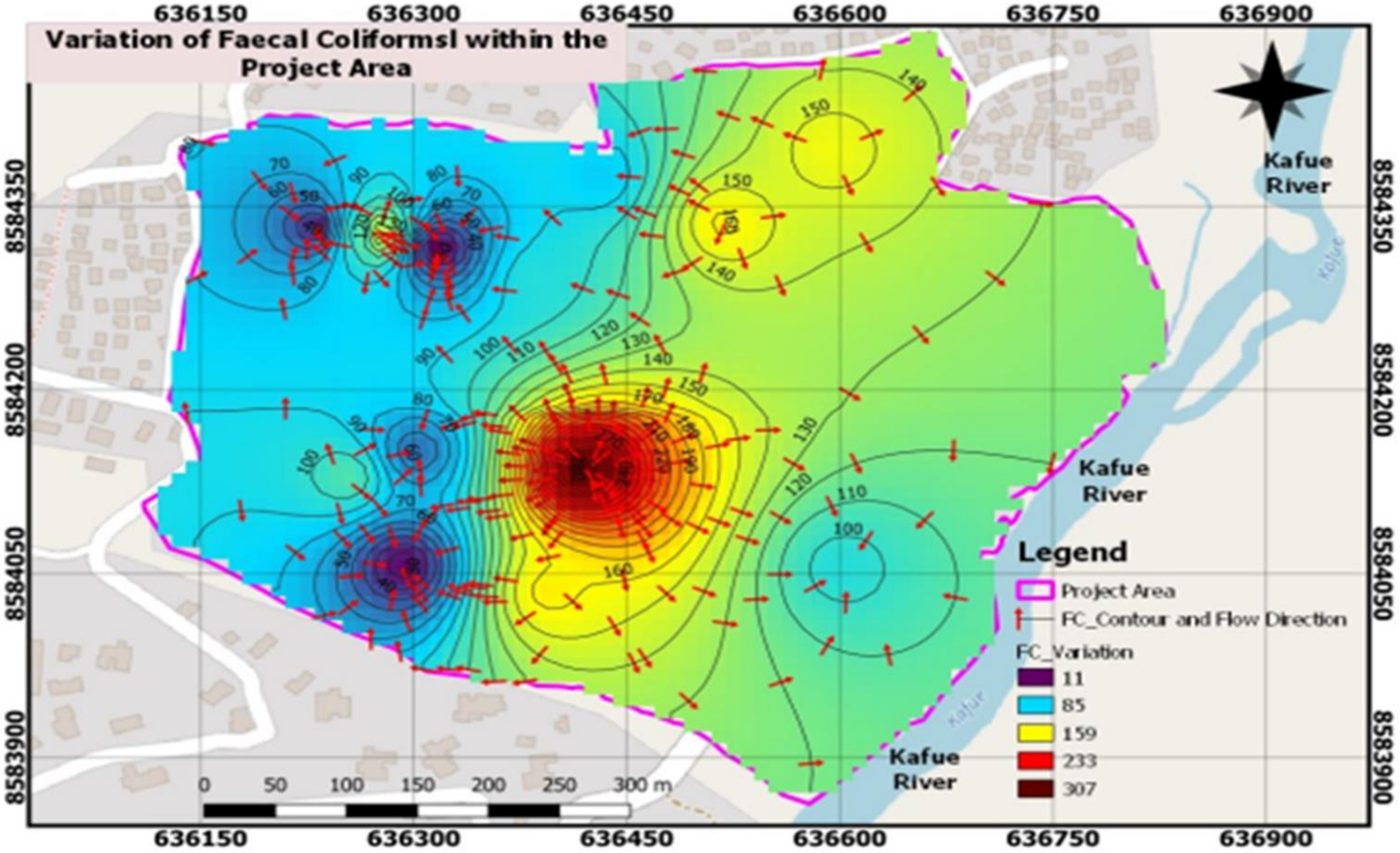


Well ID	WELL 3	WELL 4	WELL 5	WELL 8	WELL 11	WELL 15	WELL 16	WELL 17	WELL 19	WELL 25	WELL 27	WELL 28	WELL 29	WELL 30	Average	ZABS (2001)
CHLORIDES (mg/L)	52	90	84	96	124	77	57	79	94	96	99	98	89	100	88	250
SULPHATE (mg/L)	74	75	75	88	102	88	58	91	81	77	90	86	85	81	82	400
pH	6.4	6.5	6.8	6.1	6.4	6.7	6.7	6.4	6.6	6.7	6.6	6.6	6.4	6.5	6.5	6.5 - 8.5
NITRATES (mg/L)	1.3	1.3	1.7	2.2	2.1	1.6	1.5	2.2	2.3	2.5	2.1	2.4	2.4	2.4	2.0	10
TURBIDITY (NTU)	3.0	3.5	6.0	4.0	2.9	1.6	6.7	3.0	3.4	1.8	2.5	2.7	2.5	3.3	3.3	5
EC (µS/cm)	486	699	772	1207	1042	764	602	862	1016	788	1070	988	833	796	852	1500
TDS (mg/L)	292	419	463	724	625	458	361	518	610	473	622	593	450	477	506	1000
TSS (mg/L)	5.8	4.5	6.8	7.2	3.4	7.0	7.3	7.6	6.6	5.9	3.7	3.7	5.2	5.8	5.8	50
FC (CFU/100mL)	108	14	163	96	308	162	155	82	23	51	148	101	10	96	122	0
TC (CFU/100mL)	197	61	193	127	336	226	185	710	56	133	349	274	43	146	203	10

- Spatial distribution of faecal coliforms reveal that faecal coliforms are predominantly generated within the project area, with **Well 17,** being the highest contributor.

3.0 RESULTS AND DISCUSSION

faecal coliforms where predominantly generated at points of abstraction and contribution of Kafue River was negligible

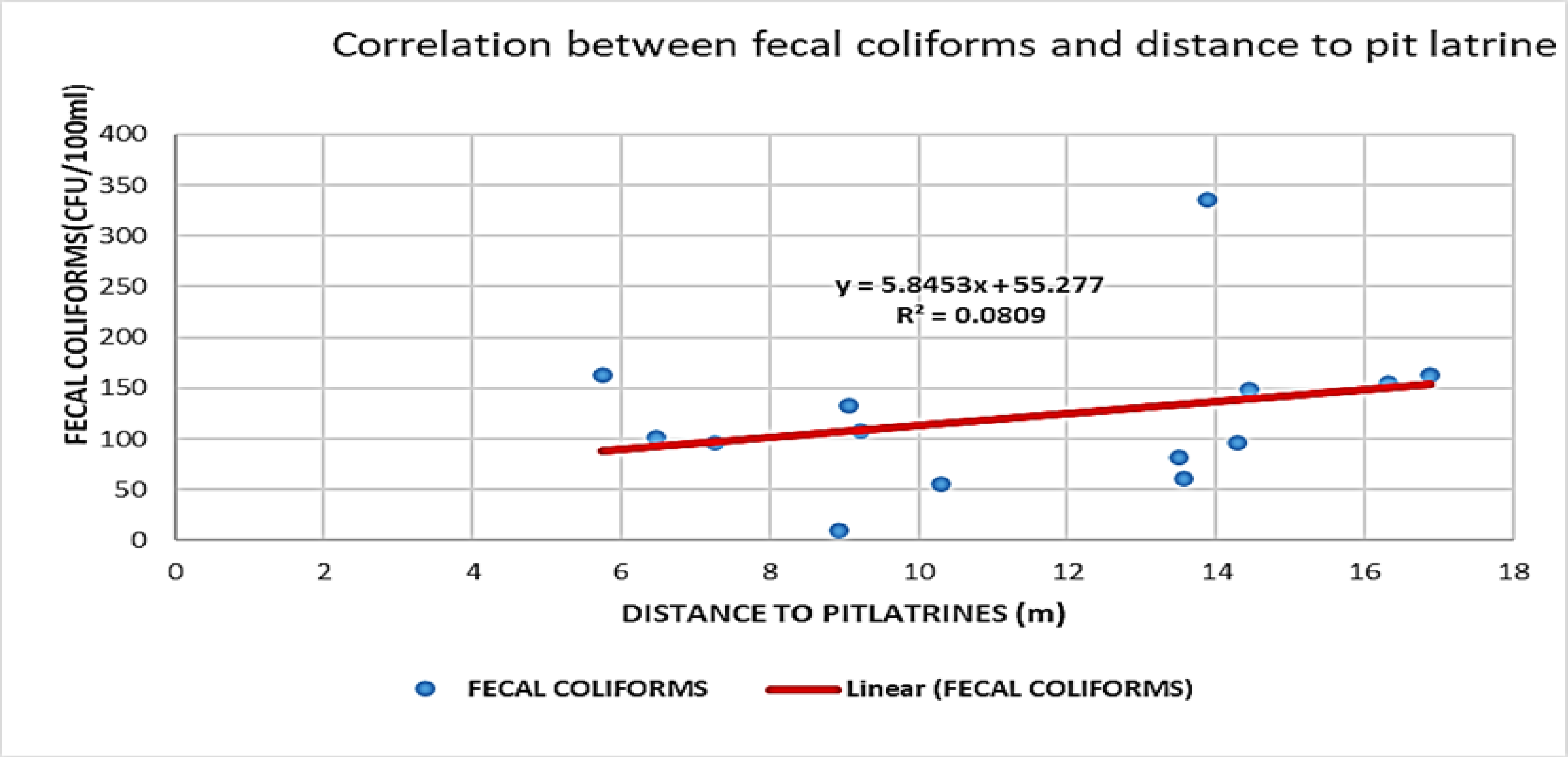


- Average distance:13.077 m
- porosity:45.08%
- hydraulic conductivity: $9.26 \times 10^{-5} m/s$

3.0 RESULTS AND DISCUSSION

- The average hydraulic gradient was estimated at **0.029**
- Using Equation1, average groundwater flow velocity was found to be **0.511m/day**
- Considering homogeneous and isotropic conditions, it would take a pollutant **25.58 days** to cover a distance of **13.077m,** the average horizontal distance between a pit latrine and the nearest well.
- Under homogeneous and isotropic conditions, the results indicate that contamination is occurring most likely at a point of drawing water and not through the geological formation as the groundwater flow rate is low and the soil formation act like a filter for contaminants.
- The correlation between fecal coliforms concentration in relation to the minimum distance to pit latrines was estimated as 0.08

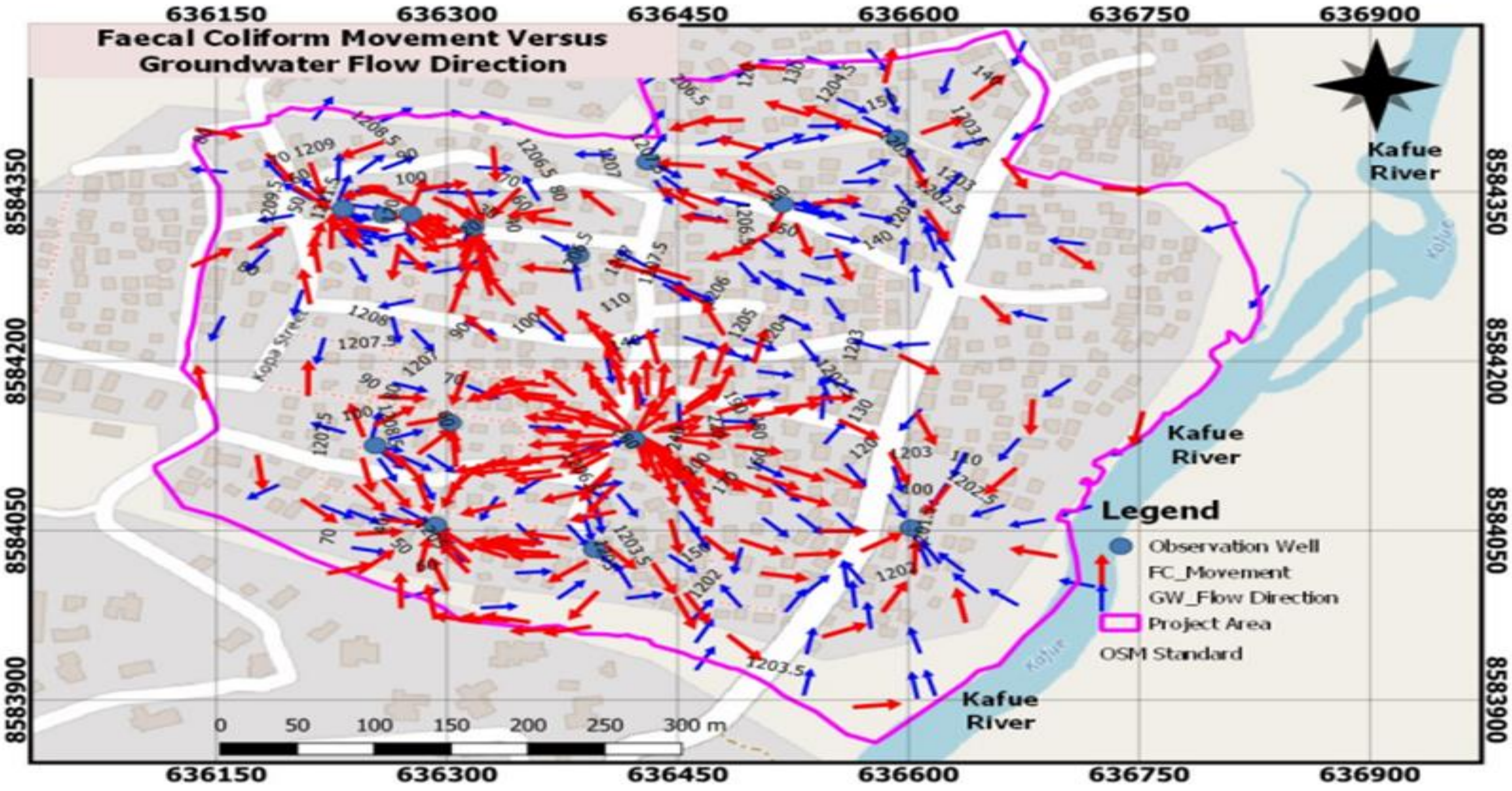
3.0 RESULTS AND DISCUSSION



- This indicates that the degree of contamination of the wells by faecal coliforms could not be attributed to the proximity to the pit latrines.
- Similar results were obtained for nitrates and total coliforms

3.0 RESULTS AND DISCUSSION

- Groundwater Flow Direction(**Blue**) and movement of faecal coliforms (**Red**) in the project area.



- **Pollutant movement** does **NOT necessarily** follow Groundwater flow direction

3.0 RESULTS AND DISCUSSION

- These lines are shown as “Blue” and “Red” arrows in the figure, which indicates a combination Faecal Coliform movement and Groundwater flow direction,
- The arrows create a visual comparison of movement of groundwater and faecal coliforms.
- it can be clearly seen that faecal coliform movement does not necessarily follow groundwater flow direction.
- Some factors that control faecal coliform movement in groundwater aquifers include adsorption, straining, hydrophobia and sedimentation.
- The findings clearly demonstrate that further research is needed to understand movement of groundwater pollutants and the interaction of groundwater with surface water

4.0 CONCLUSION

- The project was satisfactorily and successfully carried out within the limits of time and financial resources and the following conclusion have been drawn up:
- During the observation period;

➢ groundwater flow was predominantly from Kafue River to the project area, the Kafue River is a Losing Stream and it was recharging the project area.

➢ Using groundwater potential heads, Groundwater Recharge Rate for the project area was estimated from the rising limb as 0.017m/day and Discharge Rate was estimated from the recession limb as 0.011m/day.

➢ The groundwater in Chipata compound is contaminated with faecal coliforms and needs treatment by disinfection prior to consumption.

➢ Average groundwater flow velocity was estimated to be **0.511m/day**., it would take a groundwater **25.6 days** to cover a distance of **13.077m.**

4.0 CONCLUSION

- Further, correlation analysis between fecal coliforms concentration in relation to the distance to pit latrines was very low (**0.08)**
- Under homogeneous and isotropic conditions, it shows contamination likely occurs at a point of drawing water and not through the geological formation as the groundwater flow rate is low and the soil formation act like a filter for contaminants.
- it was revealed that pollutant (e.g., faecal coliforms) movement does not necessarily follow groundwater flow direction.

- These findings clearly demonstrate that further research is needed to understand movement of groundwater pollutants and the interaction of groundwater with surface water.

6.0 REFERENCES

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