



GROUND WATER QUALITY AND ITS PHYSICO-CHEMICAL NATURE AT TEN MILES, CHIBOMBO DISTRICT, ZAMBIA

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ABSTRACT

Water the eternal connectivity within the human system and with the environment is still the invaluable source, which is not possible to prepare, manufacture or produced by humans, similar to bountiful blessing of nature. However, creation to completion is incomplete without water. Due to rapid pollution, greedy attitude added with irresponsible approaches, instead of, “Life depends on Water”, has become, “Water restoration and sustainability seriously depends on the human life-style”. As the water contamination is furious including the seawater, human across the globe are in the hot spot to experience the extinction of water resources. If water and its resources not governed now, then it is never. Our own offspring may not be able to witness and enjoy the excitement extended from water to our generation. In developing countries, irrespective of the availability, water, water resources management, water supply needs immediate attention due to the swift urbanization with increase in population density. The countries in Africa gifted with plenty of natural resources of water face crisis due to the above-mentioned lack of planning. The demand and supply chain is altering at a faster rate in prominent cities like the capital cities of many countries in Africa.

In view of addressing the need of water analysis available at a particular locality, water analysis planned at possible locations. In the present study attempt made to bring out the physico-chemical properties of water available at the DMI St. Eugene University campus, Ten Miles along the Great North Road in the Chibombo area in near Lusaka. The common physico-chemical parameters that required to confirming the suitability of water for potable use such as colour, odour, turbidity, dissolved & suspended solids, hardness, etc., were analysed. Though these data are available in the existing literature, the above analysis carried out in the above mentioned fast urbanizing region. Within the scope and availability of the analytical facilities, this paper presents the preliminary data obtained on the water analysis with reference to the above parameters.

KEY WORDS: Ground water, Turbidity, pH, TDS, TH, EC, pH, Minerals, BOD and COD.

I. INTRODUCTION

Water though indispensable in the perspective of life, it is also the socio-economical factor which design and decides the progress of life. Hence, society and civilizations originated along the riverbeds such as Vedic or Indus valley civilization, Egyptian civilization, etc. The quality of life has great deal of difference between the communities who enjoy abundant water and who face water scarcity. Only 1% of the ground water is available as drinking water ^[1, 2]. Out of this 1 % water, the exact quantity of fresh water available as per the United States Geological Survey is a pinch as compared to the size of the earth ^[3]. If that fresh water availability considered as 100 %, out of this, 70 % utilized for agriculture, 22 % for industrial purpose and remaining 8 % for human day-to-day activities such as bathing, washing, cooking, cleaning and gardening ^[4, 5]. This clearly indicates that irrespective of the sources and the quantity available around 8 – 10 % of water converted into grey water (wastewater) regularly as a human contribution. Additionally this percentage soars and changes as the population and population density increases. A decade back data ^[5] certainly could vary presently in almost all the geographical locations when compared to the demography, urbanization and industrialization. As per World Health Organisation, WHO, the African continent also comes under the purview of water quality monitoring especially the Zambian region ^[6-8]. Estimation ^[9] conveys that about one sixth of the world population is deprived of adequate and affordable supply of potable water. This estimation has widened these years.

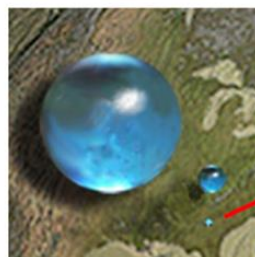


Fig. 1 (a)



Fig. 1 (b)

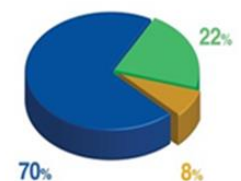


Fig. 1 (c)

Fig. 1 (a) Schematic illustration of Water Actually Available in a Particular Location ^[3]

Fig. 1 (b) Conversion of Available Water to 100 %

Fig. 1 (c) Utilization distribution of Available Water (in %) ^[5]

1.1 Geological Features of Zambia

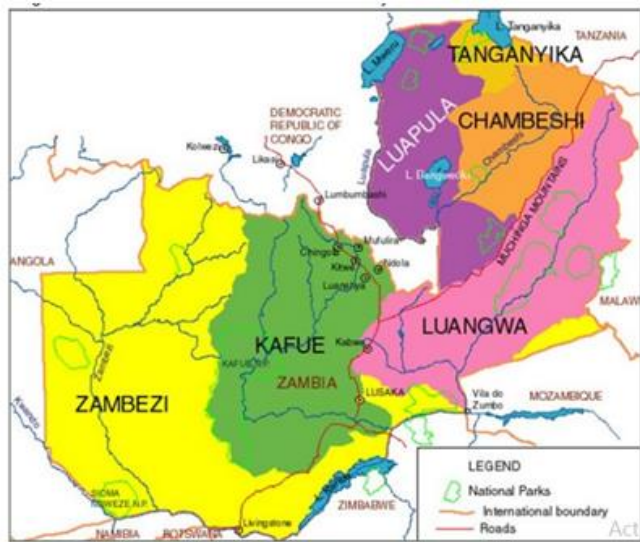


Fig. 2 Six Main Catchments of Zambia [11]

Zambia is situated in southern Africa, landlocked between the Democratic Republic of the Congo and Tanzania in the North; Malawi and Mozambique in the East; Zimbabwe and Botswana in the South; Namibia in the Southwest and Angola in the West with a total land area of around 752,612 km², which is around 2.5 % of Africa. The landlocked terrain of Zambia mainly consists of a high plateau with some mountains and hills. The elevation varies from greater than 2300 m in the Mafinga Hills on the northeast national border, down to 329 m in the Valley of Zambezi River. Zambia is endowed with good water resources among the other thankful things. The main river water sources in Zambia are the Zambezi, Kafue, Luangwa and Luapula. The four main rivers serve as the tributaries of the trans-boundary Zambezi River. The basin of Zambezi covers around three quarters of the country. The country also has major lakes such as Tanganyika, Mweru, Bangweulu and the man-made lake Kariba [10]. The six main catchments of Zambia as obtained presented here [11]. Lusaka, the capital of Zambia, is situated on the central African plateau at about 1300 m above the sea level.

Lusaka is built on a plateau, mainly composed of dolomitic marbles and schists, at an altitude of 1300 m a.s.l. to the North and dropping gently to 1200 m a.s.l. towards the East, the South and the West. The Lusaka plateau forms a watershed between the Chumba River, which ends up in the Mwembeshi River to the West, and many smaller rivers which end up into the Chongwe to the Northwest and Kafue river to the South. The flat morphology of the Lusaka plateaus is due to intense weathering of the outcropping rocks, resulting in the flat schist and carbonate plains with rounded quartzite hills, forming an immense erosion plateau known as the Gondwana and Africa surface [12].

The Lusaka area is underlain by a thick sequence of Precambrian meta-sediments which have been intruded by granite rocks and basic bodies [13]. These Precambrian rocks were divided into a mostly granitic Basement Complex. The Basement Complex crop out to the North and South of Lusaka and is composed of coarse grained quartz-muscovite-biotite schist and sheared quartz-feldspar-biotite gneiss in the North and augen gneiss, feldspathised and foliated schist in the South. The augen gneiss have been dated at 1106 ± 19 Ma [14]. The meta-sediments, which dominate in the central part of the area and underlay the city of Lusaka compose of Matero Quartzite, Ridgeway Schist and the Lusaka Dolomite formation from top to bottom [15, 16]. Quaternary alluvial sediments have been deposited locally. More or less thick soils are mainly composed of iron-oxide oolites in a clayey matrix on schist, gneiss and granite.

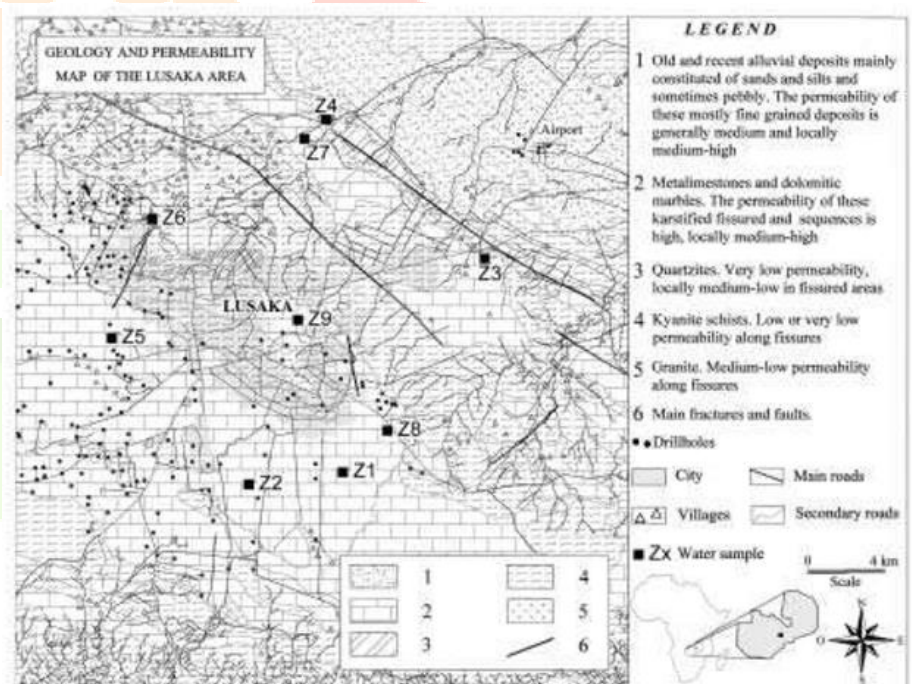


Fig. 3 Geology and Permeability Map of Lusaka City [19]

The calcareous and dolomitic marbles of the Lusaka Formation represent a karst aquifer of regional importance. An estimation before two decades reports that out of 450,000 m³/day water demand, 20 % alone supplied by Kafue river which is located 40 km south of Lusaka, while rest met through available boreholes in the karst aquifer. This aquifer comprises an epikarstic zone extending down to 25 m below the surface [17, 18]. Solution channels, round karren, solution flutes and cavities allow a fast infiltration. Many fracture joints, shears, and thrust faults at the schist-dolomite contact, also represents highly permeable areas. The geological features presented above (Figure 3) were obtained from the studies carried out by Rosa and co-workers [19].

The water table is at an average depth ranging from -2 to -25 m below the surface. Due to overexploitation and low rainfall decrease in depth were observed [20] and it is continuing [21]. In some places situated at extremely shallow depth, water table ranges from 0.5 to 30 m below the surface, however, the average depth is at 6 - 15 m [10]. The best aquifers in Zambia occur within the limestone and dolomite horizons of the katunga system. Yields in these are highest at the top 30 m of the sediment strata where fissures are best developed. These aquifers provide a significant proportion of the water supply for the municipalities of Lusaka, Kabwe and Ndola. Sporadic, thermal or saline springs occur in parts of Southern, Central and Eastern provinces of Zambia [22-24]. Nkhuwa and team made [17, 25] observations on the water quality of some shallow wells in some peri-urban areas of Lusaka between 2003 and 2005 followed by Rosa and team [19]. The geological features discussed above provide a general outline on the influence geology on the groundwater resources of Lusaka region, Zambia.

Although Zambia may have sufficient water during the rainy season, many catchment areas are not properly governed [26]. Each year the urbanisation and industrialisation leads to high contamination level in nearby urban areas [24]. Water, sanitation and hygiene factors are responsible for 11.4 percent of all deaths in Zambia [27]. The lack of data about groundwater resources also has implications for climate change research and policy making [28]. These uncertainties are critical since the climate system and groundwater storage is fundamental, integrated parts of the hydrological cycle and, in turn, of all types of life on Earth [29].

Zambia's capital Lusaka is situated on an elongated plateau that divides the sub-catchments of the Kafue River (including the Lower Mwembeshi River below the Chunga River) located in west and southward direction of the city from the Upper Mwembeshi and Chongwe river sub-catchments in the east and northeast. Geologically the plateau is made of very old carbonate rocks of Precambrian age that host a very productive groundwater body supplying water to the rapidly growing population of Lusaka. The Mwembeshi and Chongwe catchments share Zambia's most significant groundwater reserve [31].

1.2 Geological Features of Ten Miles, Chibombo

The sampling location is DMI St. Eugene University, located at Ten Miles is in the Chibombo District, situated in the central part of the Zambia. The Chibombo province is surrounded by other provinces like Kabwe, Chisamba, Lusaka, Chongwe, and Kafue. The sample location lies in the Mwembeshi catchment. The geological features represent Nyama formations in Chibombo district. This appears as colluvial deposits of carbonaceous rocks, which correlates with Lusaka dolomite and marbles of Cheta. Nyama formation is classified as aquifers of moderate and high potential possessing exceptional permeability [30, 33 & 34]. The groundwater resources as obtained presented [19, 30] with a possible matching from the Google map [32].

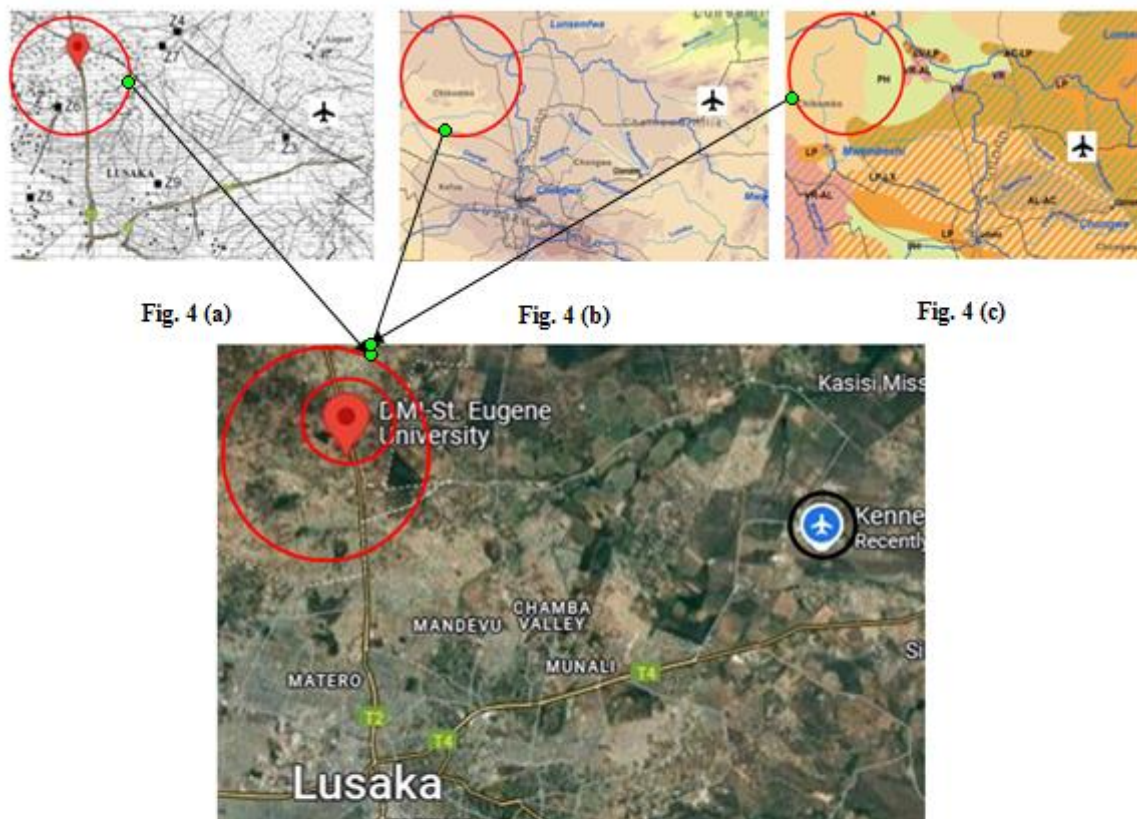


Fig. 4 (a)

Fig. 4 (b)

Fig. 4 (c)

Fig. 4

Fig. 4 (a) Representative geology and permeability map [19]
 (b) Mwembeshi and Chongwe Catchment [30]
 (c) Soils of Mwembeshi and Chongwe Catchments [30, 31]
 (d) Resemblance with the present sample location [32]

The sampling location lies in the Mwembeshi catchment (fig. 4). The Mwembeshi Catchment is characterised by an overall relatively flat undulating terrain (peneplain – land surface produced by erosion over a long period) gently sloping west or south which is broken by isolated hills or low ranges of resistant rock. The maximum altitude of the undulating hills those are typical for the upper catchment range from 1,100 to 1,200 metres asl. Only the hills with the Kawena Forest area located in the far northwest of the catchment reach heights of above 1,200 meters asl. In some areas, resistant quartzites form prominent ridges rising some 50 to 70 meters from the general surface. The southern (lower) catchment area is a part of the monotonously flat flood-plains of the Kafue, so called **Kafue-Flats**. The confluence of the Mwembeshi is at an altitude of approximately 978 meters asl [30].

The Lusaka Plateau forms in some sections, the drainage divide between the Chunga, Ngwerere, Chalimbana rivers to the north and the lower Mwembeshi, Chilngolo and Funswe Rivers to the south. The plateau is characterized by a striking absence of surface flow. A lack of surface drainage is also characteristic for the ESE-WNW (east-southeast-west-northwest) stretching outcrop of Cheta limestone located between the Mwembeshi and Chunga Rivers. This is explained by the high permeability of the parent rock, highly metamorphosed limestone and dolomite that has undergone enhanced dissolution weathering which called as **Karstification** near the surface. Karstification produced fissures, sinkholes, underground streams and caverns. This is

together with the widespread lack of a thick protective soil cover results in high infiltration of rain water into the ground and effective underground drainage. Additionally Karstification produces high level of infiltration in carbonaceous rocks [30]. This affects and effect the permeability and pollution.

1.3. Rainfall and Climatic Conditions in Sampling Location

Like elsewhere, in Zambia, the climate is sub-tropical with a clear distinction between the cool and hot dry season lasting from May to October and the wet season between November and April [17] [18]. Zambia also experiences periodic drought and tropical storms during October to April [7]. Rainfall total and intra-seasonal distribution vary greatly from year to year. The area receives long-term average annual rainfall in the order or 800 – 850 mm. Due to large seasonal variation, the flow of most rivers and stream reduces to a trickle or ceases completely during the dry season irrespective of the relative high annual rainfall totals. Only exception is the Chongwe River.

1.4 Weather Condition

October is the warmest with an average temperature of 31.3 °C at noon. July is the coldest with an average temperature of 8.7 °C at night. In winter there may be some days it freezes, overall winters are mild in temperature, with the coldest month most of being July. July is on average the month with most sunshine. Rainfall peaks around January. The time around June is driest.

The interesting geographical features and its impact on the ground water along with the fast urbanizing sample location inspired to undertake the study on the water which is available and utilized at the location. Similar studies presented to understand the nature and quality of water utilised [4]. To initiate the water quality analysis in Zambia samples from the DMI St. Eugene University were collected (fig 5) in consecutive months of August and September 2015. The physico-chemical parameters as obtained within the limitations and scope of the experiments are presented in the paper.

II. MATERIALS AND METHODS

2.1 Experimental Location

The experimental location is DMI St Eugene University, Ten Miles, Chibombo District, near to Lusaka, Zambia. No specific / special approval required as none of the classified, environmental disturbing, endangering and / or protected activities involved. The location map of the experimental location obtained from the Google resources presented in the figures 5a – 5f [32]. As the actual photograph reserved, common and available Google images of the experimental location shared. The circle in the figures 5c – 5f indicates the tap water source [32]. As the actual photograph of the sample location reserved images as obtained from the Google Maps presented [32]. The study area has latitude: 15°29' towards south and Longitude: 28°26'towards east [32].



Fig. 5a



Fig. 5b



Fig. 5c



Fig. 5d



Fig. 5e



Fig. 5f

Fig. 5a – 5f Sample Location: DMI St. Eugene University, Ten Miles, Chibombo, Zambia [32]

2.2 Sample Collection

For the present study, water samples collected from the ground water as obtained from the tap water at the DMI St. Eugene University Campus, Ten Miles, Chibombo, Zambia for a period of two months starting from August 2015 and November 2015. To maintain uniformity water sampling collection fixed from 12:00 to 12:30 hours. The physical characterization techniques include temperature, colour, conductivity, turbidity, total dissolved solids (TDS), total suspended solids (TSS) and total solids (TS). The chemical analysis include alkalinity, hardness, pH, dissolved oxygen (DO), minerals (Ca, Mg, Na, Cl₂, SO₄, PO₄, NO₃, and K), chemical oxygen demand (COD) and biological oxygen demand (BOD). The samples collected and pretreated in the field to fix the samples then immediately brought to the laboratory for an on-spot physical and chemical analysis of various parameters as per the standard methods [35-37]. The water samples are referred as Sample 1 and Sample 2 for the water sample collected and analyzed in August and September 2015 respectively. Samples were collected in the fifteenth day of the month (as per the Gregorian calendar), that is 15th of August and November 2015. The temperature of both the days noted along with the variation.

III. RESULTS AND DISCUSSION

The results and discussions presented into the following sections: (i) Climate and weather observed during the test period and (ii) physico-chemical characteristic features of the water samples obtained during the test period.

3.1 Climate and Weather during the Test Period

The months in which tests were carried out will be referred as 'test periods' henceforth. The test period lies in the 'cool and hot dry season' and the starting of the wet season [17, 18]. The temperature profile during the test period is provided in Table 1. As the sampling time was fixed around 12 hours, slight variation in the temperature was observed during the sample collection. But, the temperature profile shows a remarkable variation in the lowest temperature during the sample collection day and 'test period'. A moderate and heavy rainfall was observed during the day of collection of sample 1 in Aug 15, 2015. But the rainfall was less when exactly the sample was packed (Fig. 6) [38]. However, when sample 2 was collected totally rainfall was less (fig. 7) [38] and particularly there was no rainfall during the sample collection day. Also, when compared to the cool and dry season, rainfall was lesser during the wet season [17, 18, 38]. The analysis of the water sample collected carried out as per the American Public Health Association Standards [39]. Colour change was not observed in both the collected samples.

Temperature Profile	Temperature (°C)	
	Aug 2015	Nov 2015
Temperature at Sampling Time (around 12:00 Hours)	31	30
Lowest Temperature on Sampling Day (15 th)	11	19
Lowest Temperature of the Month	5	12
Highest Temperature of the Month	35	40

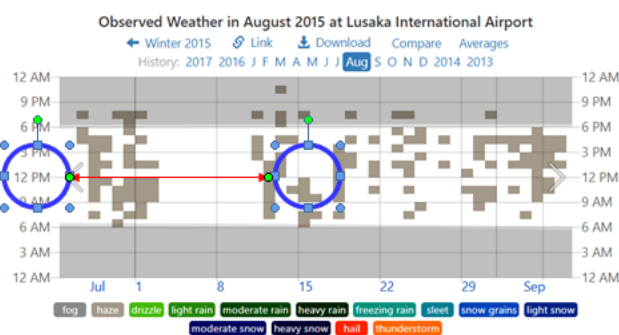


Fig. 6 Rainfall Details of Aug 15, 2015 as Obtained [38]

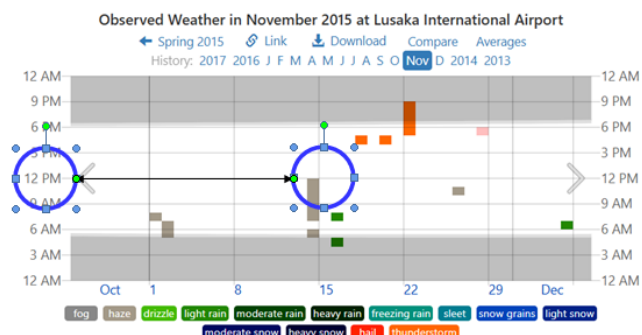


Fig. 7 Rainfall Details of Nov 15, 2015 as Obtained [38]

3.2 Physico-chemical Parameters

The complete water quality parameters as obtained for the Samples 1 and 2 are presented in Table 1 and 2. Table 1 presents the physico-chemical parameters and the nutrient contents are presented in Table 2.

Parameter	Sample 1	Sample 2
pH	8.3	8.5
TDS (mg/l)	1164.5	1088.6
EC (µS)	1687.4	1454.8
Salinity (mg/l)	1	1
DO (mg/l)	8.1	7.7
BOD (mg/l)	11.4	10.3
COD (mg/l)	25.3	20.8
TA (mg/l)	150.1	136.6
TH (mg/l)	179.6	140.1

Nutrients (mg/l)	Sample 1	Sample 2
Ca²⁺	101.4	96.5
Mg²⁺	65.6	58.8
Na⁺	63.7	56.8
K⁺	48.8	34.5
HCO₃⁻	136.3	124.1
Cl⁻	265.4	233.2
SO₄²⁻	93.5	80.1
N-NO₂⁻	8.8	7.1
O-PO₄³⁻	9.1	8.2

The physico-chemical parameters of the water sample collected in two different seasons are presented in figure 8a-8e for the convenient and effective comparison. The figure 8a, presents a comparative analysis of electrical conductivity (EC) and total dissolved salts (TDS). The taste and odour of the water is mainly due to the presence of dissolved solids. A difference of 15 % observed in the EC value with a lower value in the Sample 2. Around 7 % variation was observed in the value of TDS. The increase could be attributed to the geological features of the Chibombo region as discussed in the earlier sections and soil type is a mixture of 2, 3 and 4 type represented in figure 3. An increase in the TDS value in the heavy rainfall might have led to the medium to very low permeability feature [29-34], because hardly a 15 % reduction in the TDS observed in the Sample 2. However it is obvious that the rainfall during the month of August, which features with heavy rainfall, had influenced the water through permeability and a lesser rainfall in the month of November (fig. 6 and 7). The direct relationship of EC with TDS is confirmed [40]. Apart from the rainfall runoff increase in concentration of ionized substances, possibilities of mineral contamination, dissolved ionized salts, rock-water interaction during the recharging of water, may also be the reasons for the increase in EC value in Sample 1, which is found absent in the Sample 2 with a lower EC value [41, 42] (fig. 8a).

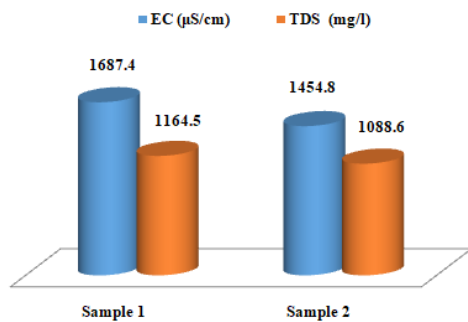


Fig 8a. Physico-Chemical Parameters - Comparison of EC and TDS

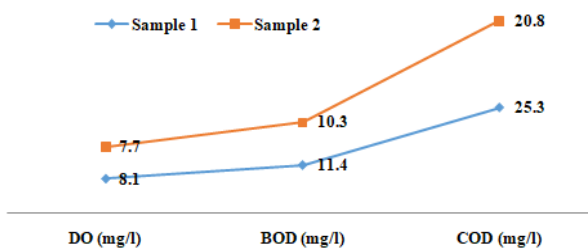


Fig.8b. Physico-Chemical Parameters – Comparison of DO, BOD and COD

Figure 8b presents the comparison of the dissolved oxygen (DO), biological oxygen demand (BOD) and chemical oxygen demand (COD), observed in the two different seasons. In both the samples the dissolved oxygen content is inversely proportional to the BOD values [50]. During the rainy season an increase above values observed from the Sample 1. This might be due to the organic matter decomposition, runoff, etc., [43-45]. The higher dissolved oxygen value during the rainy season indicates that the pollutant present in the sample is diluted due to the heavy rainfall [46, 47]. Low level DO from Sample 2 indicates the reduction of dilution effect due to lesser rainfall (fig. 6 and 7) and slightly concentrated with the associated pollutants present in water system [47-49]. During rainy season micro-organisms change the organic materials into microbial mass which may lead to an increase in BOD [50, 51]. The relationship between the level of rainfall and its runoff leading to microbial pollution with an increase in BOD values is indicated [51-55]. Variation of 10 % in BOD and a 20 % of variation in COD observed. A higher value in Sample 1 may be predominantly due to the enrichment of organic contents through surface permeability and recharging of the ground water through the water channels connected with the water source. A reduction in dissolved oxygen with an increase in BOD and COD is confirmed from the observation indicates that, the consumption of oxygen for the bio-chemical oxygen demand. The high COD value indicates decomposition of microbes when they present in a higher level during the rainy season (Sample 1, Fig. 8b) [56].

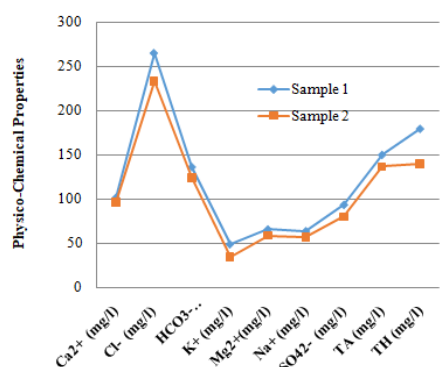


Fig 8c. Physico-Chemical Parameters - Comparison of Cations and Anions, TA and TH

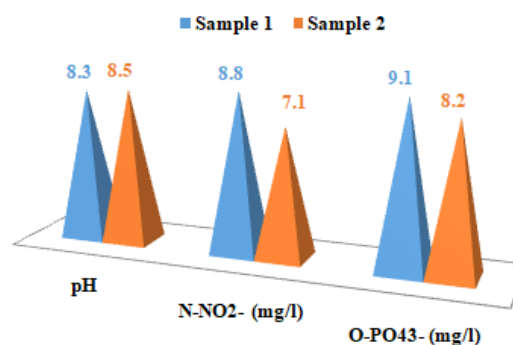


Fig. 8d Physico-Chemical Properties - Comparison of pH, Nitrite and Phosphate

The other physico-chemical parameters are presented as figures 8c and 8d. For a better representation, parameter which have a higher value than 10 mg/l are compared and shown in figure 8c and with values less than 10 mg/l are compared and shown in figure 8d. The hardness of water (fig. 8c) is due to the presence of Ca²⁺ and Mg²⁺ salts in the form CO₃, HCO₃, SO₄, NO₃, and Cl₂ [57]. The cationic part is responsible for hardness because when water is combined with CO₂ to form very weak carbonic acid [58]. As water moves through the soil and rock [59], it dissolves very small amount of minerals and holds them in solution. The degree of hardness becomes greater as the calcium and magnesium content increases and is related to the concentration of multivalent cations dissolved in the water (fig. 8c). The effect of karst features discussed in the previous section realized with a very high value of bicarbonate content. Around 25 % of increase in hardness observed and around 9 % change in total alkalinity observed. The change could be attributed to the high calcium, magnesium and chloride content in both the sampling seasons (fig. 8c). The presence high ion contents have been reflected in the TDS and EC values (Table 1 & 2, fig. 8a). The pH values observed (fig. 8d) were having a slight variation and moving towards alkalinity indicates the stable content of alkalinity producing salts in the water source. An increased nitrite and phosphate content is observed in both the seasons (fig. 8d). This may be due to the poor sanitation conditions in and around the water sources. Major issue in the country is 'Pit Toilet' system due to the fast urbanization in periurban areas. Another factor is karstified aquifer system which acts as a source of infiltration as well as a pathway for pollutants in the groundwater source [29-44].

The piper diagram of the water samples analyzed presented in figure 9. The rhombus in the diagram (fig. 9) indicates a mixed type of soil predominated by calcium chloride. The dominance of calcium in terms of bicarbonate (fig. 9, fig 8b and Table 1) is reflected and the anionic triangle confirms the chloride dominance apart from the other compositions. With a lesser data profile it is a great deal to confirm the complete water profile available in the location.

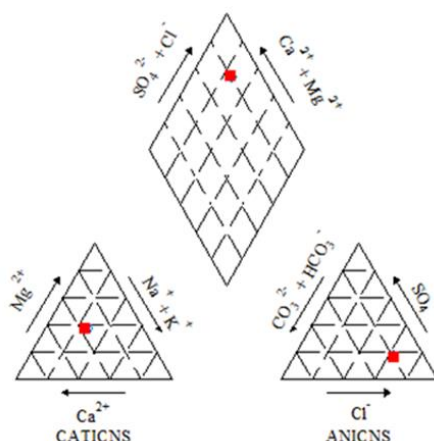


Fig. 9 Piper Diagram of Ten Miles

IV. CONCLUSION

This paper though a preliminary investigation provide a water data based on feasible observation of the water quality parameters within the experimental limitations. Water one of our life saving factors is getting deteriorated day by day, a regular experimental strategy is mandatory. The quality of water obtained in the fast urbanizing study area (Ten Miles, Chibombo District, Zambia) is presented. High deposit of salts and hardness is the fore front problem of this site. But wherever urbanisation is there pollution is inevitable. The Karstification features found to influence the water quality during seasonal variations. The research does not include the pathogenic and other water prone disease-causing bacteria and viruses in the water quality. The heavy metal analysis and other biological parameter analysis for a long duration (minimum 1 year) may provide a complete qualitative aspect. As water analysis and monitoring is time taking and expensive process, Government of Zambia can implement water distribution centres under public-private partnership (PPP) model, where UV treated reverse osmosis (RO) water could be supplied. A pilot project should be implemented to assess the economic cost associated with the technology.

V. ACKNOWLEDGEMENT

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