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# Groundwater Quality Assessment from Phalombe Plain, Malawi

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## ABSTRACT

In the present study, groundwater samples were collected from ten boreholes in the Phalombe plain, Southern Malawi. The main objective was to assess the suitability of the borehole water for human consumption. Physico-chemical and bacteriological parameters of the groundwater samples were determined using standard methods. Results were compared to the World Health Organization (WHO) and Malawi Standard (MS) drinking water guidelines to assess suitability. All analyses for physicochemical parameters were within acceptable limits except for fluoride concentration levels which were above WHO recommended limit of 1.5 mg/L in two boreholes (Lihaka Primary School, 2.9 mg/L and Phalombe T.C, 2.0 mg/L). Trace metal contamination was below detection limits with atomic absorption spectrometry. Feacal coliform units exceeding WHO tolerated limits of 0 cfu/100 mg/L were observed in five groundwater samples from Lihaka Primary School (11 cfu/100 mL), Migowi trading center (4 cfu/100 mL), Phalombe T.C (77 cfu/100 mL), Thetheleya Village (73 cfu/100 mL), and Mpasa T.D.C (102 cfu/100 mL) boreholes. It was concluded that not all the borehole water is safe for human consumption. The presence of feacal coliform in some boreholes is indicative of health risk to the inhabitants of the geographical location. The study recommends mobilization of onsite possible means of treatment of groundwater such as boiling and use of chlorination tablets so as to prevent possible adverse health effects.

**Keywords**: Bacteriological, Borehole, Malawi, Phalombe Plain, Water quality, WHO/MS drinking water guidelines

## INTRODUCTION

Water is essential to life and its quality is a very important determining factor of health, growth, survival and development (WHO, 2010). Adequate supply of safe drinking water is universally recognized as a basic human need and represents one of the most essential factors of civilization. Groundwater resource represents the world's largest and most important source of water supply in many countries in the world including Malawi. Groundwater provides potable water to an estimated 2 billion people worldwide daily and stands as the most reliable resource for meeting rural water demand in sub-Saharan Africa (Palamuleni and Akoth, 2015; Affum *et al.*, 2015).

However, availability of portable drinking water is still a major concern as millions of people in developing countries do not have access to adequate and quality safe drinking water. The Millennium Development Goal (MDG) target-7 calls for the reduction by half of the proportion of people without access to safe drinking water and basic sanitation by 2015. To attain this goal implies, tackling both the quantity (access, scarcity) and quality (safety) dimensions of drinking water provision (UNESCO, 2015).

Malawi has a fast growing population of about 18. 62 million with an annual rate of 2 percent (GoM/UNEPA, 2018). The fast growing population has not been accompanied by increase in access to good quality water supply and the gap between the area that have access to safe water supply and those without has grown wider. In Malawi, like most African countries, majority of the rural communities do not have access to potable water. Due to inability of the government to meet the ever increasing water demand and considering that only a few people can afford and rely on purified and treated bottled water particularly for drinking, groundwater water serves as a source of potable drinking water and domestic use especially in rural communities. Humans can abstract groundwater through a borehole, which is drilled into the aquifer for domestic, agricultural and industrial use. In Malawi, tens of thousands of boreholes (water points) exist across the country providing drinking and domestic water supply to rural village communities (Rivett *at al.* 2018). Most of these boreholes are equipped with handpumps installed by Malawi government and international aid programmes facilitated by non-governmental organizations (NGO) in liaison with the Malawian government to enable the villagers to pump and collect their own water supply for drinking, washing and other domestic use.

Groundwater may contain some natural impurities or contaminants, even without human activity or disturbance. Natural contaminants may results from many conditions in the water shed or in the ground. Noteworthy is the fact that, as groundwater moves through underground rocks and soils it is normally clean from anthropogenic pollution; however, due to weathering processes, groundwater may contain different chemical compounds depending on the geological and geochemical constitution of the area. These natural contaminants become a health hazard when they are present in high concentrations. Besides natural contaminants, groundwater is often polluted by human activities such as improper use of fertilizers, animal manure, pesticides, insecticides, and herbicides[2]. In addition, poorly built septic tanks and sewage systems for household wastewater, abandoned or leaking underground storage tanks, industrial waste and chemical spills at local industrial sites all contribute to the pollution of groundwater (Affum *et al*., 2015; Nyirenda *et al*., 2015; Wamalwa and Mutia, 2014). Studies have shown that groundwater quality is influenced by the geochemistry and geology of the environment, rate of urbanization, industrialization, metal salts/heavy metals pollution, landfill/dumpsites leachates, bacteriological pollution and effects of climate change (Douagui *et al*., 2012; Brindha, and Elango, 2013; Ikem *et al*., 2002; Hailu *et al*., 2017).

According to World Health Organization (WHO), an estimated more than two million deaths due to waterborne diseases such as typhoid fever, diarrhea, infectious hepatitis, and many gastro-intestinal diseases due to microbial contamination in water particularly bacteria are recorded annually, including Malawi (WHO, 2011a). Apart from waterborne diseases, fluorine is naturally occurring and when consumed in high levels on daily basis can lead to dental fluorosis in children and has been reported in Southern Malawi around the Phalombe plain (Anastasia von Hellens, 2013). It is important to note that waterborne infections are one of the greatest health concerns facing many government authorities worldwide especially in developing countries including Malawi. Therefore, there is need for periodic assessment of the quality of groundwater especially boreholes to determine their level of pollution and their safety for human consumption. The main aim of the study was to evaluate the physico-chemical and bacteriological quality of selected borehole water samples in the Phalombe plain, Southern Malawi.

## MATERIALS AND METHODS

### Study Area

A location map of the study areas is shown in Fig. 1. The Phalombe district covers an area of about 1,394 km$^2$ and has a population of 231,990 people **(**GoM, 2009). The Phalombe plain is bounded by Lake Chilwa on the north, Zomba district on the west, Mozambique on the east just beyond Songwe Hills and Mulanje and Thyolo districts on the south. The Phalombe plain is part of the famous Zomba-Phalombe Plain that lies within the Chilwa Alkaline Province (CAP), a general term used to describe intrusive igneous rocks (basement complex) composed of carbonatites, nepheline synite, syenitic granites, syenite-quartz intrusions and granite of the Precambrian age (Woolley, 1987). This basement complex is the main aquifer that hosts the groundwater.

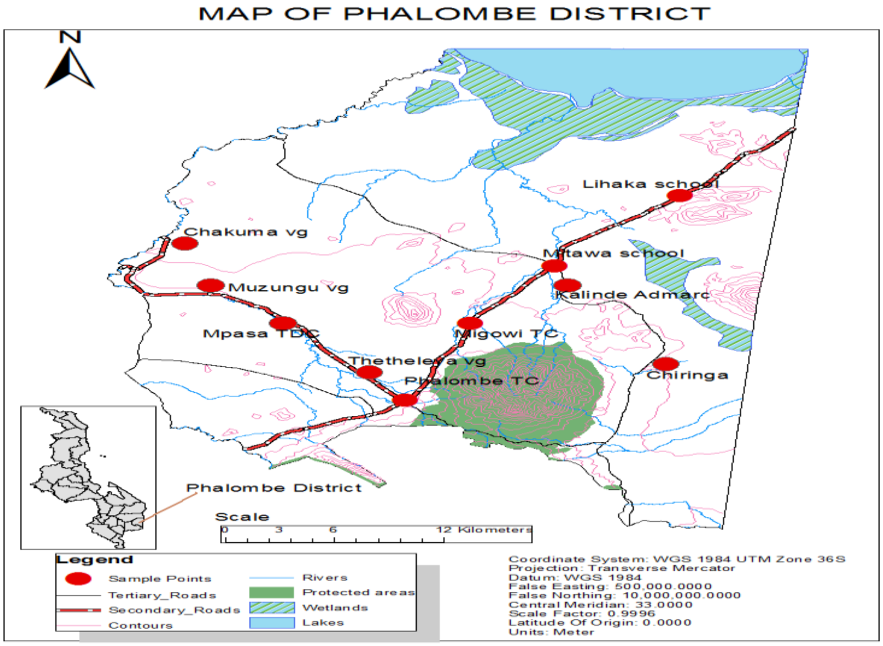

**Fig. 1: A location map of the study areas (sample borehole in red)**.

**Sample collection**

Water samples were collected in March 2018 in sterilized polyethene plastic bottles from ten boreholes in ten different locations within the Phalombe plain, Southern Malawi. Two bottles of samples were collected at each sample point. The borehole water was pumped and ran for two minutes after which the 500 mL pre-sterilized capped polythene plastic bottles were carefully uncapped and filled with water. The bottles were then transported in an ice bath to the Chemistry Laboratory of Chancellor College, University of Malawi for analysis. The samples collected from various sites were labeled as shown in Table 1.

**Table 1: Sampling sites, labels, date at which borehole was constructed, depth of bore and GPS of boreholes within study area.**

| Name of location of borehole | Sample Code | Date borehole was constructed | Depth of borehole (m) | GPS location and elevation |
|---|---|---|---|---|
| Lihaka primary school | PHP1 | 22/06/02 | 66 | 798783 UTM 8273668 |
| Mitawa primary school | PHP2 | NA | NA | 791914 UTM 8266063 |
| Kalinde Admarch | PHP3 | 27/10/16 | 30 | 792486 UTM 8264837 |
| Migowi Trading Center | PHP4 | 7/12/17 | NA | 787416 UTM 8259439 |
| Chiringa village | PHP5 | 17/7/98 | NA | 797965 UTM 8254860 |
| Phalombe Trading Center | PHP6 | 25/01/17 | 32 | 783818 UTM 8251017 |
| Thetheleya village | PHP7 | NA | NA | 781938 UTM 8253306 |
| Mpasa Trading Center | PHP8 | 23/03/17 | 46 | 778667 UTM 8258458 |
| Muzungu village | PHP9 | 28/02/15 | NA | 773106 UTM 8264019 |
| Chakuma village | PHP10 | NA | NA | 771798 UTM 8268598 |

NA = Not Available

**Physico-Chemical Analysis of Selected Borehole Water Samples**

The water samples from each borehole were examined in terms of physical and chemical properties using WHO standard methods of analysis. The water temperature, pH, electrical conductivity, total dissolved solids and turbidity were measured at the point of collection. Other parameters such as fluoride, chloride, nitrate, phosphate, sulphate, total hardness, calcium, magnesium, sodium, potassium, iron, arsenic, lead were analyzed at the laboratory.

Samples used for cation analysis were filtered using a filter paper prior to analysis in the laboratory while those used for anion analysis were not filtered. In the determination of metals and heavy metals, water samples were digested with nitric acid (conc. 55%) and the metals determined using an Agillent 240 FS flame atomic absorption spectrophotometer (Agilent Technologies, USA), after calibrating the equipment with respective standard solutions. Chemicals used for the analysis were of analytical grade and used without further purification.

**Bacteriological Analysis of Selected Borehole Water Samples**

Total viable count and feacal coliform count were determined using membrane filtration technique (Habash and Johns, 2009). A 100 mL volume of each sample was filtered through a membrane with pore size (0.45 mm) small enough to retain the indicator bacteria to be counted. Plates were incubated in an inverted position for the growth of thermo-tolerant faecal coliforms into dome-shape at 44.5 °C for 24 h. Colonies was recognized by their colour, morphology and number.

**Counting Total Bacterial and Feacal Coliform Units**

Counting of feacal coliform colonies was done after 24 h. Those which appeared pink and shiny were counted as *Escherichia coli* while those which had a deep pink color were counted as feacal colonies (Bartram and Balance, 1996). The number of coliform forming units (CFU) per 100 mL was calculated by using equation 1:(ASTM, 2012).

$$CFU/100\,mL = \frac{N \times 100}{Df}, \qquad (1)$$

Where N = number of colonies counted and Df is the dilution factor. Averages and standard deviations were calculated using Microsoft excel.

## RESULTS AND DISCUSSION

**Physico-Chemical Properties**

The physico-chemical nature and pathogenic content have a great effect on the taste and quality of water for drinking and other purposes. Table 2 shows the physico-chemical and bacteriological attributes of the selected borehole water samples compared with the WHO and MS permissible limits for drinking water quality. Temperature is one of the important ecological and physical factor that influence both living and nonliving component of the environment and as such it affects organisms and the functioning of the ecosystem (Palamuleni and Akoth, 2015). Too high temperatures negatively affect water quality by enhancing the growth of micro-organisms which may affect taste, odor and corrosion problems (UNICEF, 2008). Therefore, it is very important for borehole water not to have too high temperature in order to avoid microbial proliferation. In addition, it has been reported that increased temperature not only affects physical, chemical, and biological activities but also decrease solubility of gases such as $O_2$, $N_2$, $CO_2$ and $CH_4$ in water (Yilmaz and Koc, 2014).

There is no temperature guideline values recommended for drinking water, although it generally influences the quality of drinking water. In this study, the temperature values of the selected borehole water samples ranged from 25.4 °C to 28.5 °C, with an average value of 26.74 °C, which fall within accepted standard limits. All samples were clear, colourless and odourless with values within the acceptable limits prescribed in WHO/MS, hence characteristic of good quality water. Although pH usually has no direct impact on consumers, according to a WHO report, it is one of the most important operational water quality parameters (WHO, 2008). According to WHO, health effects are more pronounced in extreme pH values. Drinking water with an elevated pH above 11.0 can cause eye, shin and mucous membrane irritation. Additionally, pH above 9.0 may be disadvantageous in the disinfection and treatment process of drinking water as chlorination may be ineffective (Meenakshi *et al*., 2015). On the other hand, drinking water with lower pH values below 4.0 could cause irritation due to the corrosive effect. The WHO pH value for portable should be between 6.5 and 8.5. In this study, a pH range of 7.2-8.0 was obtained, which were within the WHO as well as well as the MS limits (Table 2).

Conductivity is a function of temperature, types of ions and concentration of ions present in water samples. Thus, conductivity value is a measure of the dissolved ionic component in water and gives an indication of the amount of total dissolved solids in water (Iyasele and Idiata, 2015). A high dissolved solid limits the suitability of the water for portable use. The WHO has a recommended value of 1000 µS/cm for electrical conductivity (EC) of drinking water. The mean values obtained for the ten samples were in the range of 216 µS/cm-2398 µS/cm with borehole water samples from Kalinde Admarc, Mpasa T.D.C, Muzungu village and Chakuma village having conductivity values above 1000 µs/cm (see Table 2 and Figure 2). Meanwhile the lowest of 216 µs/cm was recorded at Phalombe T.C borehole.

However, these values were below the MS permissible limit of 3500 µS/cm. It should be pointed out here that the high values of EC obtained for the four borehole water samples listed above gives a picture of more solute dissolution, low ion-exchange between the soil and water and a soluble geological rock and mineral type within these boreholes. This complemented the notion of the inhabitants around these areas that water from these boreholes has a salty taste. The values of total dissolved solids for the selected borehole water samples in this study were in the range of 108–1198 mg/L. Except for water samples from Kalinde Admarc and Muzungu Village with values above World Health Organization maximum allowable limit of 1000 mg/L (WHO 1996), the other eight borehole water samples recorded TDS values below the WHO recommended guideline value. Higher values above recommended value may affect acceptability of drinking water. Similar to conductivity values, the presence of high dissolved solids in the water samples may be due to pollution by leaching of ions due to prolonged weathering of tropical soils and rock especially since the study area is of close proximity to the topographic ring complex of Zomba and Mount Mulanje. Overall, higher levels of dissolved solids in water may affect its taste and the water not considered "fresh water" and good for drinking and irrigation purposes.

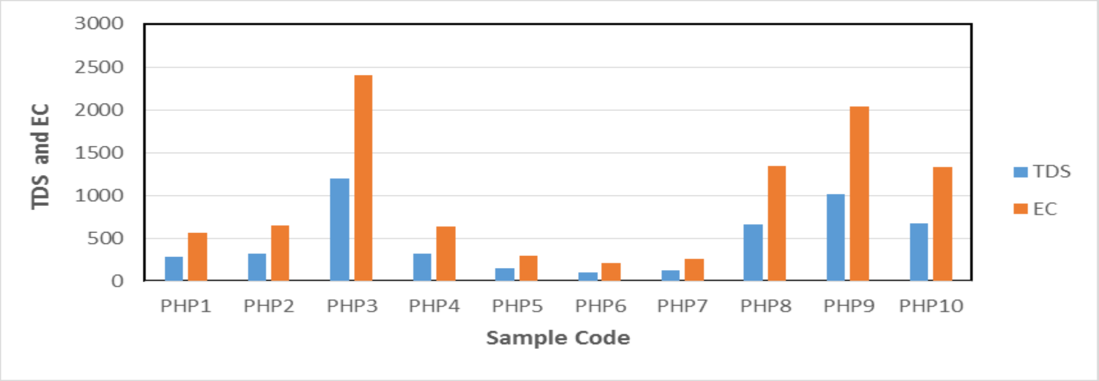

**Fig. 2: Mean TDS and EC values for water samples of selected borehole.**

Anionic parameters for drinking water quality such as chlorides, fluorides, nitrates, phosphates, sulphates were analyzed. Chlorides occur in all natural waters in varying concentrations. The presence of chloride in water could be attributed to pollutions from minerals, sewage and industrial effluents and its contents normally increase as the mineral content increases (WHO, 2011b). In addition, geochemical conditions could make the chlorides levels in natural groundwater to be present in varying conditions. In the present study, the chloride levels vary from 0.05 to 3131 mg/L. Chloride levels were within acceptable values for most boreholes except for two boreholes (Kalinde Admarc, 1307 mg/L and Muzungu village, 3131mg/L) which recorded extremely high levels of chloride. The primary reason for these high values in the above water samples could be from natural sources and saline intrusions. Chloride concentrations in excess of above 250 mg/L as in the case with the two boreholes may give rise to detectable taste in water.

Fluoride levels were within acceptable limits except for two samples (Lihaka Primary School, 2.9 mg/L and Phalombe T.C, 2.0 mg/L) with elevated levels more than the maximum allowable limit of 1.5 mg/L for drinking water (Table 2, Fig. 3). It is therefore anticipated that the inhabitants around these two borehole water sources especially children will be more vulnerable to skeletal fluorosis and dental fluorosis as a result of drinking water from these sources. However, no study has been done to ascertain the level of occurrence of these diseases. Worthy of note is the fact that during weathering and other chemical processes affecting soil and rock, such as percolation of water, fluoride can leach out and dissolve in the groundwater. Therefore, the origin and type of rock the groundwater flows through affects the fluoride content of water (Anastasia von Hellens, 2013). The most common fluorine bearing compounds are fluorite ($CaF_2$), apatite ($Ca_5(PO4)_3F$) and micas ($K_2Mg_5Si_8O_{20}F_4$) (Anastasia von Hellens, 2013), with this in mind and the fact that minerals fluorite and apatite are found around the study site, fluoride was expected to be found in elevated levels in some borehole water samples.

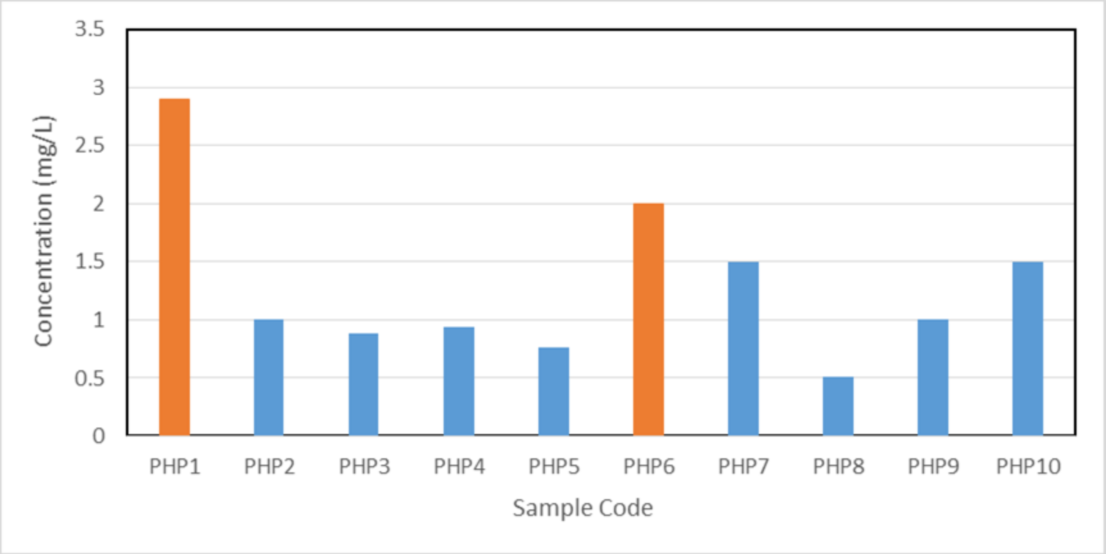

**Fig. 3: Variation in the Fluoride Levels of the Selected Borehole Water Samples.**

Nitrate concentration in water samples ranged from 0.34–55 mg/L. Most of the samples showed nitrate concentration below World Health Organization (WHO, 2011b) guideline values except water samples from Kalinde Admarc and Chakuma village which recorded higher concentration levels of nitrate above WHO tolerated limit (Table 2). Nitrates occur naturally in low concentration and pollution causes a higher concentration in water. The high values noted in the two samples above could have been due to these boreholes in close proximity to an animal waste, inorganic fertilizers and plants and animal decompositions which may have percolated the soils over time. In higher concentration, nitrates may produce a disease known as Methemoglobinemia (blue baby syndrome) which generally affects bottle-fed infants. However, no study has been done to ascertain the level of occurrence of this disease around the study area. $PO_4^{3-}$ and $SO_4^{2-}$ concentration levels were within the acceptable limits of WHO and pose no major health threats.

Cation chemistry showed a general dominance of $Ca^{2+}$, $Mg^{2+}$ and $Na^+$ in all borehole water samples analyzed followed by $K^+$, and Fe in that order (Fig. 4 and Table 2). The $Ca^{2+}$ and $Mg^{2+}$ were prominent in water samples from Mitawa Primary School, Kalinde Admarch, Migowi trading center, Mpasa T.D.C, Muzungu Village and

Chakuma Village. Generally, $Ca^{2+}$ in water is derived from minerals like limestone, dolomite and lithological calcareous constituents. Also, the source of $Mg^{2+}$ is basic igneous rocks such as amphibolites, volcanic rocks and sedimentary rocks (Dash *et al*., 2015). The abundance of these elements is not surprising since the study area is of close proximity to the topographic ring complex of Zomba and Mount Mulanje. Concentration values for $Ca^{2+}$, $Mg^{2+}$ and $Na^{+}$, $K^{+}$, and Fe were within tolerated limits except for the Fe content of water samples from Lihaka Primary School, Mitawa Primary School, Chiringa Village, Thetheleya Village and Mpasa T.D.C which recorded higher Fe content above the WHO limit of 0.3 mg/L in drinking water. This could also be the reason for the increased turbidity values of the samples.

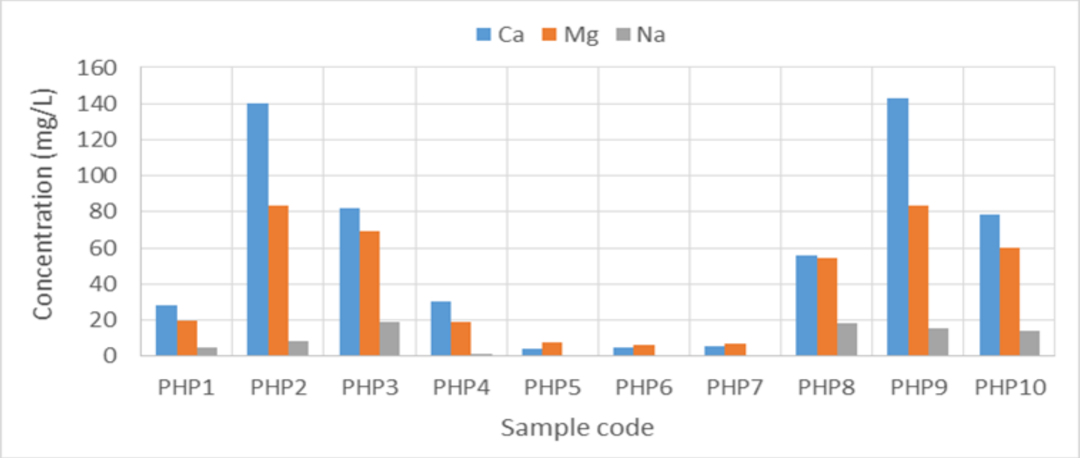

**Fig. 4: Concentration of $Ca^{2+}$, $Mg^{2+}$ and $Na^{+}$ in Selected Borehole Water Samples.**

Total hardness is a soap-destroying property which is largely produced as a result of carbonate of calcium and magnesium (Olumuyiwa *et al*., 2012). Hard water does not usually lather well which makes it unsuitable for domestic use. Water samples from Lihaka Primary School, Mitawa Primary School, Chiringa Village, Thetheleya Village and Mpasa T.D.C recorded higher levels of hardness may be due to the high level of $Ca^{2+}$ and $Mg^{2+}$ ions. Generally, total hardness values obtained were all below 500 mg/L and 800 mg/L as recommended by WHO and MS, respectively

Among the ten toxic heavy metals of major concern listed by WHO, arsenic and lead were analyzed in this study and results are presented in Table 2. Arsenic is very widely distributed throughout the earth crust and naturally present at high levels in groundwater of a number of countries. Arsenic is highly toxic in its inorganic form and long term exposure to arsenic from drinking water pose a great threat to public health. Arsenic toxicity is often cumulative with long term exposure to arsenic contaminated water can cause damage to blood vessels, various types of cancers (skin, kidney, and lungs), reproductive disorders and high blood pressure (Vunain et al.2013). Also early childhood exposure has been linked to negative impacts on cognitive development and increased deaths in young adults. Thus, the most important action in affected communities is the prevention of further exposure to arsenic by provision of a safe water supply. The primary source of Lead in groundwater is leaching from ores. The toxicity of lead is well known and documented and so strict limits on its presence in raw and finished drinking waters must be imposed (Kubare *et al*., 2010). Arsenic and lead levels in water samples were below AAS detection limits. This may suggest the environment was free of arsenic and lead.

## Bacteriological Analysis

Total coliform bacteria are known as “indicator organisms” used to measure the potential feacal contamination of water. This means their presence in water gives an indication that other disease causing organisms may be present in the water. Chief among these are the coliform bacteria which survive better, longer and easier to detect than other pathogens. *Escherichia coli* (*E. coli*) is regarded as the most sensitive indicator of faecal pollution (Nkamare *et al*., 2012). In the present study, the bacteria faecal indicator or *E coli* was used to provide an insight into the water quality from the selected borehole sources. The total bacteria count all borehole water samples ranged from 68-3700 cfu/100 mL (Table 2). Five water samples from Mitawa primary school, Kalinde Admarch, Chiringa village, Muzungu village and Chakuma village boreholes were free from total coliform count indicating that these boreholes had no sources of feacal contamination. Thus, 50% of the borehole water samples had zero total coliform counts. However, five borehole water samples recorded feacal coliform counts above the recommended WHO standard of 0 cfu/100 mL of drinking water. The five borehole water samples were (Migowi trading center (4 cfu/100 mL); Lihaka primary school (11 cfu/100 mL); Thetheleya village (73 CFU/100 mL); Phalombe T C (77 cfu/100 mL); and Mpasa T C (102 cfu/100 mL). These higher values of total coliform in water samples could be attributed to environmental sources such as soils and biofilms (Palamuleni and Akoth, 2015)., and poor sanitary completion of boreholes. Overall, these values are unacceptable according to WHO and are of health concern. Two bacterial strains were isolated and identified in the water samples from the five boreholes. *Escherichia coli* (*E. coli*) (indicator bacteria) were found in all five water samples from Migowi trading center, Lihaka primary school, Thetheleya village, Phalombe T C, and Mpasa T C boreholes (Fig. 5b). The presence of *E. coli* indicated faecal contamination and could be the proximity of the boreholes to pit latrines. *Salmonella typhi spp* was found in two samples (Phalombe TC, and Mpasa TC water samples) (Fig. 5c). This could be attributed the location of the two boreholes close to pit latrines, pens of sheep and goats and runoff from rain into borehole water sources.

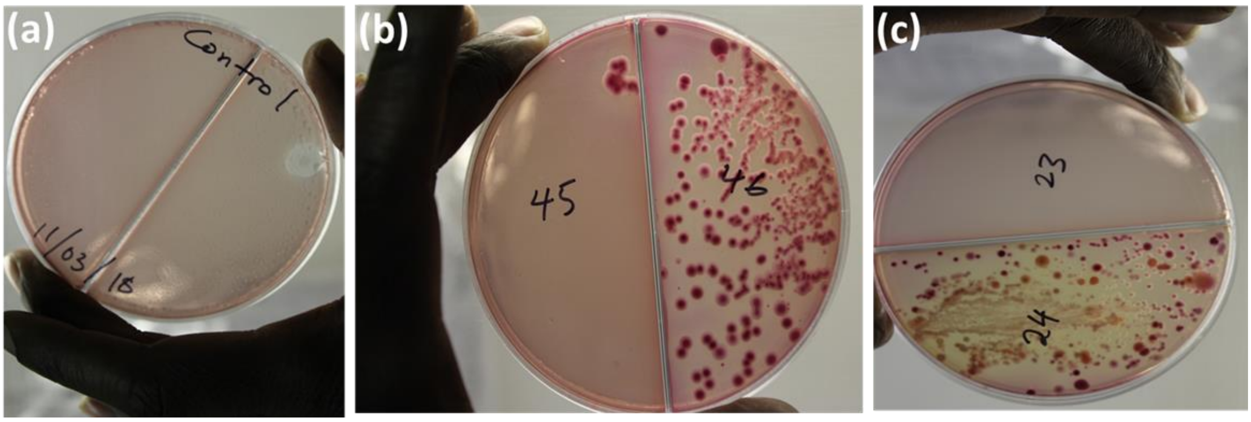

**Fig. 5: (a) control using UV-treated water (b) UV-treated water and water sample containing *E coli* (c) UV-treated water and water sample containing *Salmonella typhi spp*.**

**Table 2: Mean values of physico-chemical and bacteriological parameters of the 10 selected borehole water samples investigated.**

| **Parameter** | **PHP1** | **PHP2** | **PHP3** | **PHP4** | **PHP5** | **PHP6** | **PHP7** | **PHP8** | **PHP9** | **PHP10** | **MBS** | **WHO limit** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Temp. (°C) | 27.8 | 28.5 | 27.8 | 27.1 | 26.7 | 25.6 | 25.4 | 26.0 | 26.2 | 26.3 | No standard | No standard |
| Color | Nil | Nil | Nil | Nil | Nil | Nil | Nil | Nil | Nil | Nil | | |
| Odor | Nil | Nil | Nil | Nil | Nil | Nil | Nil | Nil | Nil | Nil | | |
| pH | 7.3 | 7.6 | 7.3 | 7.9 | 8.0 | 7.8 | 7.4 | 7.2 | 7.2 | 7.5 | 6.5-8.5 | 6.5-8.5 |
| EC (μS/cm) | 567 | 647 | 2398 | 634 | 303 | 216 | 259 | 1344 | 2036 | 1335 | 3500 | 1000 |
| TDS(mg/L) | 283 | 325 | 1198 | 316 | 152 | 108 | 129 | 667 | 1020 | 670 | No standard | 500 |
| $Cl^-$ (mg/L) | 17.1 | 2.26 | 13073 | 3.32 | 3.13 | 0.05 | 0.224 | 562 | 3131 | 114 | – | 250 |
| $F^-$(mg/L) | 2.90 | 1.00 | 0.88 | 0.94 | 0.76 | 2.00 | 1.50 | 0.52 | 1.00 | 1.50 | – | 1.50 |
| $NO_3^-$(mg/L) | 50 | 0.34 | 65 | 41.3 | 48 | 16 | 32.2 | 3.5 | 23 | 55 | – | 50 |
| $PO_4^{3-}$(mg/L) | 0.046 | 0.049 | 0.043 | 0.046 | 0.043 | 0.083 | 0.094 | 0.045 | 0.0445 | 0.054 | 0.50 | 0.50 |
| $SO_4^{2-}$(mg/L) | 4.837 | 6.581 | 108.209 | 7.977 | 5.767 | Bdl | Bdl | 9.628 | 20.651 | 57.279 | 250 | 250 |
| Total hardness (as mg$CaCO_3$/L) | 224 | 523.6 | 562 | 367 | 324 | 129 | 154 | 440 | 522 | 545 | 500 | 800 |
| Ca(mg/L) | 28.025 | 140.405 | 82.380 | 30.463 | 4.036 | 4.580 | 5.630 | 56.148 | 143.272 | 78.369 | 100 (no standard) | 100 (no standard) |
| Mg(mg/L) | 19.953 | 83.211 | 68.934 | 19.024 | 7.820 | 6.192 | 7.164 | 54.408 | 83.322 | 60.212 | 55 (no standard) | 55 (no standard) |
| Na(mg/L) | 4.701 | 8.213 | 19.166 | 1.420 | bdl | bdl | bdl | 18.615 | 15.233 | 13.677 | 500 | 500 |
| K(mg/L) | bdl | bdl | bdl | bdl | bdl | bdl | bdl | bdl | bdl | bdl | – | – |
| Fe(mg/L) | 12.36 | 0.44 | 0.19 | 0.27 | 0.40 | 0.33 | 0.43 | 0.83 | 0.15 | 0.19 | 0.00-0.30 | 0.00-0.30 |
| As(mg/L) | – | – | – | – | – | – | – | – | – | – | – | 0.01 |
| Pb(mg/L) | bdl | bdl | bdl | bdl | bdl | bdl | bdl | bdl | bdl | bdl | bdl | 0.01 |
| Total bacterial count (cfu/100 mL) | 117 | 3700 | 121 | 114 | 578 | 237 | 150 | 198 | 68 | 0 | – | 500 |
| Total Coliform count (cfu/100 mL) | 11 | 0 | 0 | 4 | 0 | 77 | 73 | 102 | 0 | 0 | 50 | 0 |

Total dissolved solids (TDS).; Malawi Bureau of Standard (MBS); Below detection limit (bdl)

## CONCLUSIONS

Water is an indispensable resource for the sustenance of life and the supply of quality drinking water in developing countries including Malawi is inadequate. Most communities in sub-Saharan Africa depend on other water resources like borehole water for drinking, domestic and irrigation purposes. The assessment of water quality is an important factor in the assessment of pollution levels. The presence of higher levels of fluoride in two water samples is a serious concern that needs an urgent remediation. The results obtained from this study showed that in terms of physicochemical parameters the selected borehole water from Phalombe plain need some degree of onsite treatment to conform to the stipulated standards. Based on the microbiological analysis, the five borehole water samples listed above with faecal contamination above the WHO limit are of health concern (e.g., may cause diarrheal, cholera, etc.).

## RECOMMENDATIONS AND OBSERVATIONS

### Recommendations

Based on the outcome of the study the following recommendations are offered:

(1) It is recommended that water quality analysis be carried out in all if not most boreholes within the country. Thus, continuous monitoring and assessment of other physico-chemical and bacteriological properties of most boreholes should be carried out. This is more groundwater research, monitoring, data archiving is needed within the country.

(2) Public awareness campaign on the need to boil water before consumption should be increased.

(3) Public awareness on the dangers associated with the consumption of contaminated water should be increased. Furthermore, as much as possible disinfectants programmes through the use chlorination tablets or other suitable methods to prevent microbial contamination and the spread of waterborne diseases should be made available to communities.

(4) The construction of pit latrines near water resources should be avoided.

(5) The development of defluoridation units based on AlOOH is very important for rural areas where the inhabitants rely on borehole water as a source of drinking as their health is at risks to dental and skeletal fluorosis.

(6) Some low-cost "point of use treatment methods" should be encouraged such as cheap and affordable ceramic filters, solar water disinfection (SODIS) etc. Solar water disinfection is a simple, green and low-cost technology for safe drinking water especially for rural communities in developing countries, most of whom are known to have high levels of solar radiation.

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