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Assessment of Groundwater Quality in Areas Surrounding Thundulu Phosphate Mine, Phalombe District, Malawi

Philip Jailos, Peter J. Chimtali* and Ephraim Vunain
Department of Chemistry, Chancellor College, University of Malawi, P.O. Box 280, Zomba, Malawi
E-mail addresses: philjailos8@gmail.com; pchimtali@cc.ac.mw; evunain@cc.ac.mw
**Corresponding author*
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Abstract

Water is one of the renewable resources essential for sustaining all forms of life and quality of drinking water is very fundamental for human health. Human activities such as mining act as sources of water contamination which consequently lead to ecological, environmental and health problems. To the best of our knowledge, no study has been conducted around the Thundulu Phosphate Mine to establish the quality of drinking water. In this regard, this study was carried out to evaluate the physico-chemical water quality parameters of areas surrounding the Thundulu Phosphate Mine in Phalombe District. Groundwater samples from the villages surrounding the Phosphate Mine were collected both during the wet and dry seasons for analysis of physico-chemical water quality parameters (pH, electrical conductivity, turbidity, nitrate, chloride, sulphate, fluoride, iron, calcium and magnesium). The study also investigated microbiological water characteristics mainly *Escherichia coli* and faecal coliforms. Results showed that pH, electrical conductivity, turbidity, nitrate, chloride, sulphate, phosphate, calcium and magnesium complied with the national and international standards set by Malawi Bureau of Standards (MBS) and World Health Organization (WHO). As regards to microbiological characteristics, it was revealed that water from three sources (B2, B3 and B4) was contaminated with *Escherichia coli* and faecal coliforms.

Keywords: Physico-chemical, Groundwater, Phalombe, Borehole, Electrical Conductivity, Turbidity, Phosphate.

Introduction

Mining is one of the paramount social economic activities for most of the developing nations in the world, and Malawi is not exceptional. Phosphate mining has gained the world's attention in search for chemical fertilizer. However, mine sites are sources of contamination which results in ecological and environmental consequences as well as health problems. A lot of research on groundwater quality has been done in areas surrounding mine sites to assess the quality of drinking water. Four main categories of mining impacts on water quality have been reported in literature, namely acid mine drainage, heavy metal contamination and leaching, process chemicals pollution and erosion and sedimentation (Emmanuel et al. 2018). Two major problems have been reported in regard to phosphate mining with respect to water resources: hydrological impacts as a result of water usage, landscape and ecological changes (Reta et al. 2019); and its effects on quality of water emanating from polluted water discharges and phosphate run off (Chraiti et al. 2016).

During phosphate production, a considerable amount of wastewater is produced as a result of phosphate washing. Groundwater is one of the major sources of drinking water for the majority of the population living in the rural areas of Malawi. The wastewater generated from mining activities run-off and consequently affects the quality of groundwater. It is worth noting that severe water pollution from mining activities is contamination by heavy metals (Jiries et al. 2004). Although, these heavy metals may occur naturally in the environment, mining activities increases their levels to quantities that may be deemed toxic to human health if consumed through drinking water (Hilson 2000).

Malawi has made tremendous efforts in the provision of safe and potable water by about 67% (WHO/UNICEF 2015). In order to achieve the United Nations (UN) Sustainable Development Goal (SDG) number 6 which aims at achieving universal and equitable access to safe and affordable drinking water for all by 2030 (Kushe 2009, Jama and Mourad 2019), the government of Malawi has set a number of policy frameworks that are aimed at improving water, sanitation and hygiene (WASH) sectors.

In Malawi, especially in rural areas, access to safe and potable water is mainly supplied using boreholes (Chidya et al. 2016). However, these water supplies in the rural areas of Malawi are not regularly monitored. To the best of our knowledge, there was no information on the quality of water for the villages within Thundulu Phosphate Mine in Phalombe District, despite such information being vital for policy formulation as far as water, sanitation and hygiene sectors are concerned. It is against this background that this study was conducted to assess the quality of groundwater for the areas surrounding Thundulu Phosphate Mine in Phalombe District, Malawi.

Materials and Methods

Description of the study area

The study was conducted in the areas around Thundulu Phosphate Mine in Phalombe District in the southern region of Malawi. Thundulu Phosphate Mine is located within the Nathache hill in Nambazo area. The mine is surrounded by the following villages: Thundulu, Nambwale, Nathiya and Nambazo. Figure 1 shows the map of the study area.

Sampling and field analysis

Water sample collection was conducted twice: during the dry season and rainy seasons. A total of six (n = 6) water sources, namely boreholes were systematically selected. The sites were coded as B1, B2, B3, B4, B5 and B6). Standard methods (APHA 1998) were followed to collect water samples in duplicate to ensure quality control and reliability of data from the sites. Great care was taken during sample collection, preservation and on-site analyses to prevent cross-contamination and degradation of samples. Water samples were collected using 500 mL sterile polypropylene bottles. Laboratory and field equipment were washed thoroughly with distilled water. To ensure quality assurance during sampling, apparati were washed thrice with distilled water and then with the sampled waters. Fixed volume purging of the groundwater sources was done prior to sample collection. All samples for microbiological and physico-chemical analyses were put in a cooler box and transported to the Department of Chemistry laboratory, Chancellor College, University of Malawi. The samples collected from various sites were labelled as shown in Table 1.

Analytical methods used on site for water samples

A field digital pH meter (Martini pH55 pocket pH/Temp meter model) was used to measure pH of water samples. Turbidity was measured using water proof handheld Oakton turbid meter (T-100 model). A digital water quality meter (Model 8603) was used to measure temperature and electrical conductivity (EC).

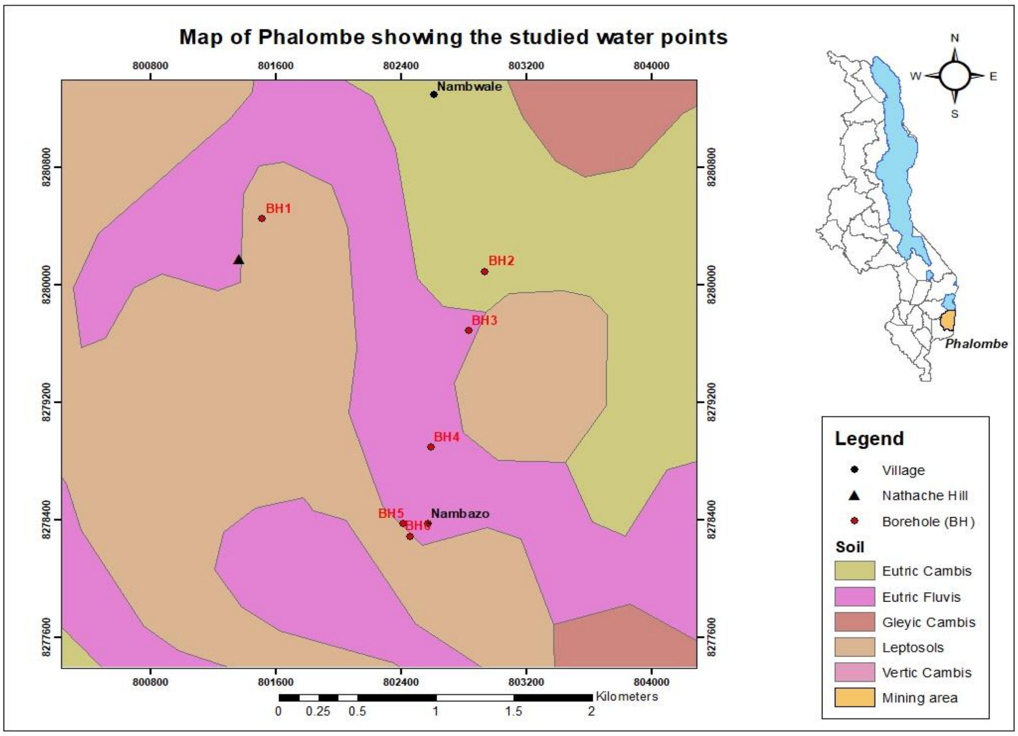


Figure 1: Map extract of the study area.

Table 1: Water sources and geographical locations of the study area

Name of water source	Site code	GPS coordinate (E and N) (UTM)	
Thundulu	B1	801512	8280449
Nambwale 1	B2	802938	8280092
Nambwale 2	B3	802831	8279687
Nathiya	B4	802589	8278894
Nambazo 1	B5	802416	8278372
Nambazo 2	B6	802458	8278287

B: borehole; GPS: geographical position system, E: eastings, N: northings.

Laboratory analyses for water samples

An atomic absorption spectrophotometer (AAS) (Agilent technologies 200 series AA**)** was used to determine selected metals (Ca^{2+}, Mg^{2+}, and Fe^{2+}) as described in APHA (1998). Nitrate, chloride and fluoride were analyzed using ion selective electrode, instrument model (Accumet AB 250 pH/MV/ion). Sulphate and phosphate were determined by turbidmetric and colorimetric methods, respectively with the aid of UV/Vis spectrophotometer as described in APHA (1998). Hardness is mostly expressed as milligrams of calcium carbonate equivalent per litre. The total water hardness, as Ca^{2+} and Mg^{2+}, was calculated according to equation (1) (Crittenden and Harza 2005, Lenntech 2007):

$$\textit{Total hardness} = 2.5\,[Ca] + 4.1\,[Mg] \qquad (1)$$

where [Ca] and [Mg] are the calcium and magnesium concentrations (in mg/L) measured in the water sample, while 2.5 and 4.1 are their molar mass ratios per 100 g $CaCO_3$.

Microbiological analyses

Water samples for microbiological tests were collected from all the boreholes during dry and rainy seasons. *E.coli* and feacal coliforms were determined using Standard Plate Count method.

Statistical analyses

The Microsoft excel (2013) was used for statistical analyses. Pearson correlation coefficient (two-tailed at 95% and 99% confidence levels) was employed to correlate the parameters.

Results and Discussion

pH, electrical conductivity (EC), and turbidity

Table 2 shows the mean results for the physico-chemical parameters. The pH for groundwater usually ranges from 6.0 to 8.5. For the current study, pH ranged from 5.5 to 6.8 (wet season) and 6.9 to 8.3 (dry season). The results obtained were compared to the set standards by MBS and WHO for drinking water. The pH values for all the water samples were within the recommended range set by MBS (6.0–9.5) and WHO (5.0–9.5). All the water samples collected during the wet season were fairly acidic. It is worth noting that groundwater in the acidic medium (pH < 6) could increase the dissolution and leaching of heavy metals, while high pH is likely to enhance precipitation of calcite minerals (Singh et al. 2011, Nishtha et al. 2012, Ansari et al. 2015). Furthermore, the low pH values can be attributed to environmental characteristic of the area such as the geology. It is further reported that low pH values may cause corrosion of pipes and aesthetic problems such as metallic or sour taste. During the study, members from communities reported that water from water sources close to the mine has sour taste and they hardly use it for drinking purposes. However, during the dry season, only the water sample from B1 was fairly acid (pH 6.9) as compared to the rest of the water samples which registered pH values of more than 7 (B2[7.9], B3[8.1], B4[8], B5[7.9] and B6[8.3]). The pH values obtained in this study are in agreement with the pH values reported in literature (Sajidu et al. 2008, Mapoma and Xie 2014, Chidya et al. 2016).

Electrical conductivity (EC) is defined as the ability of water to conduct an electric current and gives vital information on the degree of mineralization of water. Basically, EC depends on content of dissolved substances, ionization capacity, mobility, temperature and ionic charge (Benrabah et al. 2016). EC values ranged from 116 to 1178 µS/cm (wet season) and 610–1135 µS/cm (dry season). During the wet season, the highest EC was recorded at B1 (1178 µS/cm) and during the dry season, the highest EC was recorded at B5 (1135 µS/cm). EC values for all the water samples during the two seasons were below the maximum recommended value set by MBS of 3500 µS/cm. To the best of our knowledge, there are no set standards for EC for borehole water by the WHO. Similar studies conducted in Malawi have reported varied EC values [1100, 1268, 4050, and 6800 µS/cm] that are below and above the set standard by MBS (Sajidu et al. 2008, Chidya et al. 2016).

Turbidity in water is a function of the suspended inorganic or organic materials. The turbidity of groundwater samples during the wet season ranged from 0.1 to 0.76 NTU with an average of 0.53 NTU. For the dry season, the turbidity ranged from 0.1 to 0.27 NTU with an average of 0.18 NTU. All the samples were below a turbidity level of 5.00, the maximum permissible limit recommended by WHO (2011). Figure 2 shows spatial variations in mean pH, electrical conductivity (EC) and turbidity of the water samples.

NO_3^-, Cl^-, F^-, SO_4^{2-}, PO_4^{3-}, Fe^{2+}, Ca^{2+} and Mg^{2+} levels

During the wet season, nitrate levels ranged from 23.79 to 31.52 mg/L with an average 27.96 mg/L, whilst during the dry season ranged from 1.01 to 3.57 mg/L. Nitrate levels for all the water samples were below the permissible limits set by MBS of 45 mg/L and of 50 mg/L set by WHO. It can be seen from Table 2 that during the wet season, water samples showed higher nitrate levels than the dry season. This could be attributed to the use of inorganic fertilizers as well as animal wastes during farming.

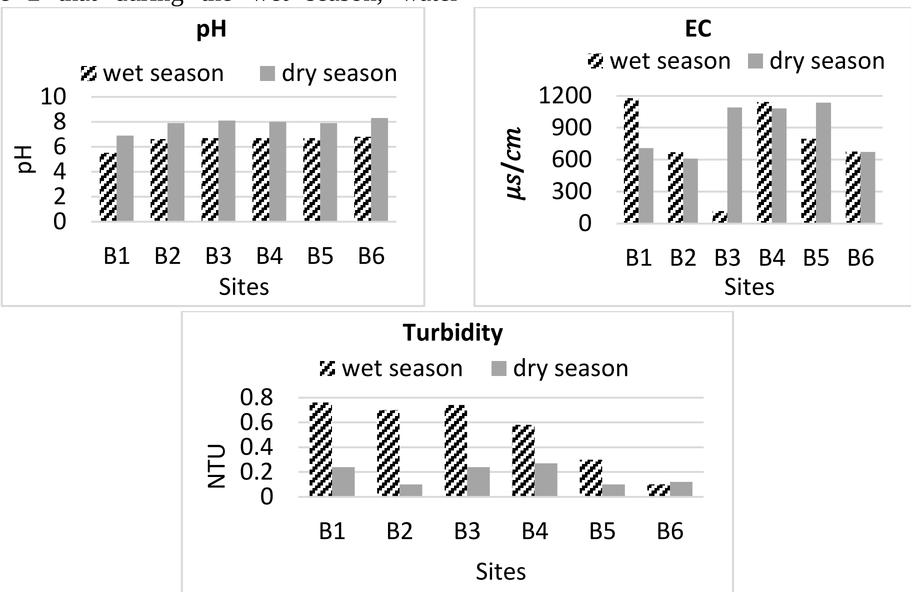


Figure 2: Spatial variations in mean pH, electrical conductivity and turbidity of water samples.

Table 2: Mean values (n = 2) of physico-chemical parameters. WS: wet season, DS: dry season

	B1		B2		B3		B4		B5		B6	
	WS	DS	WS	DS	WS	DS	WS	DS	WS	DS	WS	DS
pH	5.5	6.9	6.60	7.9	6.7	8.1	6.7	8	6.7	7.9	6.8	8.3
Temp (°C)	29.6	27.2	28.5	27	28.4	27.4	28.8	29.5	28.8	27.8	28.1	27.1
EC (μS/cm)	1178	710	669	610	116	1091	1142	1081	796	1135	676	674
Turbidity (NTU)	0.76	0.24	0.7	0.1	0.74	0.24	0.58	0.27	0.3	0.1	0.1	0.12
NO_3^- (mg/L)	31.52	1.01	23.79	1.00	26.14	1.53	30.79	1.74	28.27	3.57	27.27	2.23
Cl^- (mg/L)	0.89	5.8	0.61	2.02	2.68	5.19	0.87	3.91	0.67	4.09	0.46	5.66
F^- (mg/L)	0.89	1.86	1.54	3.39	1.23	2.07	1.55	1.76	1.22	1.91	1.51	3.11
SO_4^{2-} (mg/L)	120.24	33.84	59.2	24.77	–	46.1	120.24	46.49	56.53	40.6	58.66	67.53
PO_4^{3-} (mg/L)	0.03	0.52	–	0.82	0.032	0.78	–	0.58	0.034	1.25	0.027	0.98
Fe^{2+} (mg/L)	0.49	1.01	0.35	0.051	0.84	0.08	2.74	0.016	0.23	0.049	0.16	0.024
Ca^{2+} (mg/L)	75.06	20.93	19.99	8.61	31.59	11.48	30.43	12.49	29.19	15.37	23.06	11.78
Mg^{2+} (mg/L)	5.84	22.06	4.45	18.39	6.75	26.73	8.27	34.81	6.91	37.23	5.9	19.96

Chloride levels ranged from 0.46 to 2.68 mg/L (wet season) and during the dry season ranged from 2.02 to 5.8 mg/L. With respect to chloride permissible limit set by MBS, all the water samples were below the set standard of 750 mg/L. In this regard, all the water samples, pose no health risks to consumers. Nevertheless, it is worth noting that excess chloride (>250 mg/L) in drinking water gives rise to noticeable taste. Similar studies on groundwater conducted in other parts of Malawi reported chloride levels that were below the standard limit set by WHO (Chidya et al. 2016). Chloride presence in groundwater could emanate from anthropogenic activities, for instance applications of manure and chemical fertilizers and over pumping of groundwater.

Fluoride levels ranged from 0.89 to 1.55 mg/L during the wet season and 1.76–3.39 mg/L during the dry season. Fluoride is toxic at concentrations greater than 1.5 mg/L and causes dental fluorosis (WHO 2017). With respect to WHO permissible standard limit, B2 (1.54 mg/L), B4 (1.55 mg/L) and B6 (1.51 mg/L) recorded F^- levels during the wet season that were above the set standard of 1.5 mg/L. In view of this, water from these sources is likely to pose dental health hazards. Artificial fluoridation in the range of 0.5–1.0 mg/L is recommendation for drinking water with very low fluoride content to prevent dental caries in consumers. In view of this, water from B1 (0.89 mg/L) requires artificial fluoridation. All water samples from all the sources during the dry season recorded F^- levels that were above the set standard limit of WHO. The high fluoride content may be linked to the basic pH observed during the dry season. A basic pH with moderate conductivity favours fluoride dissolution in water (Tanouayi et al. 2016). It is also worth noting that interaction between water and rocks is one of causes of fluoride in groundwater, and apatite is one of the main ore minerals for phosphate. According to Sajidu et al. (2008) some of the solutions to fluoride and fluorosis include having alternative sources of drinking water, improvements in nutrition status of the people at risk and defluoridation.

Sulphate levels ranged from 56.53 to 120.24 mg/L (wet season) and during the dry season ranged from 24.77 to 46.49 mg/L. All the water sources recorded sulphate levels that were below the permissible standard limit set by MBS of 88 mg/L. Sulphate in groundwater could emanate from the interaction of rain water with soil. Other sources of sulphate include presence of reduced sulfide minerals, nitrate reduction, fertilizer and organic matter. During the wet season, low phosphate levels were recorded at B1 (0.030 mg/L), B3 (0.032 mg/L), B5 (0.034 mg/L) and B6 (0.027 mg/L). Though phosphate mining is taking place, a good explanation to the low phosphate levels is precipitation of phosphates and settling of phosphates as sediments. No phosphate was recorded at B2 and B4. During the dry season, phosphate levels ranged from 0.52 to 1.25 mg/L.

Iron is equally found in abundance in rocks and mainly in the form of silicates, oxides and hydroxides, carbonates and sulfides. Fe^{2+} levels for both wet and dry seasons ranged from 0.16 to 2.74 mg/L and 0.016–1.01 mg/L, respectively. For all the two seasons, all the water sources registered iron levels that were below the permissible limit (3 mg/L) set by MBS. However, with respect to WHO standard limit of 0.3 mg/L, B1 (0.49 mg/L), B2 (0.35 mg/L), B3 (0.84 mg/L) and B4 (2.74 mg/L) for the wet season registered higher iron values. Additionally, B1 (1.01 mg/L) for the dry season registered iron values above the set limit of WHO. The high values of iron can be explained in terms of magnetite (Fe_3O_4), which is associated with apatite one of the major ore minerals of phosphates. Iron in levels above 0.3 mg/L in water causes staining of laundry and plumbing fixtures, changes taste and causes development of colour (WHO 2004) which affect the water users. Iron also promotes unwanted bacterial growth within waterworks and distribution systems which result into a slimy coating on the piping (Meck et al. 2009). Figure 3 shows spatial variations in NO_3^-, Cl^-, F^-, SO_4^{2-}, PO_4^{3-} and Fe^{2+} levels.

Calcium values for the wet season ranged from 19.99 to 75.06 mg/L and for the dry season ranged from 8.61 to 20.93 mg/L. All the water sources registered calcium values below the permissible standard limit (250 mg/L) set by MBS. However, all the water sources except B1-dry season (75.06 mg/L) registered Ca^{2+} values below the permissible standard range (75–200 mg/L) set by WHO. Magnesium values for the wet and dry seasons ranged from 4.45 to 8.27 mg/L and 18.39 to 37.23 mg/L, respectively. All the water sources registered Mg^{2+} levels below the permissible standard limit (200 mg/L) set by MBS. Drinking water containing high levels of both magnesium and sulphate (>250 mg/L each) may cause laxative effects, even though with time consumers can adapt to such levels (WHO 2017). With respect to the current study, no borehole had Mg^{2+} levels above 250 mg/L, hence the water may not cause laxative effects. Figure 4 shows spatial variations in mean Ca^{2+} and Mg^{2+}.

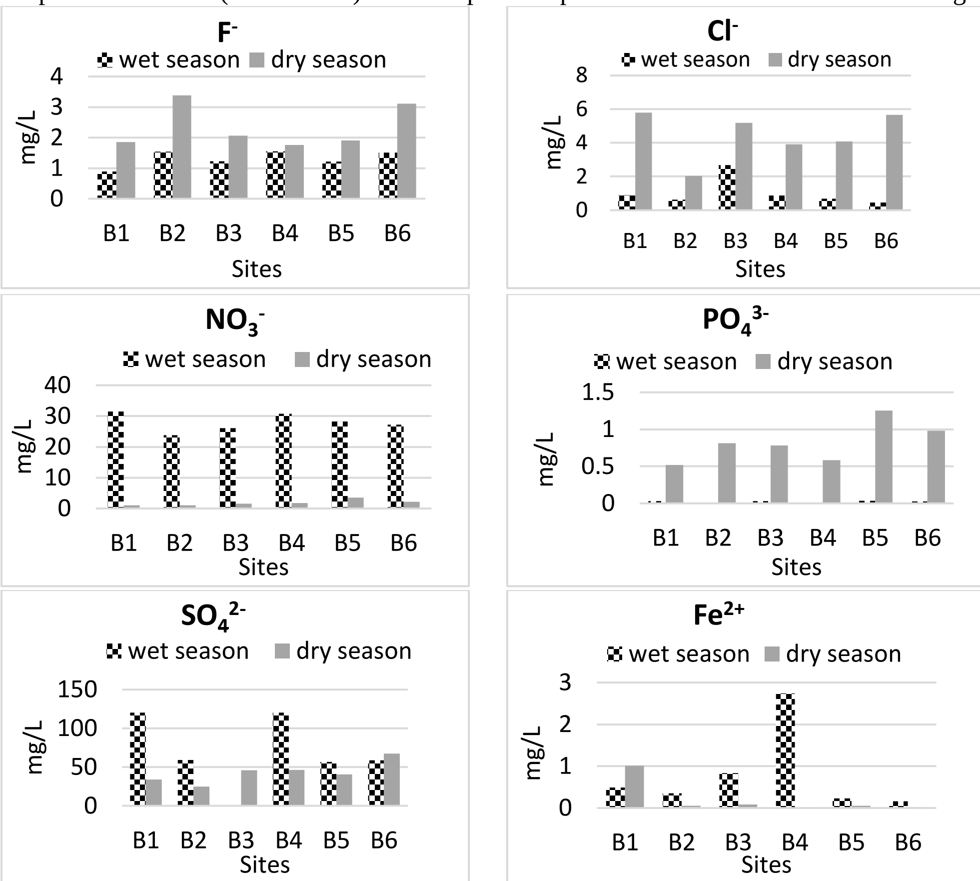
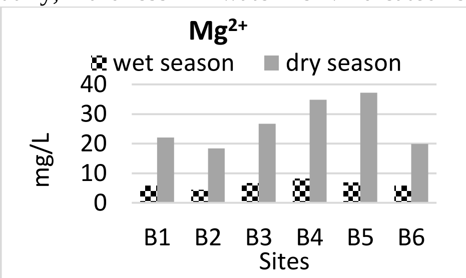


Figure 3: Spatial variations in mean NO_3^-, Cl^-, F^-, SO_4^{2-}, PO_4^{3-} and Fe^{2+} levels.

A summary and classification of water hardness are given in Table 3 and Table 4. Water hardness from all the water sources ranged from 68–212 mg/L $CaCO_3$ for the wet season and 97–191 mg/L $CaCO_3$ for the dry season. According to this classification for the wet season, water from B2 is classified as soft; water from B3, B4, B5 and B6 is classified as moderately hard and finally water from B1 is classified as hard representing 16.67% (n = 6). Whilst for the dry season, water from B1, B2, B3 and B6 is classified as moderately hard and water from B4 and B5 is classified as hard representing 33.33% (n = 6). It is worth noting that water hardness is caused by dissolved calcium and to a lesser extent, magnesium. Apatite is one of the main ore minerals for phosphate, and calcium is the major constituent of apatite (Meck et al. 2009). This can be used to justify the increase in water hardness at some of the sampling sites (B1, B4 and B5). Excess calcium intake is recommended primarily to those prone to milk alkali syndrome (the simultaneous presence of hypercalcaemia, metabolic alkalosis and renal insufficiency) and hypercalcaemia (WHO

2017). Furthermore, increased intake of magnesium salts may lead to a temporary adaptable change in bowl habits (diarrhoea) but rarely brings hypermagnesaemia in people with normal kidney functions. In this regard, continuous intake of water from B1, B4 and B5 may result into the stated health problems. Usually, hardness in water is vindicated by precipitation of soap scum; as such excess soap needs to be used during cleaning. It is also worth noting that water hardness toughens vegetables during cooking. Although there are reports that soft water may have adverse effects on mineral balance, further studies need to be done to ascertain such claims (WHO 2006).



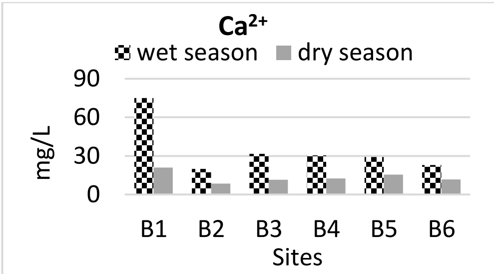


Figure 4: Spatial variations in mean Ca^{2+} and Mg^{2+}.

Table 3: Classification of the water hardness compared to the current study for the wet season

Concentration range (mg/L $CaCO_3$)	Hardness classification	Comparison with this study: Borehole (hardness, mg/L $CaCO_3$)
<75	Soft	B2 (68)
75–150	Moderately hard	B3 (107), B4 (110), B5 (101), B6 (82)
150–300	Hard	B1 (212)
>300	Very hard	–

Table 4: Classification of the water hardness compared to the current study for the dry season

Concentration range (mg/L $CaCO_3$)	Hardness classification	Comparison with this study: Borehole (hardness, mg/L $CaCO_3$)
<75	Soft	–
75–150	Moderately hard	B1 (143), B2 (97), B3 (138), B6 (111)
150–300	Hard	B4 (174), B5 (191)
>300	Very hard	–

Correlation matrix for the physico-chemical water quality parameters

Correlation matrix was used to establish the relationship between two water quality parameters so as to predict the degree of dependency. The correlation matrices (Pearson Correlations, r) for various water quality parameters for all the water sources are presented in Table 5 and Table 6. As regards to the wet season, EC positively correlated with SO_4^{2-} indicating increased contamination. High EC values indicate high availability of dissolved ions especially cations. Temperature positively correlated with Ca^{2+}. pH negatively correlated with Ca^{2+} and temperature. F^- also negatively correlated with Ca^{2+}. As regards to the dry season, EC positively correlated with Mg^{2+}. NO_3^- positively correlated with PO_4^{3-}, and Fe^{2+} positively correlated with Ca^{2+}. Furthermore, pH negatively correlated with Fe^{2+} and Ca^{2+}.

Table 5: Correlation matrix of the physico-chemical water quality parameters during the wet season

	pH	Temp	EC	Turbidity	F^-	Cl^-	NO_3^-	PO_4^{3-}	SO_4^{2-}	Fe^{2+}	Mg^{2+}	Ca^{2+}
pH	1											
Temp	**-0.883***	1										
EC	-0.519	0.682	1									
Turbidity	-0.503	0.503	-0.014	1								
F^-	0.8	-0.752	-0.142	-0.361	1							
Cl^-	0.077	-0.117	-0.695	0.504	-0.271	1						
NO_3^-	-0.548	0.714	0.746	0.024	-0.474	-0.163	1					
PO_4^{3-}	-0.22	0.112	-0.305	-0.268	-0.692	0.317	0.172	1				
SO_4^{2-}	-0.546	0.674	**0.982****	0.089	-0.114	-0.613	0.754	-0.381	1			
Fe^{2+}	0.145	0.128	0.35	0.275	0.323	0.136	0.456	-0.572	0.445	1		
Mg^{2+}	0.24	0.098	0.2	-0.112	0.038	0.241	0.608	0.038	0.209	0.751	1	
Ca^{2+}	**-0.960****	**0.891***	0.494	0.446	**-0.870***	0.054	0.701	0.362	0.521	-0.037	0	1

* Correlation is significant at the 0.05 level (2-tailed). ** Correlation is significant at the 0.01 level (2-tailed).

Table 6: Correlation matrix of the physico-chemical water quality parameters during the dry season

	pH	Temp	EC	Turbidity	F^-	Cl^-	NO_3^-	PO_4^{3-}	SO_4^{2-}	Fe^{2+}	Mg^{2+}	Ca^{2+}
pH	1											
Temp	0.161	1										
EC	0.255	0.633	1									
Turbidity	-0.326	0.527	0.354	1								
F^-	0.391	-0.587	-0.748	-0.683	1							
Cl^-	-0.222	-0.139	0.077	0.4	-0.395	1						
NO_3^-	0.389	0.189	0.55	-0.448	-0.23	0.087	1					
PO_4^{3-}	0.509	-0.249	0.227	-0.799	0.235	-0.13	**0.850***	1				
SO_4^{2-}	0.566	0.114	0.123	0.023	0.045	0.61	0.388	0.249	1			
Fe^{2+}	**-0.962****	-0.283	-0.324	0.37	-0.346	0.441	-0.431	-0.532	-0.376	1		
Mg^{2+}	0.14	0.746	**0.912***	0.216	-0.746	-0.04	0.672	0.281	0.056	-0.27	1	
Ca^{2+}	**-0.830***	-0.014	0.051	0.341	-0.642	0.6	0.06	-0.237	-0.114	**0.851***	0.17	1

*Correlation is significant at the 0.05 level (2-tailed). ** Correlation is significant at the 0.01 level (2-tailed).

Hierarchical cluster analysis

Figures 5 and 6 show results of the hierarchical cluster analysis (HCA) used to detect groupings among the 6 water sources. During the wet season, two clusters were identified on the dendrogram of physicochemical parameters. Cluster 1 (B3) and Cluster 2 (B1, B2, B4, B5, B6). From the results, it can be seen that B3 had a unique chemical composition. Cluster 2 is further divided into two sub-clusters, namely Cluster I (B2, B5 and B6) and Cluster II (B1 and B4). For the dry season, two clusters were identified, namely Cluster 1 (B3, B4 and B5) and Cluster 2 (B1, B2, and B6).

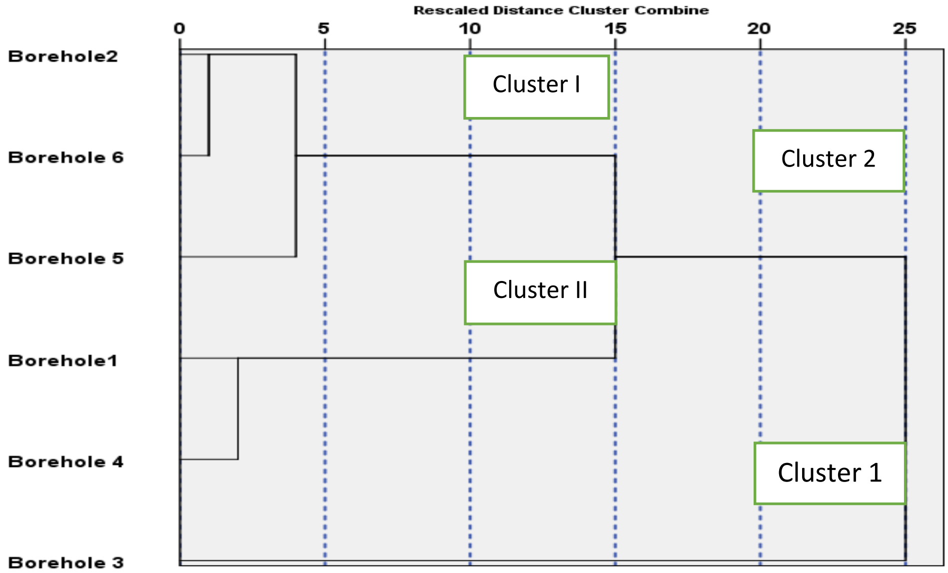


Figure 5: Hierarchical cluster analysis dendrogram showing clusters of 6 water sources with respect to their chemical compositions for the wet season.

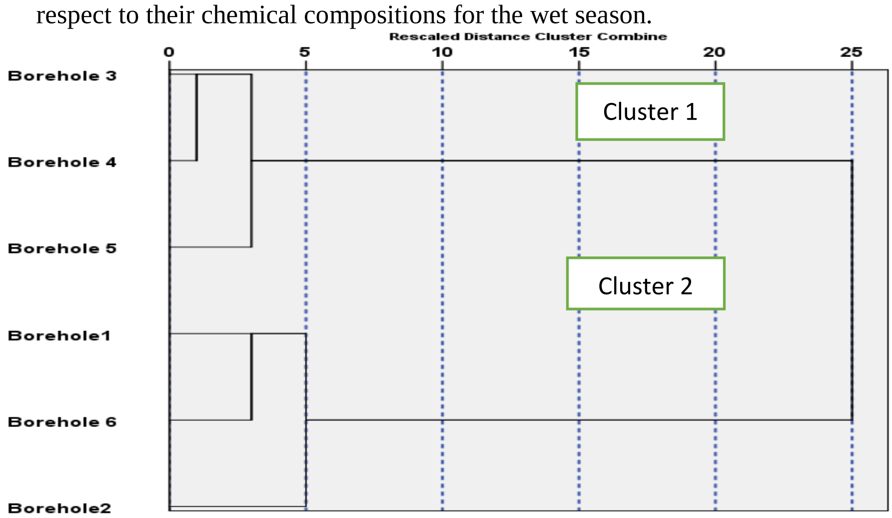


Figure 6: Hierarchical cluster analysis dendrogram showing clusters of 6 water sources with respect to their chemical compositions for the dry season.

Microbiological characteristics of the water sources

E. coli and feacal coliforms were also analyzed for both seasons. During the dry season *E. coli* was detected at B2 (8 cfu/100 mL), B3 (6 cfu/100 mL) and B4 (8 cfu/100 mL). MBS (2005) and WHO (2011) guidelines recommend the colony counts of 0 per 100 mL for *E. coli* in drinking water. In this regard, the water from B2, B3 and B4 is deemed contaminated and could pose health risks to consumers. With respect to faecal coliforms (FC), only B2 (26 cfu/100 mL), B3 (31 cfu/100 mL) and B4 (25 cfu/100 mL) registered faecal coliforms during the dry season. The MBS (MS 733:2005) recommends maximum concentration of 0 cfu/100 mL for FC in borehole water. A number of health risks have been associated with the consumption of faecal contaminated water and the problems are aggravated in children under the age of 5 years (Edokpayi et al. 2018, Diouf et al. 2014). It is worth noting that waterborne diseases such as cholera and diarrhoea are the leading causes of underage deaths (Diouf et al. 2014).This contamination by EC and FC could be attributed to open defecation, runoff and discharge of livestock faecal waste. Similar study conducted in Balaka found that FC were up to 4230 cfu/100 mL in groundwater (Mapoma and Xie 2014). Figure 7 shows a summary of the variations in *E. coli* and feacal coliforms.

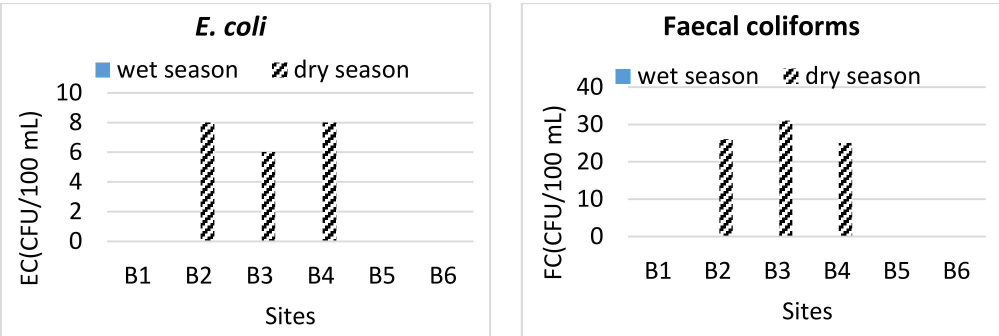


Figure 7: Variations in *E. coli* and feacal coliforms.

Conclusion

The study aimed at investigating the quality of groundwater in the areas surrounding the Thundulu Phosphate Mine in Phalombe District, Malawi, and consequently determined its suitability for domestic purposes. This was done by checking the analyzed water quality parameters' compliance with set national and international drinking water standards for borehole water. The pH, EC, turbidity, NO_3^-, Cl^-, SO_4^{2-}, Ca^{2+}, and Mg^{2+} levels of all the water samples complied with national and international standards set by MBS and WHO. Water from B2, B4 (wet season) and B6 (dry season) registered fluoride levels that were above the permissible limit set by WHO. Furthermore, water from B1 registered the lowest fluoride content and artificial fluoridation is recommended to avoid dental caries. The study has also revealed that water from B1, B4 and B5 was hard.

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