IRON AND MANGANESE LEVELS OF GROUNDWATER IN SELECTED AREAS IN IBADAN AND FEASIBLE ENGINEERING SOLUTIONS

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Abstract

This research work focused on the assessment of iron and manganese levels of groundwater in selected areas of Ibadan, South West Nigeria, and provides feasible engineering solutions for community use. The study was cross-sectional and analytical in design. Water samples were collected from a total of 93 wells (shallow and deep) and 27 boreholes within high, medium and low density areas of Ibadan. In addition, 18 soil samples were collected near these water sources at a depth of 15 cm. Water and soil samples collected were anlaysed for iron and manganese using standard methods (American Public Health Association). The pH values of waters from wells and boreholes for high, medium and low density areas were within the permissible limits of World Health Organisation (WHO), Standards Organisation of Nigeria (SON). All (100.0%) wells in the medium and low density areas had iron concentration exceeding the WHO and SON recommended limit while all (100.0%) boreholes in high, medium and low density areas had Fe concentrations exceeding the permissible limits. Most, 71.4% of wells and 81.8% boreholes in the high density area had manganese concentrations exceeding the SON standards while 35.7% of wells and 9.1% boreholes in this study area had Fe concentration exceeding WHO guideline value. An inverse correlation existed between pH and Fe concentrations of wells in high density area ($r=-0.646$, $p< 0.01$) while age of the wells in high density area was found to be significantly related to Mn concentration ($r= 0.382$, $p< 0.05$) showing the older the well, the lower the value. Most of the wells and boreholes in the high density area had high manganese concentrations. Proper and hygienic maintenance of wells and boreholes is necessary and storage, and use of water filter may be applied to reduce Fe and Mn concentrations at household level before use.

Keywords: Groundwater, Manganese concentration, Iron concentration, chlorine treatment

Introduction

Groundwater is increasingly being used globally as the surface waters are getting polluted due to human activities. Ground waters are often preferable as they are less prone to chemical and biological pollution (Yusuf, 2007; Hassan, 2008). In Nigeria, groundwater has been reported as a major source of community water supply and its contamination is a major environmental and health concern (Longe et al., 1987). The contamination of groundwater with heavy metals particularly iron and manganese is also of concern for industry and for other uses (Spellman, 2001; Kamel, 2012).

In Nigeria, the rate of urbanization is alarming and the major cities are growing at rates between 10 to 15% per annum (Yusuf, 2007). Groundwater pollution has been attributed to the process of industrialization and development that has progressively developed over time without any regard for environmental consequences which eventually results in the deterioration of physical, chemical and biological properties of water (Longe and Balogun, 2010; Isikwe et al., 2011). Further, lack of pipe borne water supply in Nigeria remains a challenge, hence many homes have wells sited around the houses and pollution prone surroundings. In most cities, since colonial times the water mains pass through open drains (Sridhar et al, 1981; Sridhar, 2000; Ikem et al, 2002). Often these pipes are leaky and the drainage enters the mains and travel to the households. Communities tend to look for alternative sources of water and groundwater sources (shallow wells and boreholes) have become an immediate option (Adekunle, 2008; Adelekan, 2010). This is also common in other African cities. Regrettably, Ibadan suffers serious water shortage as Ifabiyi (2008) posited that sights of children/women searching for water are common experience particularly in dry periods.

As the city dwellers tap groundwater extensively, depletion and contamination of groundwater is wide spread and their impacts are realized over a period of time (Macfarlane et al., 1982; Nazari et al., 1993; Das et al., 2002; Momodu and Anyakora, 2010). The major contaminants found in the groundwater include sulphates, nitrogen compounds (such as ammonia and nitrates), petroleum products, phenols and heavy metals (UNESCO, 2004). Some heavy metals like lead, chromium and mercury may impose acute toxicity even in lower concentrations. No much information is available on the iron and manganese as most of the industries in the cities always resort to in-house treatment systems for their industrial operations particularly in textiles, paper and pulp and table water supplies (Salem et al., 2000). Besides, higher dissolved concentrations of iron and manganese could not only cause aesthetic problems (Tredoux et al., 2004) but also affect neurological and muscle function in humans (USEPA, 2004; WHO, 2004; ATSDR, 2008). In Nigeria, most of the water quality studies focused more on bacteriological quality of groundwater than the mineral content. Therefore, this study assessed iron and manganese levels of groundwater and soil in the vicinity of the water sources in socio-economically delineated residential areas in Ibadan.

2. Materials and Methods

2.1 Study area

Ibadan is one of the largest urban centres in West Africa (Olayinka et al, 1999) with several settlements around. It is the capital city of Oyo state with coordinates of 7^0 23′0″N, 3^0 56′0″E and located near the forest-grassland boundary of Southwest area of Nigeria. The city has 11 local government areas (LGAs), five within the metropolis and six at peripherals with a mix of urban, peri-urban and rural communities. The population of central Ibadan with its five LGAs is 1,338,659 while Ibadan Metropolis with 11 LGAs has a population of 2,550,593 (Federal Republic of Nigeria, 2009). Ibadan area is part of Niger-guinea coast water dominated by land forms which are closely related to geological structures. The geology comprises igneous and metamorphic rocks of the Precambrian Basement complex which forms part of the African crystalline shield. It consists predominantly of migmatite, gneiss, schists, quartzite, granite and few basic materials. The quartzites form the most prominent residuals in the Ibadan Area (Fagbami and Shogunle, 1995). The climate is characterized by a rainy season from March through October, while the dry season stretches from November to February.

2.2 Study design and sampled areas

This study was cross sectional and analytical in design which involved collection of groundwater samples from deep and shallow wells and boreholes (Figure 1). The city was classified using population density into three: High, Medium and Low density areas as illustrated in Figure 2. Water sources within the classified areas were selected by simple random sampling and soil samples were also picked up in the vicinity of the water source with a view of finding the impact of soil elements on water. Overall, samples of water were collected from 120 points and 18 soil samples from the same area (Table 1). Geographical Positioning System (GPS) of each sampling point was determined and used to produce map while a surface geological map was derived from the laboratory results of analysis of iron and manganese (Figure 3). Information on the age and depth of the selected water sources were also collected. The soil samples (six each from High, medium and low density area) at a depth of 15cm were collected. Water and soil samples collected were anlaysed for pH, iron and manganese using standard methods (APHA, 1998).

Table 1: Summary of water samples collected

Sampling area	**Water Source**		**Total**
	Well	**Borehole**	
High density	30	11	**41**
Medium density	34	6	**40**
Low density	29	10	**39**
Total	**93**	**27**	**120**

Six samples of soil were also collected from the three areas;

Figure 1: Ttypical wells sampled in the areas

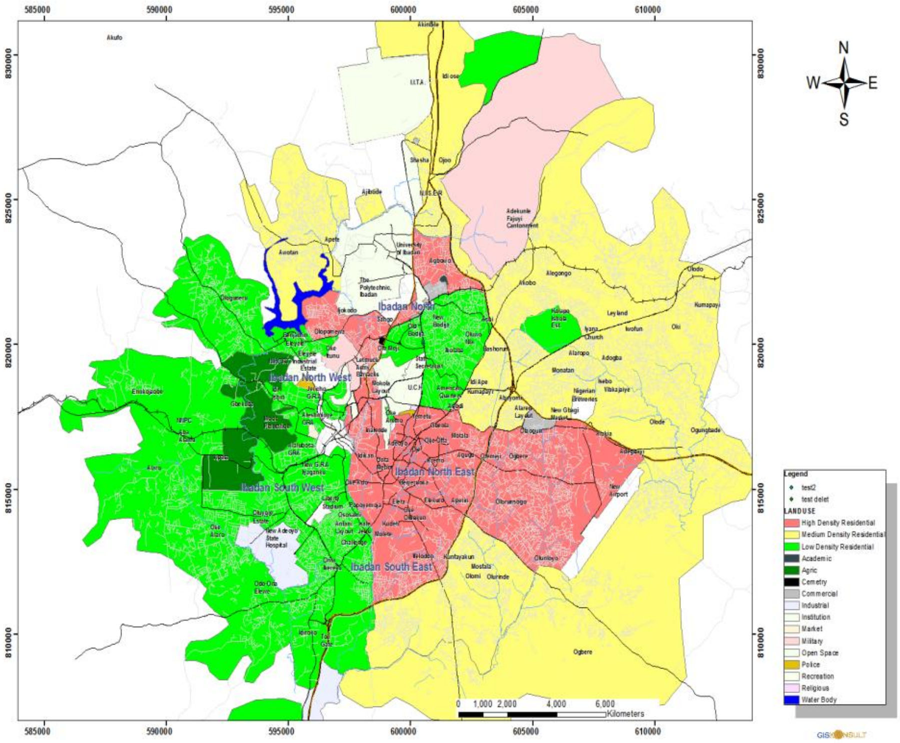

Figure 2: Population density map of Ibadan Metropolis

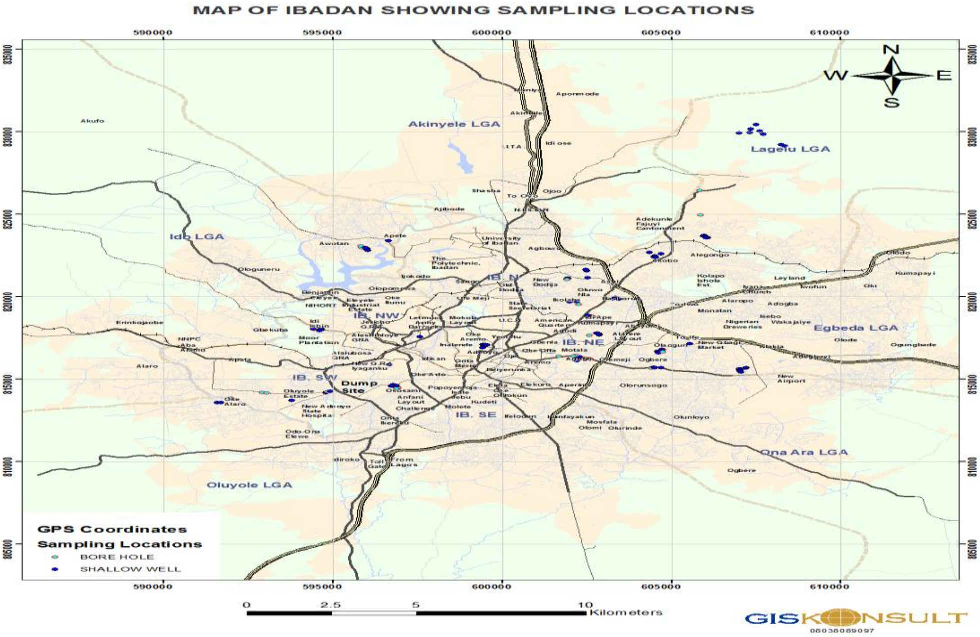

Figure 3: Map of Ibadan showing locations for water and soil samples

2.3 Sampling method

Plastic kegs of 2 litres capacity were used to collect water samples for pH determination while Polytetrafluoroethylene (PTFE) bottles of 60ml capacity were used to collect samples for heavy metal analysis. The samples were fixed with concentrated nitric acid to prevent the metals from adsorbing to the walls of the containers. Water samples were collected according to recommended standard methods described by the American Public Health Association (APHA, 1998). Samples were collected in triplicates in all the sampling points. The sample bottles were tightly stoppered after each collection and transported under 4^0C to the laboratory for physico-chemical (including heavy metal) analysis. Please state the date and season when samples were collected.

2.4 Laboratory analysis

The filtered water samples were analysed for pH (using Jenway pH meter) and an Atomic Absorption Spectrophotometer (AAS) Model: TECHCOMP (Version: AA6000) and BUCK Scientific, Model 210VGP was used for the determination of iron (Fe), and manganese (Mn) by direct reading (APHA, 1998).

2.5 Data Analysis

Data were analysed using Statistical Package For Social Sciences (SPSS) Windows Version 18 (Chicago, IL). The mean and the corresponding standard deviation were used to summarize the characteristics of the water samples, while the results were compared with Standards Organization of Nigeria (SON) for drinking water and World Health Organization (WHO) Guidelines for drinking water quality (Table 2). ANOVA test was used at 5% level of significance to determine if there were significant differences in the water quality parameters across the sampling area. Also, association between water source characteristics (Age and Depth) and physico-chemical (pH, Fe and Mn) parameters at the three sampling areas was determined using Spearman's correlation coefficient at 5% level of significance.

Table 2: World Health Organization (WHO) Guideline, Nigerian Industrial Standards (SON) Guideline for potable water

Characteristics	WHO Limits	SON Limits
pH value	6.5-8.5	6.5-8.5
Iron (mg L^{-1})	0.3	0.3
Manganese (mg L^{-1})	0.5	0.2

Source: SON (2007), WHO (2006)

The reference WHO (2006) was not listed in the reference section.

3. Results

3.1 Characteristics of water sources

Figure 4 presents the characteristics of the water sources. The pH values of water samples, from both the wells and boreholes for High, Medium and Low density areas were within the permissible limits of 6.5-8.5 specified by World Health Organisation (WHO), and Standards Organisation of Nigeria (SON). Age of the water sources (wells vs Boreholes) in High, Medium and Low density areas were (11.8±7.8 vs 2.6±1.0) years, (8.2±6.9 vs 3.3±2.5) years and (11.0±5.9 vs 2.5±0.9) years respectively. Mean depth of the wells in High, Medium and Low density areas were 8.9±3.4 m , 8.4±3.1 m and 9.8±1.8 m, respectively while depth of the boreholes could not be measured but in these areas they vary between 40 to 60m.

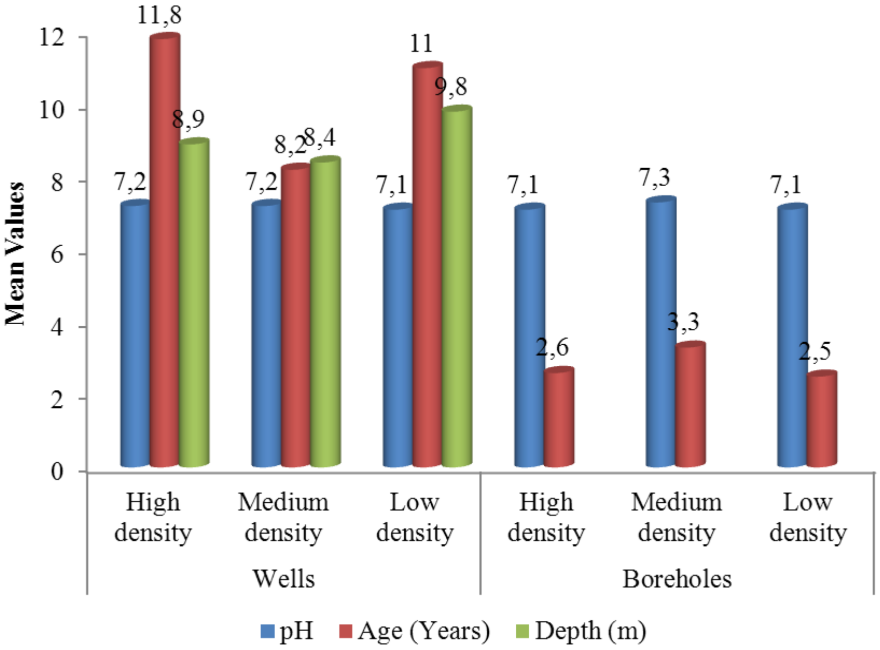

Figure 4: Characteristics of the water source

3.2 Distribution of iron and manganese in the water sources

The iron (Fe) and manganese (Mn) status in the water sources in high, medium and low density area are shown in Table 3. The results indicate that wells located in the medium density area had the highest average iron concentration (1.64±0.2 mg L^{-1}) while boreholes in the low density area had the highest average iron concentration (1.89±0.8 mg L^{-1}). Also, 100.0% of the wells in the medium density and low density areas had iron concentration which exceeded the SON and WHO recommended limits while 100.0% boreholes in these areas showed Fe concentrations exceeding the permissible limits. The lowest average manganese concentration for well and borehole water sources (0.29±0.1 mg L^{-1} and 0.26±0.2 mg $L^{-1)}$ were found for medium density area. However, 71.4% of wells and 81.8% boreholes located in the high density area had manganese concentrations which exceeded the SON standard while 35.7% wells and 9.1% boreholes in this study area also had exceeded WHO guideline value for the same heavy metal. .

Table 3: Distribution of Iron (Fe) and Manganese (Mn) in the water sources

Sampled area	No. of water sources surveyed	Mean±SD (mg L^{-1})	% exceeding SON standard	% exceeding WHO standard
		Fe concentration		
Wells				
High density	30	0.66±0.4	93.3	93.3
Medium density	34	1.64±0.2	100.0	100.0
Low density	29	0.53±0.3	100.0	100.0
Boreholes				
High density	11	0.53±0.3	100.0	100.0
Medium density	6	0.50±0.2	100.0	100.0
Low density	10	1.89±0.8	100.0	100.0
		Mn concentration		
Wells				
High density	30	0.38±0.2	71.4	35.7
Medium density	34	0.29±0.1	53.3	20.0
Low density	29	0.31±0.2	51.9	29.6
Boreholes				
High density	11	0.33±0.1	81.8	9.1
Medium density	6	0.26±0.2	50.0	16.7
Low density	10	0.29±0.1	77.8	0.0

3.3 Comparison of pH, Iron and Manganese values in the study areas

The mean pH, Fe and Mn values of the water sources (wells and boreholes) among the three categories (High, medium and low density) of the sampling area are shown in Table 4. The mean pH value of the wells and boreholes among high, medium and low density areas did not show any significant variation. Similarly, the Fe and Mn concentrations also did not vary. However, Table 5 shows that there was an inverse correlation between pH and Fe concentrations of wells in high density area ($r=-0.646$, $p< 0.01$) indicating that pH of the water influences the dissolution of Fe. Also, age of the wells in high density area was found to be significantly related to Mn concentration ($r= 0.382$, $p< 0.05$). The older the well, the lower is the metal level. However, in medium density area Fe concentrations was found to be inversely related to the depth of wells ($r= -0.467$, $p< 0.05$) and pH ($r= - 0.466$, $p< 0.05$). The Mn concentrations of wells in low density area was inversely correlated with the pH value of the wells ($r= -0.511$, $p< 0.01$). Similarly, an inverse correlation existed between pH and Fe concentration of borehole water samples in high density area ($r=-0.555$, $p< 0.05$) and in the medium density area ($r= -0.560$, $p< 0.01$). Manganese concentrations of borehole water samples were significantly related to pH in low density area ($r=-0.521$, $p< 0.01$) while age was inversely related to the Fe concentration in this sampling area($r= -0.558$, $p< 0.05$).

Table 4: Comparison of pH, Fe and Mn values in the sampled areas

Parameters	Sampling area	Mean±SD	F-statistics	p-Value
Well water				
pH	High density	7.2±0.5	1.179	0.312
	Medium density	7.2±0.4		
	Low density	7.1±0.2		
Fe	High density	0.66±0.4	2.363	0.105
	Medium density	1.64±0.2		
	Low density	0.53±0.3		
Mn	High density	0.38±0.2	0.898	0.411
	Medium density	0.29±0.1		
	Low density	0.31±0.2		
Borehole				
pH	High density	7.1±0.4	0.461	0.636
	Medium density	7.3±0.1		
	Low density	7.1±0.5		
Fe	High density	0.53±0.3	1.922	0.216
	Medium density	0.50±0.2		
	Low density	1.89±0.8		
Mn	High density	0.33±0.1	0.322	0.728
	Medium density	0.26±0.2		
	Low density	0.29±0.1		

Table 5: Correlation between water sources (wells and boreholes) characteristics (Age, Depth and pH) and chemical (Fe and Mn) values

	Age	Depth	pH	Fe	Mn
Wells					
High Density					
Age	1.000				
Depth	0.000	1.000			
pH	0.213	0.250	1.000		
Fe	0.257	0.016	-0.646**	1.000	
Mn	0.382*	0.084	-0.147	-0.354	1.000
Medium Density					
Age	1.000				
Depth	-0.165	1.000			
pH	-0.198	-0.211	1.000		
Fe	-0.140	-0.467*	-0.466*	1.000	
Mn	0.202	-0.136	-0.047	0.110	1.000
Low Density					
Age	1.000				
Depth	0.063	1.000			
pH	0.143	-0.034	1.000		
Fe	-0.555*	-0.062	-0.071	1.000	
Mn	-0.117	-0.054	-0.511**	-0.313	1.000
Boreholes					
High Density					
Age	1.000				
pH	0.127		1.000		
Fe	0.243		-0.555*	1.000	
Mn	0.250		-0.129	-0.193	1.000
Medium Density					
Age	1.000				
pH	-0.180		1.000		
Fe	-0.025		-0.560**	1.000	
Mn	0.303		-0.269	0.260	1.000
Low Density					
Age	1.000				
pH	0.153		1.000		
Fe	-0.558*		-0.073	1.000	
Mn	-0.119		-0.521**	-0.314	1.000

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

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

3.4 Occurrence and distribution of Iron (Fe) and Manganese (Mn) in soils around the sampled areas

Occurrence and distribution of Fe and Mn in soil around the sampled areas was depicted in Figure 5. The pH values of soil sample for High, Medium and Low density areas were within the permissible limits specified by WHO and SON. Iron concentration were 12.7±1.9 mg L^{-1}, 16.1±2.8 mg L^{-1}, and 16.2±1.0 mg L^{-1} in high, medium and low density areas respectively. Likewise, the Mn concentration were 12.6±2.5 mg L^{-1}, 10.9±1.0 mg L^{-1} and 10.8±0.6 mg L^{-1} in high, medium and low density area respectively. These concentrations are within critical levels recommended in soils for plant growth. WRONG. The result of Fe and Mn in soils CANNOT be expressed in mg L^{-1}. It must be expressed in mg/kg.

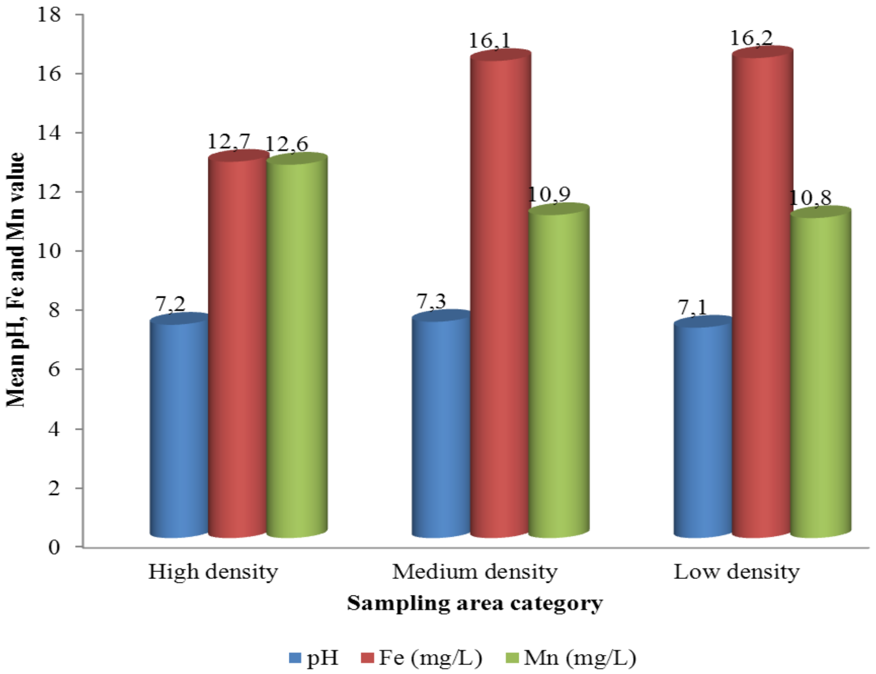

Figure 5: pH, Iron and Manganese levels in soil samples WRONG UNIT. Results must be expressed in mg/kg.

Discussion

This study focused on the assessment of iron and manganese levels of groundwater in selected areas of Ibadan and provides feasible engineering solutions for community use. It was evident that pH values of water samples, both the wells and boreholes for high, medium and low density areas fell within the permissible limits specified by WHO, and SON for potable water. This contradicts several studies that reported the acidic nature of most of the ground waters studied (Longe et al., 1987; Longe and Kehinde 2005; Longe, E.O. and Enekwechi, 2007; Yusuf, 2007). Ages of the wells in high, medium and low density areas were higher compared to the boreholes in the three areas. This suggested that wells have been in existence in the study areas before commencement of boreholes drilling. This may also be due to depletion of well waters as extraction in Ibadan has been on increase in recent years. This could also be as a result of low cost of digging either shallow or deep wells compared to borehole drilling. BGS and DPHE (2001) in their study categorized wells into shallow (< 150 m) and deep (> 150 m). This study however found that all the wells in high, medium and low density areas were shallow. Moreover, the study observed that wells located in the medium density area had the highest average iron concentration while boreholes in the low density area had the highest average iron concentration. It has been observed in a study that iron contents in 50% of the samples were more than the WHO limit for iron concentration in drinking water supplies (WHO, 2004, 2008). This study found that greater proportion of wells in the medium density and low density areas had iron concentration exceeding the SON and WHO recommended limits.

All boreholes in high, medium and low density areas had Fe concentrations exceeding SON and WHO limits. However, the study found lowest mean manganese concentration for well and borehole water sources in medium density area. Moreover, most of the wells and boreholes located in the high density area showed manganese concentrations higher than the SON standard. This is similar to the findings of BGS and DPHE (2001) study that high concentrations of manganese were found in water samples in most areas of the country surveyed. Contrarily, Hasan and Ashraf Ali (2010) reported about 32% of wells containing safe level of arsenic had unsafe level of manganese. It was documented in this study that only 35.7% wells and 9.1% boreholes in high density area had Mn concentration exceeding the WHO guideline value.

Data from this study further indicated that pH value of the wells and boreholes among high, medium and low density areas did not show any significant variation likewise the Fe and Mn concentrations. These findings indicate that category of the sampling area had no influence on the pH value, Fe and Mn concentrations. However, pH of the well water in high density area significantly influenced the Fe levels in wells, indicating that pH of the wells inversely influences increase in Fe concentration. A decrease in pH- meaning pH range towards acidic medium favours an increase in Fe concentration of the wells in high density area. This concurs with Matheis (1985) findings that pH has a strong influence on the chemical behaviour of iron and its solubility in water. Also, age of the wells in high density area was found to be significantly related to Mn concentration. This shows that aged wells in high density area are prone to more Mn concentration compared to new ones. Also, Fe concentrations in medium density area was inversely related to the depth of wells and pH.(What is the effect of season on some of the parameters measured, e.g. depth of well. Was this study conducted during the dry season or rainy season???? Please state explicitly the season when samples were collected. ALSO, discuss the effect of season on the results obtained. These findings suggested that the most shallow wells with favourable pH condition had more Fe concentration. The Mn concentrations of wells in low density area was significantly related to the pH value of the wells. It is evidently shown from these findings that well water in low density area had favourable pH condition for high Mn levels. Furthermore, pH of borehole water samples in high density area favour increase in Fe concentration while similar trend was observed in medium density area. This is evident from pH of boreholes in both the high and medium density area influenced the increases in iron concentration. While manganese concentrations of borehole water samples was inversely correlated with pH in low density area, age of the boreholes was inversely related to the Fe concentration in this sampled area. This is an indication that low pH of boreholes water in low density area favours an increase in the Mn concentration whereas aged boreholes had less Fe concentration in this sampling area. The latter findings could be a consequence of geological features of the site of boreholes.

Foster (1985) observed that iron and manganese are common elements in the earth’s crust and as water percolates through soil and rock it can dissolve these minerals and carry them into groundwater. Data on the occurrence and distribution of Fe and Mn in soil around the sampling area indicated that although, iron concentrations were higher in all the three sampled areas, medium and low density areas accounted for more Fe concentration in the adjoining soil. It was found that Mn concentration were present in soil around high, medium and low density area, higher Mn concentration was observed in soil around high density area. These findings suggested that ground water sources around the high density area are prone to high Fe and Mn concentration from soils around their area. Iron (Fe) and manganese (Mn) are metallic elements present in many types of rock and are commonly found in water. They may also arise from occupations carried out by the residents, as in this case people residing in high density areas engage in small trades and businesses where metals play a major role. Both are essential elements required in small amounts by all living organisms while any quantity above the required standard are harmful to health. It has been reported that manganese at very high levels can pose a neurotoxic risk (ATSDR, 2008; USEPA, 2004; WHO, 2004). Ingestion of more than required quantity of iron results in Haemochromatosis-ineffective operation of normal regulatory mechanisms which could lead to tissue damage (ATSDR, 2008; USEPA, 2004; WHO, 2004).

Conclusion

This study revealed that all the wells in high, medium and low density areas were shallow and greater proportion of wells in the medium and low density area had iron concentration exceeding the SON and WHO recommended limit. Also, most of the wells and boreholes located in the high density area had manganese concentrations exceeding the SON standard. The pH of the waters were found to be significantly related to Fe and Mn concentration in all the sampled areas. Furthermore, higher Fe and Mn concentrations were observed in soils around high density area compared to medium and low density areas. Therefore residents of these study settings (High, medium and low density area) especially those in high density area may be at risk of suffering from aesthetic and health challenges which iron and manganese concentration might cause. Hence, proper and hygienic maintenance of wells and boreholes is necessary while adequate storage and use of water filters are required for removal of Fe and Mn concentration of water at household level before use.

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