



Article

Physico-chemical Quality Assessment of Groundwater within Gusau Metropolis

Y. Adejo¹, B.U. Bagudo¹, A.I. Tsafe¹, A.U. Itodo^{2,*}

¹ Department of Pure Chemistry, Usmanu Danfodiyo University, Sokoto, Nigeria

² Department of Chemical Sciences, Federal University Wukari, Taraba State, Nigeria

* Author to whom correspondence should be addressed; E-Mail: itodoson2002@gmail.com.

Article history: Received 15 November 2012, Received in revised form 13 January 2013, Accepted 14 January 2013, Published 15 January 2013.

Abstract: Physico-chemical quality assessment of borehole water samples obtained across Gusau metropolis in April 2011, indicated various types of contaminants that are of health and quality concern, based on the WHO guideline for drinking water quality. The total dissolved solid, hardness, nitrate, chloride, phosphate and sulphate in the water samples were 248-3764, 8.39-81.27, 1.2-5.2, 0-3.78, 0.2-1.03 and 1.3-19.5 mg/dm³, respectively. The contents of the heavy metals Pb, As, Zn, Fe and Mn were 0.013-0.036, 0.005-0.021, 0.016-2.550, 0-0.43 and 0-0.21 mg/dm³, respectively. The concentrations of Co, Cr and Cd were below detection limit of adopted analytical method. Hence, these elements were considered to be of no significant risk in groundwater sources within Gusau metropolitan area. Absence of heavy industrial activities within the same area also suggested natural and other anthropogenic activities to be the primary sources of groundwater contamination.

Keywords: physico-chemical parameter; quality; groundwater; borehole; heavy metals.

1. Introduction

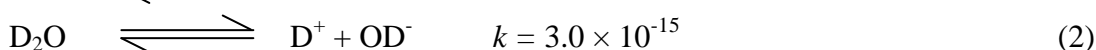
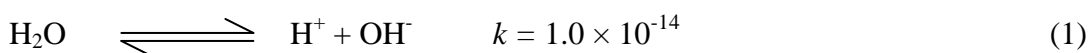
Water is one of the most abundant chemical substances on earth, as it covers two third of the earth's surface [1]. Water is perhaps the most important inorganic compound in the biosphere, for it has conditioned the ecology and evolution of terrestrial organisms to an extent far greater than any

other compound [2]. Water was also an important factor in the location of the earliest civilizations. The human body contains between 55% to 78% water depending on body size. To function properly, the body requires between one and seven liters of water per day to avoid dehydration; the precise amount depending on the level of activity, temperature, humidity, and other factors [3].

Acceptability of water for any kind of purpose is defined by the type and level of impurities it contains. Drinking water for instance, is considered safe if it contains some dissolved impurities at concentrations within permissible limit of a given standard, such as the World Health Organization's (WHO) standard. The same applies to water for agricultural and industrial purposes in terms of the type and level of impurities they might contain, which makes them suitable for their respective uses [4]. Groundwater chemistry can vary tremendously over very short distances depending upon whether a sample is drawn from an actively flowing conduit or from rock matrix [5].

Water pollution happens to be one of the major environmental topics of present day time. Rapid industrialization arising from modern and sophisticated technology has introduced many synthetic materials into the environment [1]. For example, worldwide indiscriminate use of chemicals such as herbicides, insecticides, fungicides, bactericides and fertilizers have resulted in the contamination of total ecosystems. A situation that may have arisen from the fact that in many developed and developing countries, there are only limited controls on industrial and domestic waste discharges to water bodies that serve as drinking water sources. Water is an odorless, tasteless, transparent liquid that is colorless in small amounts but when present in large amounts exhibits a bluish tinge [4].

All the complex chemical processes involved in the development and maintenance of living organisms are sensitively attuned to the physical properties of liquid water as earlier mentioned. These properties are as a result of the unique chemistry of water molecules based on the chemistry of protium which is the most abundant of all the known isotopes of hydrogen. Although the chemical properties of most isotopes of the same element are basically the same, the percentage difference in mass between isotopes of H is greater than between those of other elements. Thus, isotopes of H exhibit anomalous chemical and physical characteristics compared to most other elements. For example, the chemical properties of water and heavy water differ in terms of their reaction rates and equilibrium constant [6].



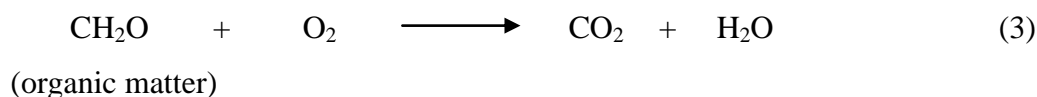
The value for dissociation constant of heavy water is doubled compared to that for ordinary water as indicated in equations 1 and 2 above, this difference is of significance in many respect. For instance, if all H atoms in water is to be replaced with deuterium (D) to give D₂O otherwise known as

heavy water, this form of water will be of no physiological use as seeds will not germinate in D₂O and animals drinking only D₂O will die of thirst [7]. Oxygen also has three natural isotopes, ¹⁶O, ¹⁷O and ¹⁸O, with relative abundances in natural oxygen of 99.67, 0.04 and 0.20 percent respectively. Hence, it can be said that the chemistry of water is so sensitive to the slightest of molecular variation introduced through H atoms. This phenomenon is known as isotope effect [6].

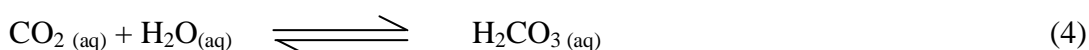
Groundwater is a commonly used term to refer to water that has percolated from ground surface through the soil pores. They are contained in soil and rock (porous media) formations that have become saturated with water. This water that occurs in the saturated zone of variable thickness and depth, below the earth's surface are known as groundwater reservoir or aquifers. They are vital source of water supply, especially in areas where dry summers or extended droughts cause stream flow to stop. Each groundwater system in an area is known to have a unique chemistry, which is acquired as a result of chemical alteration of the meteoric water recharging the system [8].

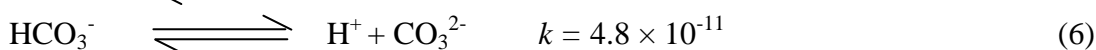
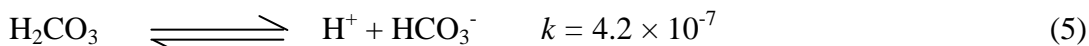
In the water cycle, precipitation happens to be the least contaminated link in the chain of cycle [9]. Although, during rainfall, water tends to dissolve particulate matters, atmospheric gases such as CO₂, CO, N₂, NO₂, SO₂ and other green house gases that are present in the atmosphere. Dissolution of these substances in rainwater compromises the natural purity of rainwater. On reaching the earth's surface, some of these solute components are associated with the acid rain phenomenon [10]. Surface water on the other hand is the most contaminated water body as it is interfaced between the earth crust and the atmosphere. The earth crust is composed of mainly silicate minerals that can be washed off or weathered by running surface water, and this has the effect of likely increasing the turbidity of surface water.

Before reaching the saturated zone, percolating water is charged with some oxygen and carbon dioxide. Microbial degradation of organic matter present in the soil leads to the formation of CO₂, which further dissolves in the percolating water as shown in equation 3 [11].



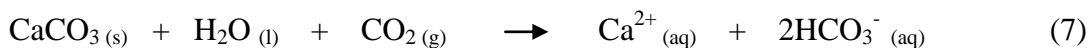
Hence, in addition to the CO₂ and other atmospheric gases it already carries, the percolating water further dissolves more CO₂ produced from the soil due to degradation of organic matter as shown in equation 3, thereby enriching the percolating water more with carbon dioxide which is the precursor for carbonic acid [11]. Equilibrium is usually established as shown in equation 4 between the CO₂ and H₂CO₃. However, at room temperature only 1% of the dissolve CO₂ will exist as H₂CO₃. Since H₂CO₃ is a weak acid it dissociates in two steps as shown in equations 5 and 6 [12].



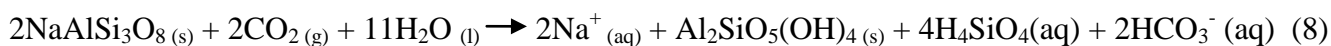


Formation of carbonic acid in this manner has the effect of lowering the pH of the percolating water, which is why groundwater tends to be acidic. And as a result, occurrence of carbonic acid and other acids in the percolating water tend to encourage a number of mineral-weathering reactions. These reactions are sometimes responsible for leaching out mineral components from the earth's crust, the leachates often goes into solution with the percolating water, thereby causing further contamination. Sometimes these dissolved mineral solutes also tend to undergo secondary changes by means of either congruent or incongruent dissolution.

Simple dissolution of mineral solute into its constituent ions is known as congruent dissolution, while dissolution leading to the formation of secondary minerals is known as incongruent dissolution. Dissolution process for calcite and albite are typical examples of the two respectively [13].



(Calcite)



(Albite)

(Kaolinite)

From equations 7 and 8, we can see the role of CO₂ is playing in the two chemical weathering reactions for the simple and basic silicate rocks. For the basic silicate it consumes twice the amount of atmospheric CO₂ compared to that of carbonate rocks, and thus predominantly regulates the global CO₂ cycle [11]. These chemical reactions in the soil as water percolates through, can be of oxidation-reduction, precipitation and chelation types as well. And they may influence the mobility and toxicity of many pollutants that are introduced into the soil and groundwater system.

However, besides natural factors, anthropogenic factors particularly those that tend to introduce harmful substances to the soil are also of significance in the evolution of groundwater quality [1]. Effluent discharge from industry, fertilizers/manures application on farmland is some examples. Some of these substances could undergo secondary changes, as they are washed along the soil strata [6]. This is more likely to take place with water containing dissolved ionic solutes that could replace metallic ions from the silicate minerals [11].



Ascertaining water quality for whatever purpose it is intended for, is achieved by means of carrying out quality analysis on them. Water quality analysis is one of the most important aspects in groundwater quality assessment. The hydro chemical study reveals quality of water that is suitable for

drinking, agriculture and industrial purposes. Further, it is possible to understand the change in quality due to rock-water interaction or any type of anthropogenic influence [14].

Heavy metals are the class of metals having densities greater than 5 g/cm^3 . They are found mostly in groups III – V of the periodic table. These along with other light metals are often present in some natural water sources. Some of these metals are essential for healthy living of organisms. However, when the individual concentrations of these metals are very high beyond certain tolerable limits in foods or drinking water, they become toxic [2]. Advancement in technology has led to high level of industrialization leading to the discharge of effluents containing heavy metals into the environment [2]. Some of these heavy metals may be lacking in abundance on earth, they are however, not lacking in significance, as ingesting minute quantities of them can lead to death due to their toxicological effect [1].

Atomic absorption spectroscopy is an analytical technique that uses light as a tool for quantitative and qualitative determination of metal contents in a sample using an atomic absorption spectrophotometer (AAS). Quantitative determination using this technique is based on measuring the decrease in the intensity of light mostly from a hollow cathode lamp source. The reduction in light intensity is due to the absorption of light that have passed through a layer of atomized vapour containing the elemental specie of interest. Atomization is achieved by aspirating into a flame, sample containing the element of interest. During analysis, the amount of light intensity absorbed in the flame is proportional to the concentration of the element in the sample in accordance with Beer's law [2,15]. Each metallic element has its own characteristic absorption wavelength, which is produced by the appropriate hollow cathode lamp fitted to the spectrophotometer [15].

It has been observed that 97.96% of groundwater samples from Surulere middle class area of Lagos, Nigeria contain Al, Cd and Pb, sometimes at a concentration beyond WHO's maximum contamination limits [16]. In a similar study on borehole water from Ali Sheriffiti, Sagir and Danbore resettlement areas of the Lake Chad region, it was also observed that the levels of Fe, NO_2^- , and Mg all exceed the WHO standards for all samples analyzed, while the NO_3^- , Cl^- , electrical conductivity, hardness, color and turbidity were all within the permissible limit [17]. This present research work is a quality assessment of groundwater samples obtained from borehole sources within Gusau metropolitan area of Zamfara State.

2. Materials and Methods

Sampling Area: Gusau is the capital town of Zamfara state, located in the northwestern part of Nigeria at the geocoordinates; 12.17°N and 6.66°E . The relative position of the town on the Nigeria map is indicated as shown on Fig. 1. The population of the town is 132,392 in 1991, and this is

projected to be at 147,034 in 2012 [18].

2.1. Sampling and Sample Collection

Catch water samples [9] were collected within Gusau town, from fifteen different borehole sites as indicated on the map (Fig. 1), using polyethene containers. The choice of area for sample collection was guided by availability of boreholes.

The water containers used were previously washed and rinsed with 5% nitric acid [19] and was again later rinsed with distilled water after which they were dried and labeled before use for sample collection. Three separate samples were collected at approximately four hours intervals from each of the boreholes. Before samples were collected, water was allowed to run out of tap for two minutes to ensure removal of unwanted residues at the mouth of the tap openings. Water bottles were capped tightly after sample collection. The samples were then kept refrigerated under 4°C before they were analyzed [2]. The samples were labeled as coded.

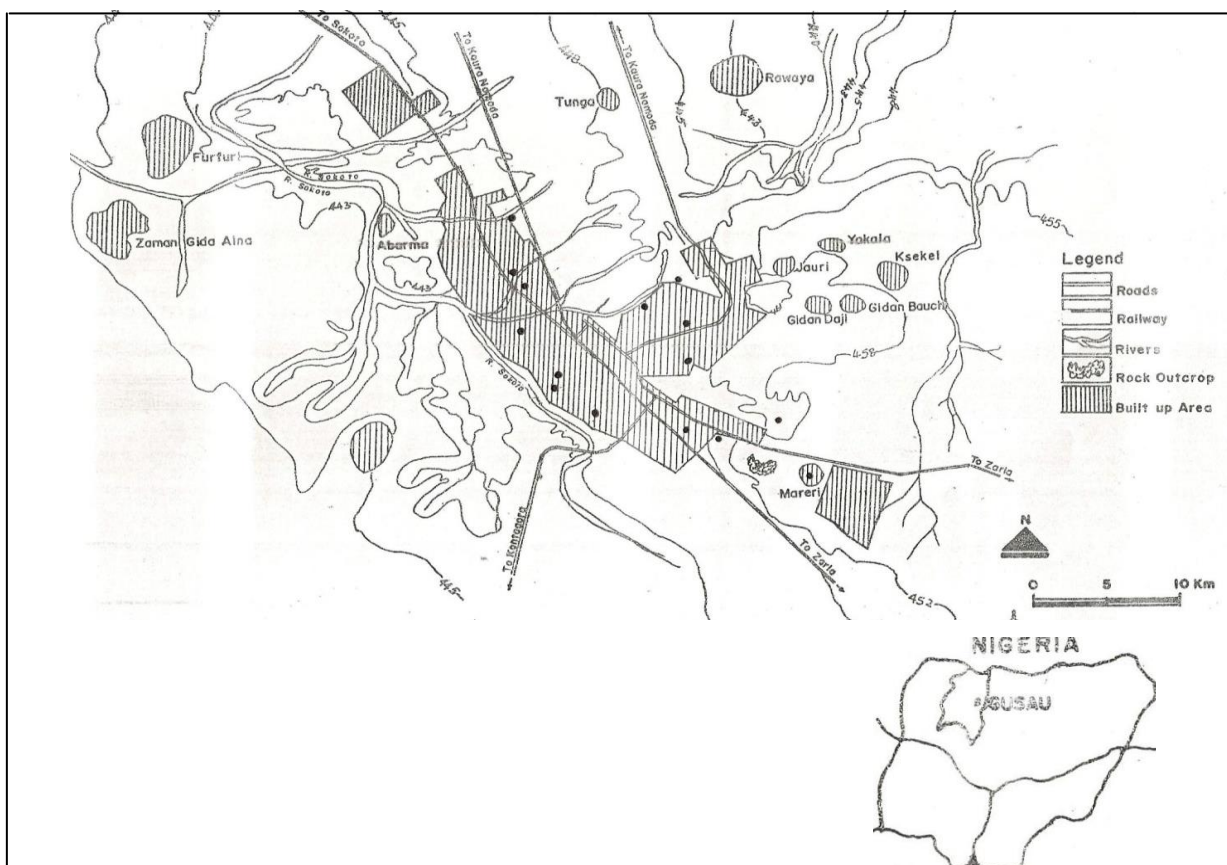


Figure 1. Sampling points on map of Gusau town, Nigeria [20]

Composite samples were obtained from all sets of catch samples [9]. The obtained composite of each borehole was again split into three equal parts for intra and inter laboratory use for the study. Each set of sample was preserved according to specific needs of the intending analysis [2].

Investigated physical parameters include pH, temperature, conductivity, turbidity, total dissolved solid, chemical parameters, total Kjeldahl nitrogen, chloride, total hardness, sulphate and phosphate. They were estimated using standard methods.

Prior to heavy metal analysis, 100 cm³ of acidified water sample was poured into a conical flask. The 5 cm³ of 1:1 mixed acid (conc. HNO₃ and H₂SO₄) was gently added. The solution was stirred and heated on a hot plate until the volume of the solution was approximately halved. The solution was cooled and diluted with distilled water to 100 mL mark. The pH of the solution was adjusted to 4.0 with 5 N NaOH solution. Quantitative amount of the digested samples were then collected in a thoroughly rinsed sample bottles. The samples were appropriately preserved before being analyzed for their metallic content [2].

Through series of dilutions, arsenic standard solutions with concentration of 0.20, 0.40, 0.60, 0.08 and 1.00 mg/L were prepared from the arsenic stock solution. This was followed by setting up a 211/210 VGP model of the Buck scientific atomic absorption spectrophotometer. A working air-acetylene burner, the right hollow cathode lamp and also the right adjustments for monochromator slit width were all put in a ready position for the AAS analysis. This was followed by running the standards on the spectrophotometer and their corresponding absorbance noted. Calibration curve of absorbance against concentration was then plotted for the standards. Each of the fifteen water samples was then analyzed and their corresponding concentrations were read from the calibration curve.

The same analytical procedures were followed for the determination of cobalt, chromium, lead, cadmium, manganese, zinc and iron in the water samples with the right choice of working stock solutions and hollow cathode lamps.

3. Results and Discussion

The results for the physico-chemical analysis carried out were discussed accordingly while those detailing the relative concentration of the various chemical parameters in respective samples are also indicated as Figs. 2-13.

The pH values for the samples lies within the range 5.94-6.64, with BH3 having the least value and BH10 with the highest. The mean average for all samples is 6.30. This implies that all the water samples are slightly acidic. The relative acidity of each of the samples was based on their pH readings. It can also be seen that pH values for 11 out of the 15 samples were slightly below the 6.5-9.5 recommended limit [21]. Only those of BH1, 6, 10 and 13 falls within the limit. Hence, it can be said of those outside the recommended limit to have better tendencies of leaching silicate and other minerals into the water [22]. This acidic nature of groundwater is traceable to some dissolved matter in the water. For instance, rainwater being the major source of groundwater recharge, dissolves

greenhouse gases during rainfall, it is the dissolution of these gases that is responsible for increasing rainwater acidity [1,9]. Also, the pH of rainwater tends to be higher than that of groundwater, and this is as a result of differences in the chemical dynamics of the two water source types. One of the major reasons why groundwater is likely to become more acidic is that more carbon dioxide from organic matters present in the soil could further dissolve in percolating water during percolation, before they reach an aquifer system.

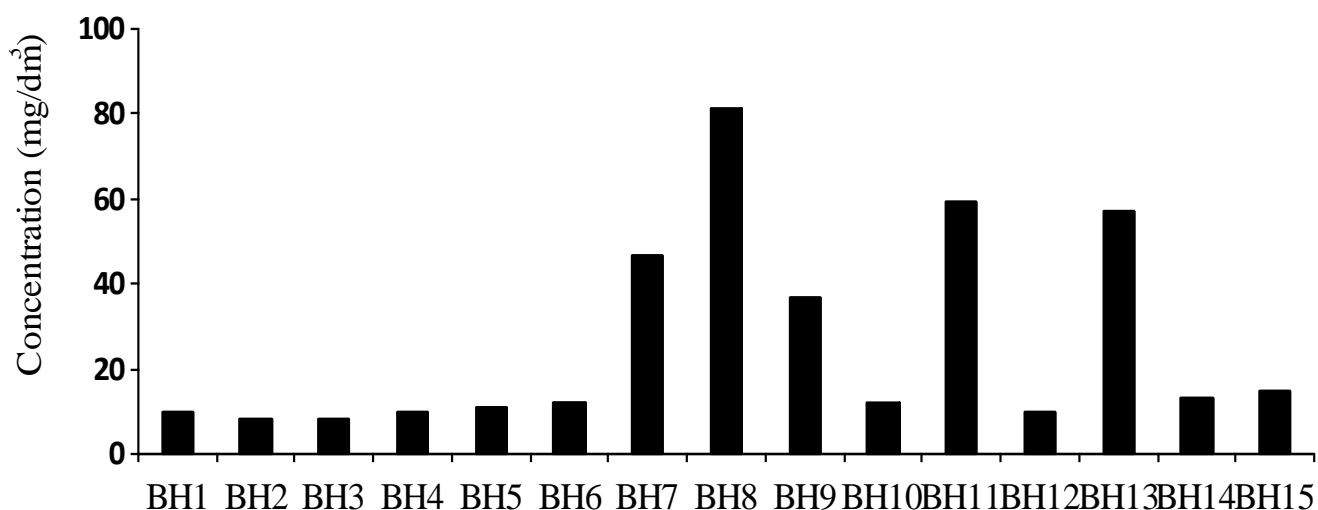


Figure 2. Hardness as mg/dm³ CaCO₃ of samples

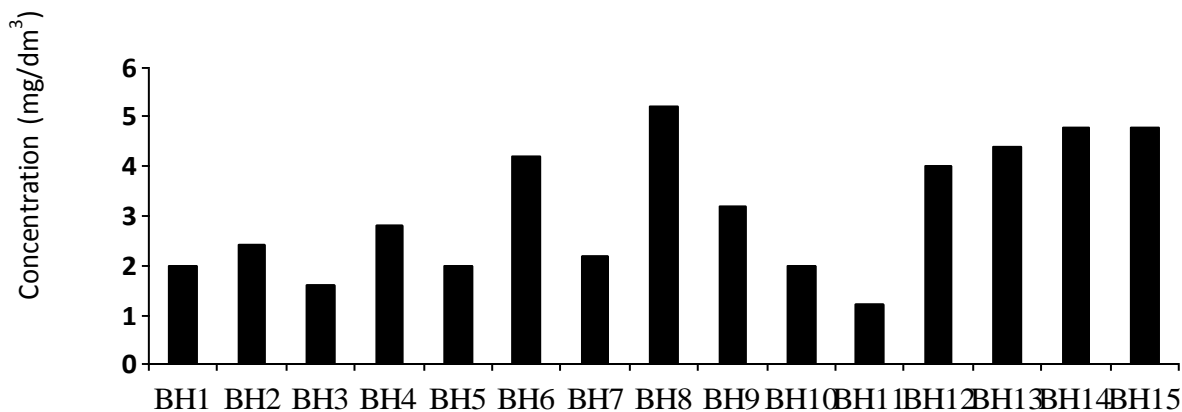


Figure 3. Nitrate concentration in samples

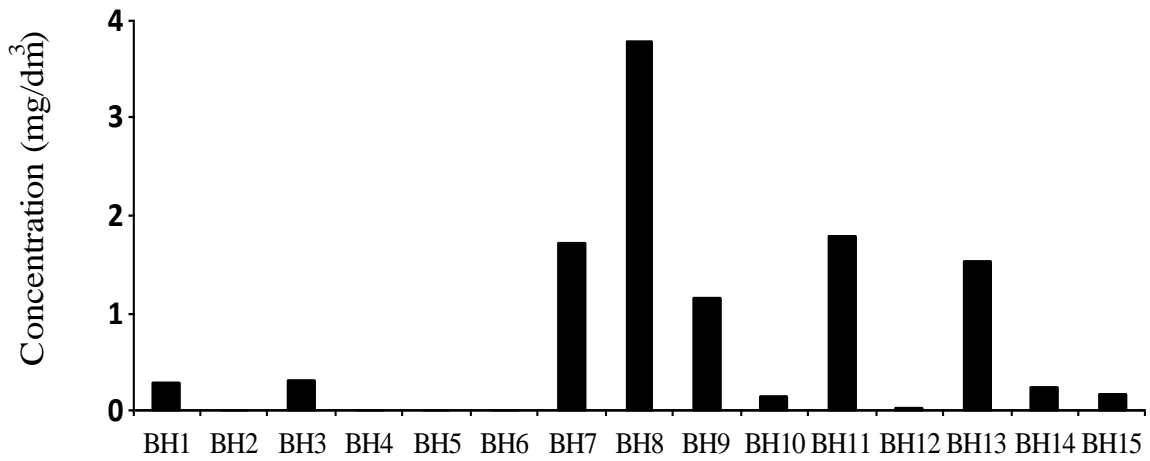


Figure 4. Chloride concentration in samples

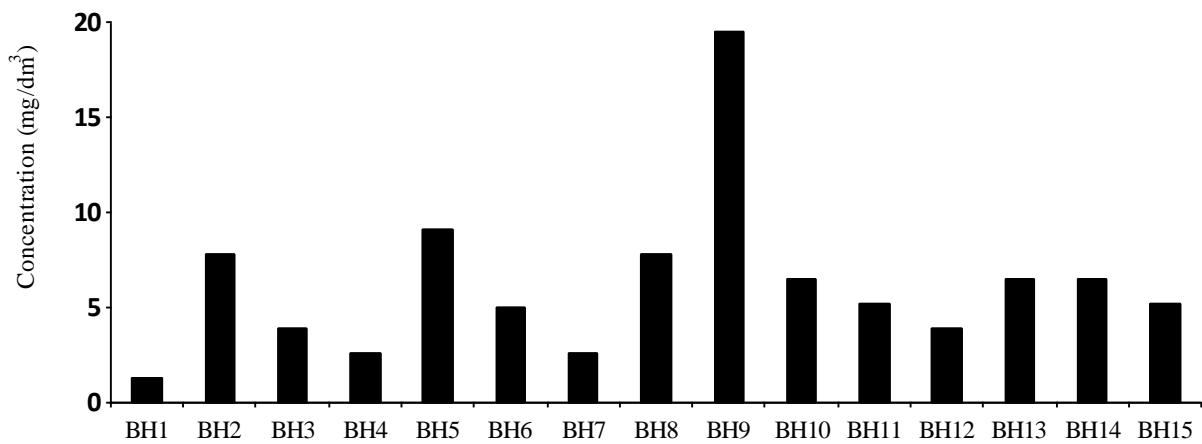


Figure 5. Sulphate concentration in samples

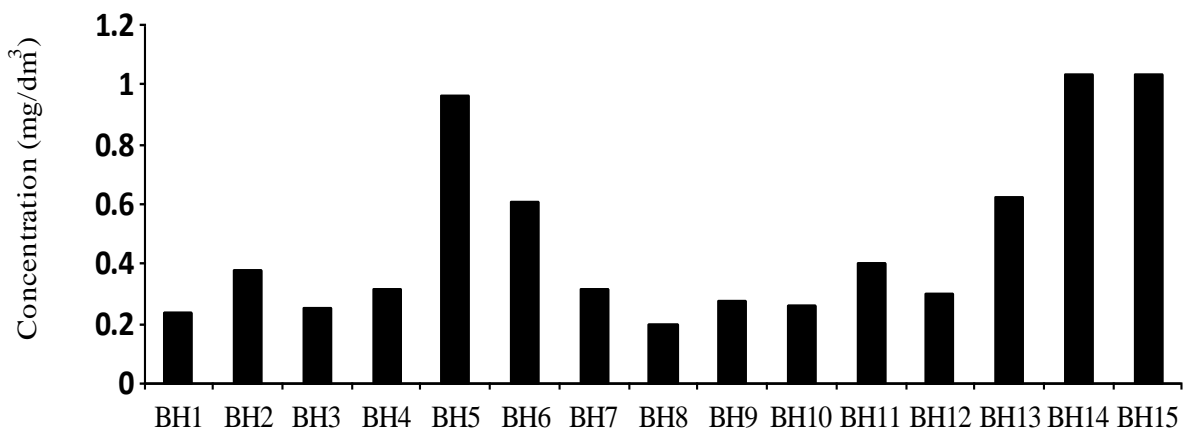


Figure 6. Phosphate concentration in samples

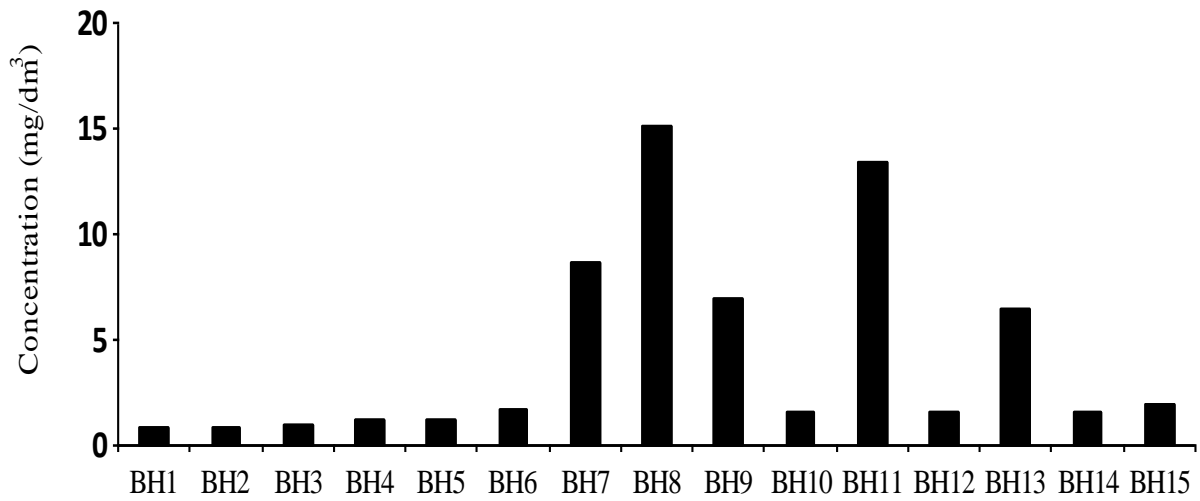


Figure 7. Calcium concentration in samples

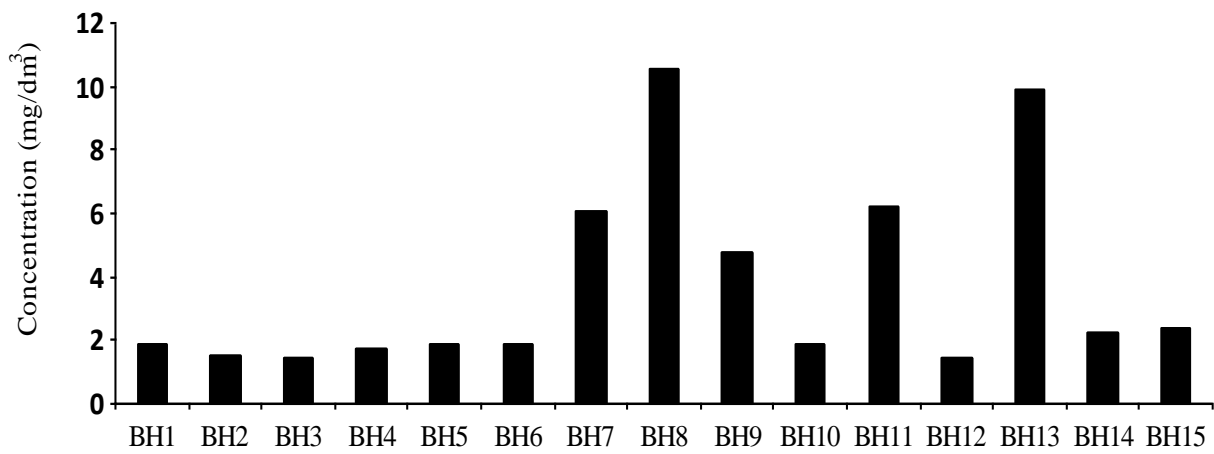


Figure 8. Magnesium concentration in samples

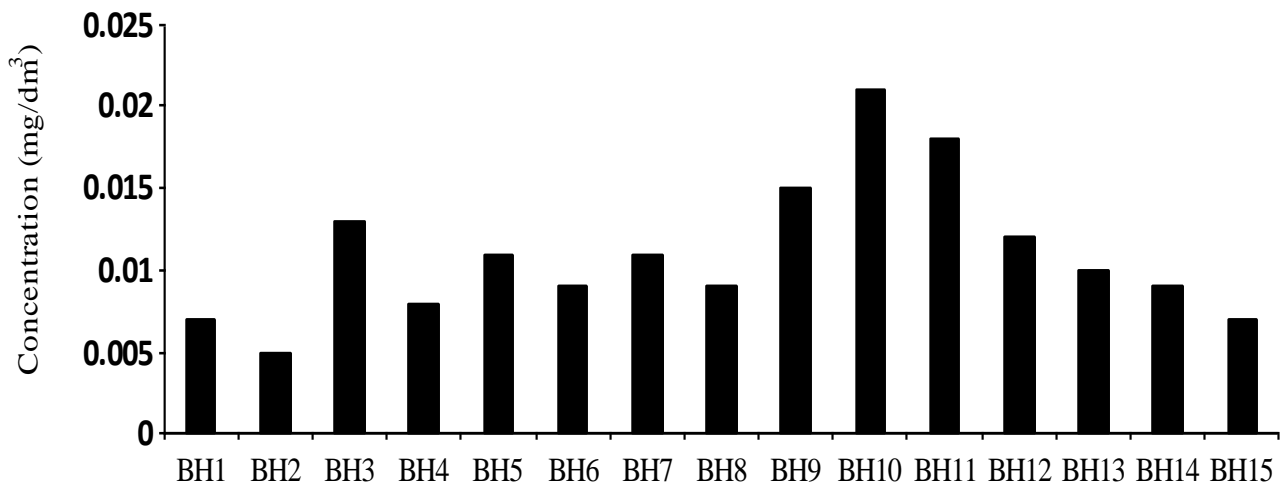


Figure 9. Arsenic concentration in samples

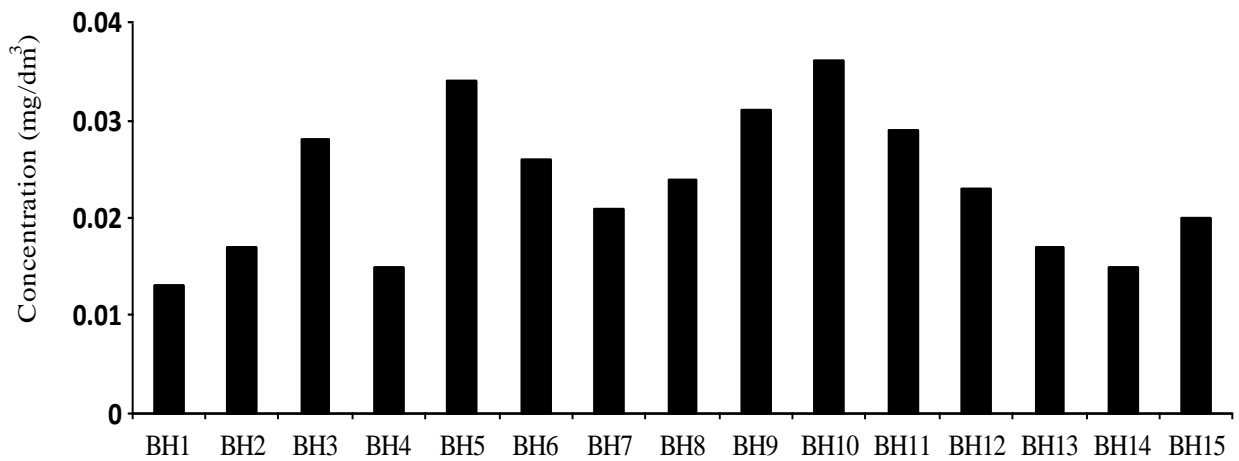


Figure 10. Lead concentration in samples

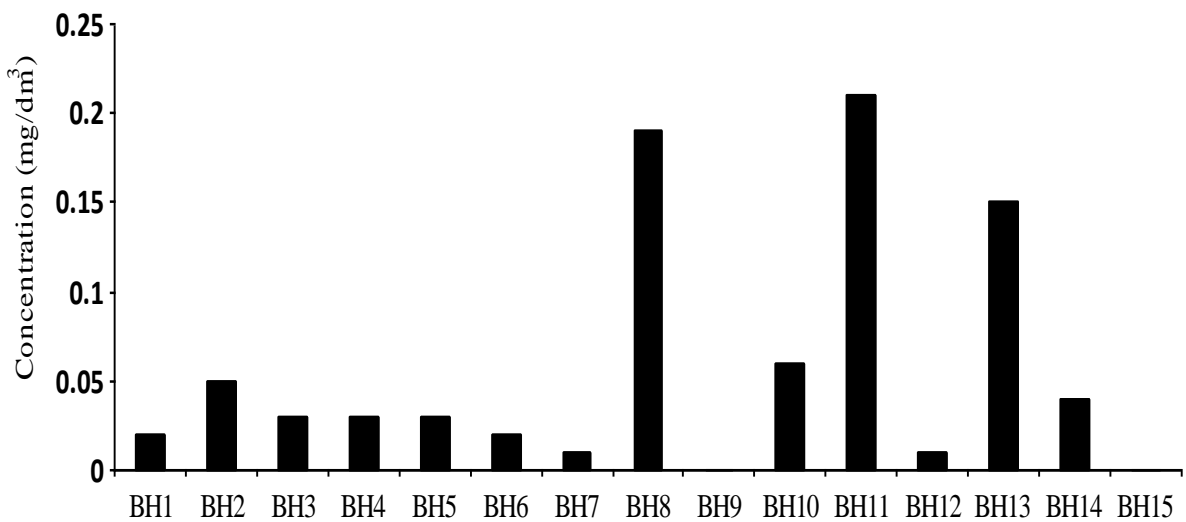


Figure 11. Manganese concentration in samples

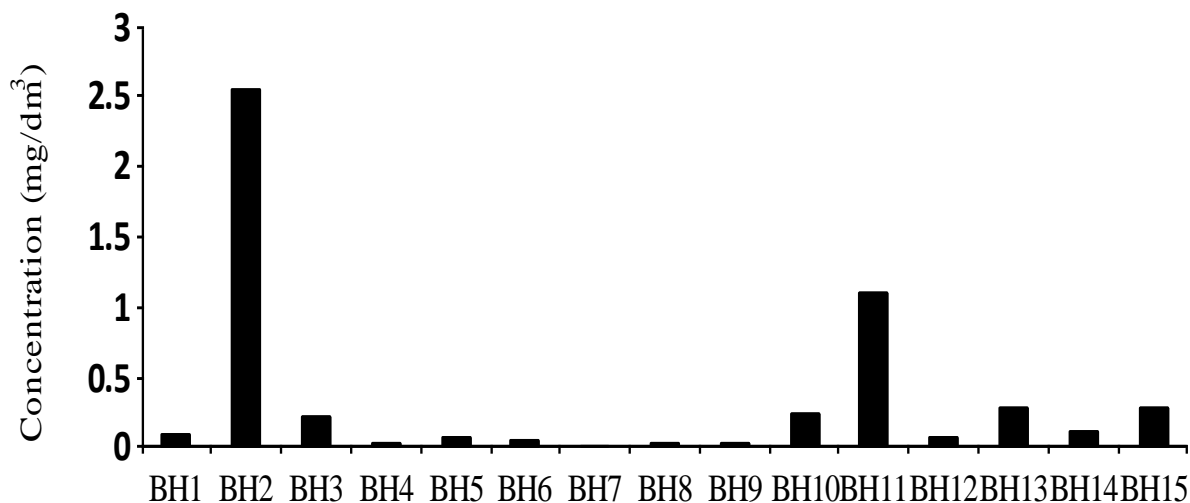


Figure 12. Zinc concentration in samples

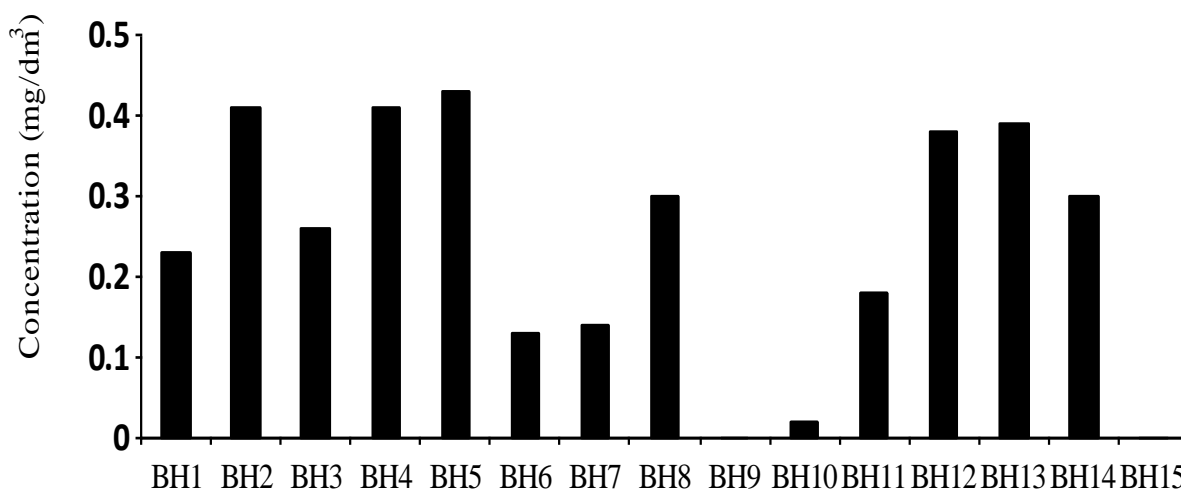


Figure 13. Iron concentration in samples

Temperature readings for the water samples at the time of sample collection, lies in the range of 28.5-33.0 °C. BH2 and BH14 recorded the least readings while BH8 recorded the highest temperature reading. Groundwater is known to exist in the matrix of rocky materials which are composed mainly of silicate materials and other minerals which can leach into water. Water temperature condition tends to affect the rate at which these rocky materials dissolve into water during contact time. For water, it is a known fact that, high temperature greatly enhances dissolution of inorganic solid and liquids into water [23]. Temperature condition of water also affects the viscosity of organic oil and greases whenever it comes into contact with them and as a result, it tend to affect their mobility and dissolution as well. Plumbing fittings such as those of steel and other metals are also affected by water temperature especially where they are utilized in extracting groundwater from aquifer systems (as it is the case for

all the boreholes from which samples were collected from). The temperature of the water could as well affect the rate at which these plumbing materials dissolves into water, as the water passes through pipes of the plumbing fittings. For the temperature condition at which these borehole water samples were found within their respective localities, the water can be said to be relatively palatable and will only moderately dissolve dissolvable materials it comes into contact with, such as pipe fittings and rock materials. Agbaire and Oyibo [24] indicated in their work that pH and temperature condition of borehole water are both prone to seasonal variation. Likewise temperature and other groundwater quality parameters are likely to vary within respective localities of Gusau metropolis, with regards to seasonal changes.

The relative value of conductivity for all the samples was also presented. Conductivity values obtained for the samples lies within the range of 248-3764 $\mu\text{S}/\text{cm}$ and the average for the samples is 112.6 $\mu\text{S}/\text{cm}$. From the values it can be seen that BH4 has the least conductivity value, which implies that it has the least amount of dissolved ionic solute [1,25]. At the other extreme is BH8 with the highest value, which implies that it is more saline and could possibly be having the heaviest load of dissolved ionic solutes in them compared to the other samples. The value for BH8 surpassing the mean value by over 338%. There is also tendency for seasonal variation for these parameters as reported in some works [24].

The range value for total dissolve solid (TDS) determination is 140-3460 mg/dm^3 and the average is 929.33 mg/L . The range for TDS follows the same trend as conductivity, whereby water samples from BH4 and BH8 registered the least and highest values, respectively. This also confirms that conductivity is a function of amount of dissolved solutes [1], although conductivity also depends on the nature of the dissolve solutes [4]. A health-based TDS value has not been proposed by the WHO. However, a value above 1200 mg/L may be objectionable to consumers, as may a too low value [25]. Four out of the fifteen samples exceeded the 1200 mg/L threshold. These samples are BH7, BH8, BH11 and BH13. For these samples, the observation implies they have a much heavy load of dissolved solutes in them relative to the other samples and as a result they may likely present taste quality problems from this observation. While for the other 10 samples their TDS value lies in the range of 140-480 mg/dm^3 which is much below the 1200 mg/dm^3 threshold. Water pH and the nature of geological materials around aquifer systems and aquiferous flow pattern underneath the ground from where these boreholes draw their water from, are very much to be a contributing factor responsible for this observation.

The values for turbidity lie in the range of 0.28 - 7.2 NTU with the average of 2.39 NTU. Water from BH9 happens to be the least turbid while that from BH14 is the most turbid. Groundwater is usually less turbid than surface water due to the restraining effect of soil and gravel on suspended

particles that causes turbidity [1]. Turbidity level of 5 NTU and below is usually acceptable to consumers. The WHO recommends median turbidity level in drinking water to be 0.1 NTU. Although this varies from place to place depending on local circumstances, sometimes, high levels of turbidity tend to protect microorganisms from the effects of disinfection, stimulate the growth of bacteria and give rise to a significant chlorine demand [21]. In terms of acceptability standard, only 3 of the water samples namely BH3, BH5 and BH14 were beyond the 5 NTU limit, this infer that they contain more particulate matter relative to the other samples which are within the 5 NTU and below limit. By standard, none of the samples satisfy the recommended 0.1 NTU limit. Hence, despite the popular belief that, due to the natural filtration process groundwater undergo makes treatment unnecessary, is not at all times true as indicated by this observation. The result also shows that the clarity of the water from these boreholes can further be enhanced possibly by utilizing the use of coagulating agents. Also, since disinfection is of unquestionable importance in the supply of safe drinking-water. Turbidity need to be checked, for optimal disinfection process where necessary. It is also noteworthy, that because of the possible existence of these particulate matters in groundwater, there is also the need for effective digestion of water samples during elemental determination of metals, using AAS technique. This is because of the possible clustering effect turbidity may render on some solute materials that may be present in the water.

None of the water samples possesses objectionable odour, as this will have profoundly suggested contamination due to some organic matter. This also, implies that all the water samples may be of relative good quality in terms of organic contaminants [1].

The range for the nitrate level in all the water samples is 1.2-5.2 mg/dm³. BH11 has the least value, while BH8 has the most nitrate content. The average is 3.09 mg/L for all samples analyzed. Fig. 3 show the relative nitrate content in all the samples. Oruonye and Medjor [17] in their work observed a mean nitrate level of 1.3 mg/dm³ in borehole water located at some resettlement area in the Lake Chad Region, with all the samples being within the WHO standard permissible limit. Meanwhile, similar observation by Schafer *et al.* [25], confirms the possibility of having high level of nitrate in borehole water. Low levels of nitrate are naturally present in water, however high levels result from anthropogenic sources such as sewage or excessive fertilizer use [1]. The WHO organization standard permissible limit for nitrate content in drinking water is 50 mg/dm³ [21]. This is because, consumption of nitrate rich water do have pronounce physiological effect more on children due to methaemoglobinaemia also known as blue baby syndrome [26]. Hence, this is a health based limit [20]. Nitrate content in all the samples were all within the WHO permissible limit of 50 mg/dm³. The source of these nitrate levels could be from both natural and anthropogenic sources around the area. The low level could be attributed to moderate use of fertilizers in agricultural activities within the

region. It can also be attributed to good sewage systems around the areas where boreholes are sited [27]. Also the rock system within the area is very likely to be low in nitrate [9].

Results for the water hardness of the samples were in the range of 8.38-81.07 mg/dm³, and the mean value is 26.00 mg/dm³, with BH3 recording the least value and BH8 the highest value. BH11 is just close to the 60 mg/dm³ threshold and it may be considered moderately hard, based on the concentration range of classification for hardness. The relative value of total hardness in the samples can be seen from Fig. 2. This indicates that most of water is relatively soft. There is no guideline value for hardness [21].

From Fig. 4, the chloride level in all the samples were all within the range value of 0-3.78 mg/dm³, with an average of 0.72 mg/dm³. Four of the fifteen water samples, namely BH2, BH4, BH5 and BH6 were observed to contain no chloride in them. While BH8 sample registered the highest observed chloride level at 3.78 mg/dm³. Yet, this was far below the recommended 250 mg/dm³ WHO chloride level in drinking water [21]. This again implies that all the borehole water was all of satisfactory quality in terms of their chloride contents and that chloride does not contribute to taste problems in some of the water.

For all the samples analyzed, the sulphate level (Fig. 5) was in the range of 1.3-19.5 mg/dm³. BH1 has the least sulphate level while BH9 has the highest sulphate level. The mean sulphate level value for all analyzed samples was 6.08 mg/dm³. This result also confirms the acceptability of these borehole water sources in terms of their sulphate contents. Also, it confirms that sulphate in the water does not contribute to problem of taste. However, it might contribute to hardness of the water samples as observed.

Phosphate levels in all the water samples were in the range of 0.2-1.03 mg/dm³, with an average of 0.48 mg/dm³ (Fig. 6). BH8 recorded the least value while BH14 recorded the highest value. The WHO guideline value for phosphate in drinking water is 5 mg/dm³. Thus, all the samples were within the limit. The water can be said to be of good quality in terms of phosphate content. The low level of phosphate may be due to low phosphate containing rocks system or absence of such rock system around the areas where boreholes are sited [28]. It could also be due to minimal use of phosphate containing fertilizers around these areas.

The mean concentration of arsenic (Fig. 9) in the water samples was 0.011 mg/dm³, and the values for concentration ranged between 0.005-0.021 mg/dm³. BH2 and BH10 recorded the least and highest arsenic level, respectively. Arsenic itself is believed to be a carcinogen, and its presence in water above the WHO's 0.01 mg/dm³ permissible limit is of health concern [21]. BH3, BH5, BH7, BH9, BH10 and BH11 all contain arsenic level beyond the permissible limit as indicated in Fig. 9. BH10 and BH11 both contain arsenic nearly twice the permissible limit at 0.18 and 0.21 mg/dm³

respectively. Presence of arsenic in all the samples suggests presence of arsenic in the earth crust around this area. Arsenic may have leached into the water during percolation and/or during groundwater flow within rock pores holding them.

Lead level (Fig. 10) in all the samples was in the range of 0.013-0.036 mg/dm³ with mean value of 0.023 mg/dm³. Relative lead concentration for individual samples is also indicated on Fig. 10. It can be seen that BH1 has the least lead content, and BH12 has the highest. The WHO has recommended 0.01 mg/dm³ as the permissible limit for lead in drinking water [21]). Some works have reported elevated lead level in borehole water at a concentration beyond this guideline value [29]. Observations here indicate that the entire sample contains lead above the 0.01 mg/dm³ permissible limit. Hence, the borehole water is contaminated with lead at an elevated level that is of health concern to children within the age of 5 and below [21]. This observation may also be due to the geological composition of the area, which is likely to be rich in lead.

Cadmium, chromium and cobalt level were investigated for all the samples and it was observed that these elements were not detected in all the samples. This could also be attributed to the geological composition of the area, which can be said to be low in these elements. These elements could be completely absent or present at concentrations below the detectable limit of the AAS technique used for their determination.

Manganese was found in twelve out of the fifteen samples analyzed. Fig. 11 shows the relative manganese level in all the water samples. It can be seen that the range value of manganese level in the water samples is 0-0.21 mg/dm³ with a mean value of 0.05 mg/dm³ for all the samples. BH9 and BH15 were found to contain no manganese, while BH11 happens to have the highest level of the metal at 0.21 mg/dm³ which is still below the provisional guideline value for manganese in drinking water of 0.4 mg/L [21]. All the samples contain manganese below the recommended health based limit. Hence, they can be said to be of acceptable quality with regards to their manganese level. Although, when considering the possible effect on taste quality, samples with manganese content above 0.1 mg/dm³ are likely to have taste. These samples include those from BH13, BH8 and BH11.

The range value for zinc concentration (Fig. 12) in all the samples is 0.016-2.550 mg/dm³, with mean value of 0.346 mg/dm³. BH7 has the least zinc content in them while BH2 has the highest. There is no health-based guideline value for zinc in drinking water. However, it has been observed that drinking water containing zinc above 3 mg/L tend to impart astringent taste on the water and also give rise to greasy films when boiled [20]. Occurrence of zinc in all the samples can be understood from the believing that zinc occurs in small amount in almost all igneous rocks. For all the samples analyzed, zinc level is all below the 3 mg/dm³ taste threshold limit. Hence, the water samples can be said to be of acceptable quality. This also infers that the geological composition of the area where BH2 and BH11

samples were obtained could be relatively rich in zinc compared to others.

The iron content (Fig. 13) in the water samples ranged between 0-0.43 mg/dm³ with a mean value of 0.24 mg/dm³. BH15 and BH9 happen to contain no iron in them while BH5 contains the highest level of iron. Iron is of significance in water quality assessment due to acceptability concern associated with taste and colouration. There is no health based guideline value for iron in drinking water, however 40 mg/dm³ is recommended for iron content in drinking water [21]. All the samples happen to contain far less than this recommended value. The low level of iron in these borehole water samples could be attributed to the geological composition of the earth crust around the area, which can be said to be low in iron. Also due to the soft nature of most of the water samples, they could leach out metals like iron and lead from plumbing fittings that contains them. The mildly acidic condition of the water could also contribute to this effect [28].

4. Conclusions

Based on WHO's standard for drinking water quality, all the water samples were of acceptable quality in terms of their nitrate, chloride, sulphate, phosphate, cobalt, chromium, cadmium, zinc and iron contents. The only major quality concerns are those due to PH, turbidity, dissolve solid, lead, manganese and arsenic level in the water. At the same time the observed pH of the water samples (5.94-6.64 and mean value of 6.30), also suggests that the mildly acidic condition of the water, is likely to facilitate the rate at which some of these chemical contaminants will leach out from their base minerals in the earth crust, during percolation of water into aquifers. Also the combined effect of the water pH condition and water-rock contact time may also play an important role as to the extent, water leaches out minerals from the rocky matrix which holds the water in place.

References

- [1] Ademoroti, C. M. A. *Environmental Chemistry and Toxicology*. Foludex Press Ltd, Ibadan, **1995**, pp. 171-204.
- [2] Ademoroti, C. M. A. *Standard Methods for Water and Effluent Analysis*. Foludex Press Ltd, Ibadan, **1996**.
- [3] Narayana, P. *Environmental Pollution: Principles, Analysis and Control*. CBS publishers and Distributors, India, **2007**, pp. 128-153.
- [4] Sharma, R. K.; Sharma, T. K. *A Textbook of Hydrology and Water Resource Engineering*, 5th edn. Ish Kapur for Dhanpat Rai Publications, **2000**, pp. 615-786, 939-964.
- [5] Quinlan, J. F.; Ewers, R. O. Ground water flow in limestone terranes: Strategy rationale and procedure for reliable and efficient monitoring of ground water quality in Karst Areas. In:

Proceedings, Fifth National Symposium on Aquifer Restoration and Ground Water Monitoring, Natl. Water Well Association, **1985**, pp. 197-234.

- [6] Lee, J. D. *Concise Inorganic Chemistry*, 5th edn. Blackwell Science, Wiley India Edition, **1995**.
- [7] Ghildyal, B. P.; Tripathi, R. P. *Soil Physics*. New Age International (P) Ltd., **1987**, pp. 44 - 42
- [8] Linsley, R. K.; Franzini, J. B.; Freyberg, D. L.; Tchobanoglous, G. *Water Resources Engineering*, 4th edn. Mc Graw Hill, **1992**, pp. 89-92.
- [9] Nsi, E. W. *Basic Environmental Chemistry*, 1st edn. The Return Press Ltd, Markurdi, Nigeria, **1997**.
- [10] Housecroft, C. E.; Constable, E. C. *Chemistry: An Introduction to Organic, Inorganic and Physical Chemistry*, 3rd edn. Pearson Prentice Hall, **2006**.
- [11] GWIndia. *Groundwater Quality in Shallow Aquifers in India*. A publication by Central Groundwater Board, Ministry of Water Resources, Government of India, **2010**. Retrieved from <http://cgwb.gov.in/documents/waterquality/GW> on 27th March, 2011.
- [12] Shakhashiri, B. Z. *Carbon Dioxide: Chemical of the Week*. Internet Resource Material, 2008. Retrived from <http://scifun.chem.wisc.edu./chemweek/co2/co2> on 24th February, 2011.
- [13] Yadav, S. K.; Chakrapani, G. J. Dissolution kinetics of rock-water reactions and its implication. *Current Sci.* **2006**, 90: 932-937.
- [14] Sadashivaiah, C.; Ramakrishnaiah, G. R.; Ranganna, G. Hydrochemical analysis and evaluation of groundwater quality in Tumkur Taluk, Karnataka State, India. *Int. J. Environ. Res. Public Health*, **2008**, 5: 158-164.
- [15] Bhatia, S. C. *Environmental Pollution and Control in Chemical Process Industries*, 2nd edn. Romesh Chander Khanna for Khanna Publishers, **2005**, pp. 164-291, 513-562.
- [16] Momodu, M. A.; Anyakora, C. A. Heavy Metal Contamination of ground water: the Surulere case study. *Res. J. Environ. Earth Sci.* **2009**, 8: 39-43.
- [17] Oruonye, E. D.; Medjor, W. O. Physicochemical analysis of borehole water in the Resettlement Areas in Lake Chad Region of Nigeria. *Nigeria J. Microbiol.* **2009**, 23: 1846-1851.
- [18] World gazeeter. Internet Resource Material, 2012. Retrieved from www.world-gazeeter.com/index./gusau. on 17th February, 2012.
- [19] Vogel, A. I. *A Textbook of Quantitative Inorganic Analysis*, 3rd edn. Willey New York, 1971.
- [20] DURP. *Gusau Masterplan*. A Publication by the Department of Urban and Regional Planning, Ahmadu Bello University, Zaria, Nigeria, **1998**, pp. 2-9.
- [21] WHO. *Drinking Water Quality Guideline*. Vol. I, Recommendations, **2006**. Retrieved from http://www.who.int/ water_sanitation_health/dwq/gdwq0506 on 4th July, 2011.
- [22] Babagana, K.; Jibrin, M. D.; Ishaku, I. N. Elemental analysis of tap and borehole water in

Maiduguri, Semi Arid Region, Nigeria. *Europ. J. Appl. Sci.* **2009**, 1(2): 26-29.

- [23] Silberberg, M. S.; Randy D.; Gold, L. P.; Charles, G. H.; Arlan, D. N. *Chemistry: The Molecular Nature of Matter and Change*, 3rd edn. McGraw Hill, **2003**.
- [24] Agbaire, P. O.; Oyibo, I. P. Seasonal variation of some physico chemical properties of borehole water in Abraka Nigeria; *Afric. J. Pure Appl. Chem.* **2009**, 3(6): 116-118.
- [25] Shafer, A. I.; Rossiter, H. M. A.; Owusu, P. A.; Richards B. S.; Awuah, E. Developing country water supplies: Physicochemical water quality in Ghana. *Desalination* **2008**, 251: 193-204.
- [26] Manassaram, D. M.; Backer, L. C.; Moll, D. M. A review of nitrate in drinking water: maternal exposure and adverse reproductive and developmental outcomes. *Environ. Health Perspec.* **2006**, 114: 1371-1374.
- [27] Ibe, S. N.; Okpelenye, J. I. Bacteriological analysis of borehole water in Uli, Nigeria. *Afric. J. Appl. Zool. Environ. Biol.* **2005**, 7: 116-119.
- [28] Zuane, J. D. *Handbook of Drinking Water Quality*, 2nd edn. John Willey and Sons Inc., New York, **1996**, pp. 69-142.
- [29] Musa, H.; Yakasai, I. A.; Musa, H. H. Determination of lead concentration in well and borehole water in Zaria, Nigeria. *Chem. Class J.* **2004**, 8: 14-18.