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Research Article

Analysis of Groundwater Quality in Bauchi Metropolis (Nigeria) and interpretation using GIS

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Abstract: Fresh water resources include groundwater as a crucial component. It is essential to meeting the water needs of the country's diverse users and sectors. If the water quality is not evaluated, the usage and sustainability of the natural resources cannot be ensured. This study deals with the analysis of ground water quality in Bauchi metropolis and interpretation using ArcGIS according to the inverse distance weighting (IDW) technique. Water samples were taken from 18 hand dug wells randomly selected from six districts to assess for both bacteriological and physiochemical parameters. The bacteriological parameter tested for was Total Coliform Count, while the physiochemical parameters were: pH, Electrical Conductivity, Total Dissolves Solids, Free residual chlorine Cl-, Lead Pb, Total Hardness, Calcium Ca2+ and Magnesium Mg2+ using standard procedures prescribed by American Public Health Association, APHA. The results showed that all samples tested positive to Total Bacteria Count in the laboratory when compared to WHO Standard. whereas samples S3, S4, S5, S6, S7, S8, S12, S13, S14, S16, S17 tested negative to Total Bacteria Count under NSDWQ Standard while the remaining samples tested positive. Sample S10 was the highest at 134 cfu/100ml while S17 was the least at 1 cfu/100ml. Samples S1and S2 were not within the standard recommended pH range. Only sample S7 at 0.60 mg/L tested positive to free chlorine when compared with the NSDWQ guideline value. Sample S6 had the least TDS value of 90 mg/L while the highest value of 710 mg/L was recorded for S7. For lead content, Maximum value was recorded as 0.26 mg/L in samples S14 and S15. Sample S2 had the highest calcium value of 1.45 mg/L while S14 had the least value of 0.00 mg/L. Maximum value of magnesium was recorded in sample S14 having 3.58 mg/L while the lowest value was recorded in S11 having 0.52 mg/L. All Water samples were within the allowable limits for total hardness and are considered to be soft. It was concluded that samples S6 and S16 conformed to most of the standards while sample S7 did not conform to most of the standards when compared to WHO and NSDWQ.

Keywords: Geographic Information System (GIS); Ground water; Water quality; Bacteriological parameters; Physiochemical parameter

1. Introduction

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Water is one of the precious natural resources whose quality is crucial for human well-being. Groundwater is the main source of water for agricultural, industrial and domestic water needs. The availability of groundwater depends on the nature of the rock and its aquifer properties. Groundwater is one of the most valuable natural resources, supporting human health, socio-economic development and ecosystem functioning. Africa is a home to several communities who rely significantly on groundwater. Declining surface water abstraction has led to an increasing reliance on groundwater abstraction as pollution has increased and water treatment costs have risen [1]. About 65% of the Nigerian population population is highly dependent on groundwater for drinking water [2]. Inputs from the atmosphere, soil and water rock interactions, as well as pollution sources like mining, clearing land for agriculture, acid precipitation, and domestic and industrial pollutants, all have an impact on groundwater quality [3, 4].

The kind and concentration of dissolved minerals determine the suitability of water for different uses, and groundwater has a higher mineral content than surface water [5]. Groundwater quality management for the present and the future now requires the assessment of groundwater for drinking and irrigation. The monitoring and evaluation of groundwater quality for home and agricultural purposes around the world has become a major subject of many studies in recent years [5, 6, 7, 8, 9]. Groundwater quality has the potential to change due to hydrological and geological conditions over time [10]. Additionally, one of the main causes of groundwater pollution is incorrect trash or rubbish disposal [11]. As a result, physio-chemical and bilogical parameter study helped setermine the groundwater's quality [12, 13, 14]. Groundwater assessment can be done using hydrochemical parameters of the water [15]. When evaluating the quality of groundwater and how it will be used for irrigation, drinking, and construction purposes, a Geographic Information System (GIS) mapping system is a useful representational tool [16, 17]. ArcGIS software can be used to visualize the data and provide a better knowledge of groundwater quality[18]. In order to lessen parameter uncertainty, the datasets were statistically evaluated as well using methods including correlation matrices, box plots, and multivariate analysis.

Geographic information system (GIS), hydrochemistry, and factor statistical analysis were used by El-Rawy et al. [19] to examine the quality of groundwater under expanding agricultural operations in Qena Governorate, Egypt. A total of 73 groundwater samples were collected, and their physio-chemical parameters, including total hardness, major cations (Mg2+, Ca2+, K+, Na+), total dissolved solids, pH, electrical conductivity (EC), and major anions (SO42-, Cl-, F-, HCO3-), were analyzed. The spatial distribution of the results was mapped using GIS. On the basis of the magnesium hazard (MH), sodium adsorption ratio (SAR), Kelley ratio (KR), and residual sodium carbonate (RSC), the suitability of groundwater for irrigation was examined. It was found that 99% of the wells were deemed suitable for irrigation under the EC and SAR values. But just for Na+%, RSC, and KR. In the outlet and center areas of Wadi El-Assiuti, Assiut Governorate, Egypt, Megahed and Bull [20] conducted an investigation into the quality of groundwater and its suitability for drinking and irrigation based on GIS. 159 samples of groundwater were used in the experiment, and main ions, trace elements, and heavy metals were all examined. According to the findings, the concentration of trace elements (Fe++, Mn++, and Ni+) varies between 0.05 and 0.46, 0.11 and 0.221, and 0.01 and 0.6 ppm, respectively, whereas TDS values vary from 1972 to 6217 ppm. According to the World Health Organization, these findings show that all groundwater samples are categorically unsuitable and unfit for human consumption because of their high concentrations of total dissolved solids, trace elements, and heavy metals, especially in the majority of samples (WHO) standards for the purity of drinking water. The salinity is higher in the northeast and gradually decreases southward, according to a spatial study of the TDS values in an environment of geographic information systems. Most groundwater samples were found to be appropriate for irrigation based on measurements of sodium adsorption ratio, US Salinity, residual sodium carbonate, soluble sodium percentage, and permeability index. Concentrations of specific heavy metals and total dissolved solids (TDSs) in drinking water from shallow wells in some of the Ibadan metropolitan, southwest Nigeria, according to Ganiyu et al. [21]. Using an atomic absorption spectrophotometer and a calibrated meter, respectively, heavy metals and TDS were examined. Zn, Pb, Mn, Fe, and Cd had respective mean concentrations (mg/L) of 3.930, 0.658, 0.0304, 1.698, and 0.501. In 60%, 86.7%, 100%, and 100% of groundwater samples, respectively, the concentrations of Zn, Fe, Pb, and Cd were greater than advised norms. The mean amounts of Mn and TDS in water samples, however, are all within the permissible ranges established by the World Health Organization. Additionally, both TCA and PUA revealed nil-to-moderate pollution status, whereas PLI values > 1 in UA indicated moderate contamination. The pollution load index (PLI) range was 0.55 to 1.32 in both TCA and PUA. The results of the EF and the measurement of metal pollution in water samples showed geogenic and anthropogenic inputs. It was determined that for the three demographic classes—infants, children, and adults—the risk index caused by ingested heavy metals exceeds the allowed range. The prevalence and sources of trace metals in groundwater, as well as the risk to human health from ingesting groundwater directly, were examined by Brindha et al. [22]. From 2016 to 2018, samples were taken twice a year from 68 locations. The three main forms of groundwater were mixed Ca-Mg-HCO3, Ca-Cl, and Ca-Mg-Cl. Hydrogeochemical techniques revealed that anthropogenic sources, cation exchange processes, silicate weathering, carbonate dissolution, and other processes all contributed to groundwater mineralization. After monsoons, faecal coliforms were more common in groundwater. It was clear that wastewater penetration had contaminated the soil with nitrate and microbes. The Bureau of Indian Standards' recommended drinking water standards for iron, manganese, lead, cadmium, and arsenic were exceeded. In terms of water quality, the index showed that 1.5% of samples had low, 8.7% had marginal, 16.2% had fair, 66.2% had acceptable, and 7.4% had exceptional water quality. The primary ions and trace metals' origins, which were determined using hydrogeochemical techniques, were confirmed by correlation and principal component analysis. They came to the conclusion that groundwater that contains hazardous amounts of trace metals must first undergo appropriate treatment. In the Indian state of Chhattisgarh, Singha et al. [23] research looked at how mining operations affected the quality of the groundwater near the Korba coalfields. In order to create a base map using ArcMap 9.3, information was gathered from maps, toposheets, water quality data, well locations, mining lease areas, village sites, etc. For a number of variables, including pH, turbidity, total hardness, chloride, total dissolved solids, calcium, nitrate, iron, and fluoride, a water quality index was computed. The data were displayed as maps, which were then used to better comprehend the research area's current water quality situation. According to analysis, the groundwater in the area must first undergo field-specific treatment before being used.

As a geographic prediction tool for investigating the groundwater potential of the drainage area, Çelik [24] assessed the potential of the Geographic Information System (GIS)-based multicriteria decision-making (MCDM) analytic hierarchy process (AHP). In the analysis, eight hydrological and hydrogeological criteria—geology, rainfall, drainage density, slope, lineament density, land use, and soil properties—were taken into account as contributing factors. The Arc GIS 10.2.2 program and its submodules were used to determine the weights of these criteria using the AHP approach. Groundwater potential zone (GWPZ) maps of the sub-basin were made based on the findings, which led to the following groundwater potential zone rating of the basin: very poor (19%), poor (17%), moderate (34%), good (17%), and very good (13%). Fuzzy logic was applied to the geographic Information System (GIS) platform by Mallik et al. [25] to determine the appropriateness of groundwater for drinking. For variable reduction and mapping of the physicochemical characteristics, Principal Component Analysis (PCA) and Ordinary Kriging (OK) were employed. The findings of the correlation study revealed a strong positive association between Cl and EC (Electrical conductivity) and pH and HCO3-. The optimal overlay operation for suitability analysis was determined to be the fuzzy GAMMA (0.9) overlay approach. The findings of the suitability analysis showed that, correspondingly, 24, 28, 6, and 46.7% of the total surface area were unsuitable, somewhat appropriate, and suitable. The study demonstrates the potential of fuzzy logic linked with the GIS platform to assess the suitability of groundwater for drinking. Groundwater's physio-chemical characteristics, such as pH, conductivity, total dissolved solids, chlorides, total alkalinity, calcium hardness, magnesium hardness, and sulfate, were evaluated by Umamaheswari et al. [26]. For the examination of groundwater quality, correlation matrices, box plots, and multivariate statistical procedures like cluster analysis and principal component analysis were used. The suitability of the groundwater samples for irrigation and drinking was examined, and GIS techniques were used to map the results in relation to WHO guidelines. Total dissolved solids and electrical conductivity showed a high correlation in a box plot study. Strong association (R2 > 0.7) between total dissolved solids and electrical conductivity, as well as anions like Ca2+ and Mg2+, is shown by correlation analysis for both study areas. By comparing the outcomes of the analysis of wet and dry seasons from water resources with chosen standards, Herfeh [27] used GIS to study the status of the aquifer, the effects of nature and human activity on aquifer quality, evaluation and investigation of quality monitoring results of the Ardabil aquifer, as well as quality limitations. To analyze the quality of the aquifer's water, identify any evolving contamination processes, and conduct statistical analyses of the quality indicators NTU, TDS, Nitrates, and Chloride, groundwater samples were taken from 76 wells. The geographic information system (GIS) was then used to create maps for each parameter using a scientific approach. Following that, the situation and state of the water quality were assessed using the basin-wide application of the NSFWQ's quality mapping index. The maps and information that the software generated demonstrated how it may be used for better management of these water resources and planning to stop additional pollution by pertinent entities. In order to map the potential of ground water in the area, evaluate the quality of ground water, and relate it to land use and land cover, Nelly and Mutua [28] evaluated the quality of ground water in the Juja site. GIS and remote sensing techniques were used to create thematic maps for the research region. A ground water potential map was created using the ArcGIS software's reclassification and weighted overlay features. Randomly chosen groundwater samples were gathered, and a portable GPS was used to determine where they were. The water's physical and chemical characteristics were examined in a lab setting. Using the Kriging method of interpolation in ArcMap software, spatial distribution maps of the water quality parameters were created. Then, a drinking water quality index was created. Masoud et al. [29] identified probable groundwater zones in the Tushka area, west of Lake Nasser, South Egypt, using the capabilities of multi-criteria decision approaches (MCDA), geographic information systems (GIS), and groundwater field data. Frequency ratio (FR) models and the analytical hierarchy process (AHP) were used as analysis tools. The zones of groundwater potentialities were developed by integrating the governing parameters with the geographic information system (GIS). According to the findings, the AHP and FR models' high- and moderate-potential zones, respectively, account for about 61% and 52% of the overall area. The models were validated using data from a total of 44 groundwater production wells and well yields. The receiver operating characteristics (ROC) curve was used to evaluate the outcomes. AHP and FR achieved the highest prediction rates, 83% and 81%, respectively. The results also showed that the AHP model outperformed the FR model in terms of performance. By examining the pH, total hardness (TH), total dissolved solids (TDS), electrical conductivity (EC), bicarbonate (HCO3-), chloride (Cl-), sulphate (SO42-), fluoride (F), calcium (Ca2+), magnesium (Mg2+), sodium (Na+), and potassium (K+), Adimalla et al. [30] investigated the quality of groundwater for drinking purposes. The groundwater samples from the research location had a cation and anion dominance of Na+ > Ca2+ > Mg2+ > K+ and HCO3- > Cl- > SO42- > F, respectively. In the groundwater of the research area, Na+ was found to be the major cation and bicarbonate to be the predominant anion. 43% and 37% of groundwater samples, respectively, had Na+ and Cl- concentrations that exceeded the study area's permitted WHO guideline. It was discovered that fluoride had a significant impact on groundwater, with roughly 60% of groundwater samples in the research area being unsafe for drinking. The physicochemical properties of 60 collected groundwater samples were measured by Chowdhury et al. [31]. In the groundwater of the research region, cations and anions occur in decreasing order as follows: Ca+2 > Na+ > Mg+2 > K+ > Fe+2 and HCO3- > Cl- > SO4- > NO3- > F-, respectively. The piper plot indicates that the water type is composed of 80% Ca-HCO3, 19% mixed CaMgCl, and 1% CaCl. According to the Gibbs diagram, the rock-water interaction is the dominant process at work in this area. Using a geographic information system and the analytical hierarchy process (AHP), the groundwater suitability zones for irrigation were determined (GIS). According to the zonation map, there are highly and poor suitability zones in 32.37% and 19.23%, respectively, of the research region. In order to evaluate the groundwater potential in the Sawla-TunaKalba district of Ghana with a few chosen surface-level parameters while projecting the groundwater recharge from 1981 to 2021, Kpiebaya et al. [32] used QGIS. newest hydrological discoveries Random Forest (RF), one of the investigated classification methods, had the best overall accuracy (93.63%), followed by Gaussian Mixture Model (GMM), with 90.22% accuracy, and Support Vector Machine (SVM), with 84.73% accuracy. The AHP model assigned geology the greatest weight, 0.279. According to the Chaturvedi formula, groundwater recharge is caused by rainfall, and it accounts for an average of 2.85% of the total annual rainfall, with a variance of ±0.35 mm. In contrast to the overall recharge of 1191.18 ± 0.35 mm from 1981 and 2021, the total recharge for 2021 was found to be 30.18 ± 0.35 mm. The recharge and current surficial conditions can be used to explain the significant groundwater potential that was found in the research area. Based on the physico-chemical analysis of 58 samples with the help of a geographic information system (GIS), analytical analysis, nitrate pollution index (NPI), and groundwater pollution index, the level of groundwater pollution in the Meskala-Ouazzi sub-basin, a coastal area of Essaouira, was assessed (GPI). The NPI was in the range of 0.9 and 7.8. 44.8% of the total groundwater samples are classified as clean water by NPI, indicating that the groundwater in the research area is appropriate for irrigation. 37.9% of the groundwater samples have low pollution levels, according to GPI values ranging from 0.6 to 3.7, with an average of 1.7. The sub-upstream basin's portion has the necessary groundwater, according to the inverse distance weighting (IDW) technique. Overall, the forte concentration demonstrated that the nitrate originated from significant amounts of nitrogen fertilizer applied by people during irrigation times for agricultural activities [33].

The quality of groundwater is constantly changing in response to daily, seasonal and climatic factors. A number of factors influence water chemistry. Gibbs [34] proposed that rock weathering, atmospheric precipitation, evaporation and crystallization control the chemistry of water. The influence of geology on chemical water quality is widely recognized [34, 35, 36]. The influence of soils on water quality is very complex and can be ascribed to the processes controlling the exchange of chemicals between the soil and water [37]. Apart from natural factors influencing water quality, human activities such as domestic and agricultural practices impact negatively on groundwater resources. Pollution of water bodies as a result of metal toxicity has become a source of concern among consumers. These concerns have become alarming in response to increasing knowledge on their toxicity to human health and biological systems [38].The toxicity of trace metals in water depend on the concentration of the metal below a certain level, which could be considered as essential for biochemical processes. However, in certain cases, high levels could bio-accumulate raising toxicity concerns. Hence, the study as proposed by this project. The aim of this study is to assess the quality of groundwater in Bauchi metropolis and interpret the groundwater quality using Geographical Information System (GIS); by analyzing various physiochemical parameters for some selected wells in the study area, compare the datasets for the groundwater with Nigerian Standard from the Federal Ministry of Water Resources and World Health Organization (WHO) and provide a good representation of findings using GIS.

2. Experimental programme

2.1 *Introduction*

The analysis of ground water quality using the Geographical Information System (GIS) seeks to interpret results by graphical representation of the availability of quality groundwater within Bauchi Metropolis. The first step in analyzing the quality of groundwater from selected hand dug wells was to collect all the data of well conditions.

2.2 *Study Area*

The study area is Bauchi metropolis located in Bauchi State, Northeast Nigeria, its geographical coordinates are 10°17′0″ North, 9°47′0″ East. The annual rainfall ranges between 1300 mm per annum in the south and only 700 mm per annum in the extreme North for three to four months. The predominant mother tongue spoken in the metropolis of Bauchi, Bauchi State is Hausa. The land is gently sloping with little or no stream flowing across. There is a lot of sunshine in the metropolis and temperature ranges between 29.2°C in July and August to 37.6 ° C in March and April. The metropolis has 59% humidity and average minimum and maximum temperatures of 13.1°C and 32.4°C respectively. The dry harmattan winds blow over this area during the hazy dusty months of December to February.

Bauchi metropolis has six districts namely Makama (A & B), Miri, Dan iya, Tukum, Birshi. It is a commercial as well as a residential area which is lacking in housing due to overpopulation. The map of the metropolis is shown below.

Figure 1. Satellite map showing some parts of the metropolis (google map, March 2019)

2.3 *Water Sampling and Analysis*

2.3.1 *Selection of Wells and Collection of Water Samples*

An average of hundred (100) hand-dug wells are dug in each of the district within the metropolis and eighteen (18) hand-dug wells have been randomly selected from the six (6) districts, with a selection of three hand-dug wells from each district.

The metropolis is divided into six (6) zones due to its size and population in order to facilitate the selection of wells and provide a broad understanding of the state of the wells in the metropolis. The primary factors considered in the choosing of wells for the metropolis were the wells' style of operation and the geographical regions that made up those districts. 18 different water samples in all were gathered. In total, 18 samples total, drawn from three distinct sampling wells in each of the six districts. The code of the sampling sites, the location, and the date were entered on a field data form. As a result, 18 hand-dug wells in total were chosen, and Table shows their codes. This led to the selection of a total of 18 hand-dug wells, whose codes are shown in Table 1 below:

Table 1. Sampled wells and codes

DISTRICT	AREA	SAMPLE CODE	LATITUDE	LONGITUDE
Birshi Ward	SabonKaura	S1	10.296786 °E	9.801243 °N
	YelwaTsakani	S2	10.265982 °E	9.803322 °N
	Gwallameji	S3	10.263086 °E	9.783472 °N
Miri Ward	Wuntidada	S4	10.310000 °E	9.784800 °N
	Kyaure	S5	10.310476 °E	9.781389 °N
	Tambari Estate	S6	10.310000 °E	9.680000 °N
Turum Ward	BakasMwelalawa	S7	10.326010 °E	9.832475 °N
	Ibrahim Bako	S8	10.351313 °E	9.857651 °N
	Turum	S9	10.346159 °E	9.845170 °N
Makama A	NasarawaGwaba	S10	10.304278 °E	9.829334 °N
	Wunti	S11	10.313997 °E	9.829440 °N
	Jahun Road	S12	10.299135 °E	9.834329 °N
Makama B	Emir Drive Fada	S13	10.309769 °E	9.845840 °N
	SaloSalo	S14	10.285330 °E	9.835226 °N
	Tasha Maza	S15	10.306243 °E	9.841537 °N
Dan Iya Ward	GRA Airport Road	S16	10.291291 °E	9.824354 °N
	Nursing Quarters	S17	10.292298 °E	9.844658 °N
	Federal Lowcost	S18	10.292980 °E	9.826037 °N

Key: S- Sample well

2.3.2 *Measurement of Water Temperature and pH*

Samples for the chemical analysis were collected in 1.5 liters gallons. All the gallons were sealed. The gallons were filled with the samples after rinsing it with part of the sample water. It was then covered, packed and transported to the laboratory for analysis. Samples were also taken for bacteriological tests. Samples were carefully taken to ensure that there were no other forms of contamination to the samples.

The water temperature was taken on site with the aid of a calibrated mercury thermometer. It was ensured that extra care was taken in reading the temperature to avoid errors. It was also ensured that the sensitive bulb of the thermometer did not touch the sample bottle while measuring the temperature.

The pH values of all samples collected were measured using a digital pH-meter. Three hundred (300) milliliters of water sample was measured into a beaker and the pH-meter sensor was carefully inserted into the beaker, ensuring contact with the water sample but not with the walls of the beaker.

2.3.3 *Laboratory Analyses*

The laboratory analyses were carried out in the Public Health Laboratory, Abubakar Tafawa Balewa University, Bauchi, Bauchi state. The bacteriological parameter tested for was total bacteria count while the eight physiochemical parameters measured were: as pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), free chlorine, Lead, Total Hardness (TH), calcium hardness and magnesium hardness of the well water samples. Test procedure/measurement are stipulated in British and Indian standards [39, 40 , 41, 42, 43, 44, 45, 46, 47] respectively.

2.3.3.1 Measurement of Total Coliform Count

One (1) milliliter of the well-mixed water sample was put into a sterile petri dish using a pipette and mixed with 100ml of sterile nutrient gelatin or agar. The gelatin was stored under sterile conditions in tubes, liquefied at 30°C before pouring into the petri dish. Tubes of nutrient agar water liquefied in boiling water and cooled before pouring.

The petri dishes were swung in a figure 8 movement to achieve thorough mixing and left horizontally until it solidified. The culture plates were then inverted and incubated at 20°C and/or 37°C for 44h + 4h. The visible coliforms were then counted with the aid of a magnifying glass. The total bacterial count was then scaled up for 100ml of sample.

2.3.3.2 Measurement of Physiochemical Parameters

The eight physiochemical parameters sited above were measured using standard procedure provided by the United States Environmental Protection Agency, USEPA:1996-[48] and standard procedures prescribed by American Public Health Association, APHA:1998–[49]. The heavy metals (lead) in the sample were measured using the Atomic Absorption Spectrophotometer (AAS). Hundred (100) millilitres of the sample were measured using a measuring cylinder and mixed in a beaker with twenty-five (25) millilitres of nitric acid (HNO3). The solution was then analyzed with 1-2% HNO3 blank and standard using the AAS machine. The AAS machine gave the total metals; extractable suspended and dissolved and their concentrations.

2.4 *Data Analyses*

The data were entered in Microsoft Excel programme and descriptive and statistical analyses were computed. The physiochemical and bacteriological quality parameters were imputed and compared with the guidelines of World Health Organization (WHO) and Nigeria Standard for Drinking Water Quality (NSDWQ).

2.5 *Geographical Information System GIS*

After the above data was analyzed the result was then represented by spatial referencing of the data set. In this project, the GIS application used was ARC GIS, software that has gained relevance in Municipal Solid Waste collection and Water Management. The application (ArcGIS) was used to capture, store analyse and manage the result so as to geographically interpret the relationship and patterns of water quality within the metropolis. Under ArcGIS, there are three methods namely: Deterministic, Geostatistical and Interpolation methods. The deterministic method was adopted in which the Inverse Distance Weighting was preferred to Radial Basis Function because it is quick and exact, and it does not require assumptions [50].

2.6 *Measuring Water Quality*

Thousands of potential elements or agents can be found in water, yet most drinking water regulations only cover roughly 100 of them. According to Brian [51], the following standards of the US Environmental Protection Agency (USEPA) have been established for private wells: microbiological, inorganic (IOCs), secondary contaminants, volatile organic chemicals (VOCs), synthetic organic chemicals (SOCs), and radio-nuclides, which are radioactive substances. The National Agency for Food and Drug Administration and Control (NAFDAC) and Nigeria Standard for Drinking Water Quality (NSDWQ) have accepted the WHO classification system for water quality. Microbiological (faecal coliform, E coli, Total coliform) and physicochemical criteria may be included for drinking water (colour, concentration of organic, turbidity, inorganic compounds, temperature and dissolved oxygen level).

Table 2 provides the WHO drinking water quality recommendations from 2006 [52] and the Nigeria Standards for Drinking Water Quality (NSDWQ) from 2010 [53]. The primary motivation behind these regulations was health. The rules do, however, also take into account the psychological impact and aesthetic aspect of drinking water, such as the objection of the water owing to color, odor, or turbidity.

Table 2. Drinking Water Quality Guidelines for the WHO, NAFDAC and NSDWQ

PARAMETER	WHO		NAFDAC	NSDWQ
	Max. desirable level	Max. Permissible level		
Temperature 0C	-	40	-	Ambient
Colour(TCU)	6	15	15	15
Turbidity (NTU)	5	25		5
pH	7.0-8.5	6.5-9.2	6.5-8.5	6.5-8.5
Total dissolved solids (mg/L)	500	1500	500	500
Iron (mg/L)	-	0.3	-	0.3
Chloride (mg/L)	-	250	-	250
Fluoride (mg/L)	-	1.5	-	1.5
Total hardness (mg/L)	-	500	-	500
Sulphate (mg/L)	-	100	-	100
Nitrate (mg/L)	-	50	-	50
Faecal Coliform (per 100ml)	-	0	0	0
E.coli(per 100ml)	-	0	0	0
Total coliform count (per 100ml)	-	0	10	10

WHO (2004) - World Health Organization

NAFDAC (2008) - National Agency for Food and Drug Administration and Control

NSDWQ (2010) - Nigerian Standard for Drinking Water Quality

3. Analyses of results

3.1 *Presentation of Results*

This includes observations made on site, the physiochemical and microbiological parameters. Data have been presented in the form of tables and figures based on the results obtained.

3.1.1 *Bacteriological Parameters*

The quantitative bacteriological analysis of the 18 hand-dug wells was done in the month of October, 2019 and the result is as presented in Table 3. The result as seen in the table has been compared with the WHO and NSDWQ standards and adequately discussed in table 3 below.

Table 3. Quantitative bacteriological analysis for the sampled wells

Samples	WHO	NSDWQ	S1	S2	S3	S4	S5	S6	S7	S8	S9
Total Bacteria count per 100 ml	0 per 100 ml	10 per 100 ml	20	6	8	5	12	13	5	16	10

Samples	WHO	NSDWQ	S10	S11	S12	S13	S14	S15	S16	S17	S18
Total Bacteria count per 100 ml	0 per 100 ml	10 per 100 ml	134	2	9	32	2	7	2	1	12

3.1.2 *Physiochemical parameters*

The result of the physical parameters of the sampled wells is presented in tables.The mean ± sd values of the physiochemical parameters of the sample wells were compared with the WHO and NSDWQ guidelines for drinking water quality and are presented in Tables 4.1-4.4.

Table 4.1. Comparison of physiochemical parameter of S 1-10 water quality with WHO and NSDWQ drinking water guidelines

Parameter	Unit	Mean value					WHO		NSDWQ
		S1	S2	S3	S4	S5	Max. desirable level	Max. permissible level	
pH	-	6.3	5.9	6.5	6.6	7.1	7.0-8.5	6.5-9.2	6.5-8.5
EC	µS/cm	400	300	400	800	300	<300 excellent	>1500 Very bad	1000
TDS	mg/L	260	230	290	530	190	<300 excellent	500 acceptable	500
Free Chlorine	mg/L	0.10	0.00	0.20	0.10	0.10	-	-	0.00-0.25
Lead, Pb	mg/L	0.00	0.00	0.00	0.01	0.03		0.05	0.01

Table 4.1 continuous

Parameter	Unit	Mean value					WHO		NSDWQ
		S6	S7	S8	S9	S10	Max. desirable level	Max. permissible level	
pH	-	6.7	6.6	7.1	6.7	6.6	7.0-8.5	6.5-9.2	6.5-8.5
EC	µS/cm	100	1100	500	500	400	<300 excellent	>1500 Very bad	1000
TDS	mg/L	90	710	330	320	300	<300 excellent	500 acceptable	500
Free Chlorine	mg/L	0.00	0.60	0.10	0.20	0.10	-	-	0.00-0.25
Lead, Pb	mg/L	0.00	0.03	0.06	0.15	0.24		0.05	0.01

Table 4.2: Comparison of physiochemical parameter of S11-18 water quality with WHO and NSDWQ

Parameter	**Unit**	**Mean value**					**WHO**		**NSDWQ**
		S11	S12	S13	S14	S15	Max. desirable level	Max. permissible level	
pH	-	6.7	6.7	6.8	6.5	6.6	7.0-8.5	6.5-9.2	6.5-8.5
EC	µS/cm	800	900	200	500	800	<300 excellent	>1500 Very bad	1000
TDS	mg/L	500	580	120	310	520	<300 excellent	500 acceptable	500
Free Chlorine	mg/L	0.10	0.10	0.10	0.10	0.10	-	-	0.0-0.25
Lead, Pb	mg/L	0.01	0.10	0.15	0.26	0.26		0.05	0.01

Table 4.2 continuous

Parameter	**Unit**	**Mean value**			**WHO**		**NSDWQ**
		S16	S17	S18	Max. desirable level	Max. permissible level	
pH	-	6.7	6.7	6.5	7.0-8.5	6.5-9.2	6.5-8.5
EC	µS/cm	200	700	600	<300 excellent	>1500 Very bad	1000
TDS	mg/L	170	440	400	<300 excellent	500 acceptable	500
Free Chlorine	mg/l	0.10	0.10	0.20	-	-	0.00-0.25
Lead, Pb	mg/L	0.04	0.08	0.18		0.05	0.01

The result for Hardness is presented in the Tables 3.3-3.4 below.

Table 4.3: Comparison of physiochemical parameter (Hardness) of Samples water quality with WHO and NSDWQ drinking water guidelines

Parameter	**Unit**	**MeanValue**			**WHO2011**	**NSQDW Max. Permissible**
		S1	S2	S5		
Total Hardness, CaCO3	mg/L	1.38	3.86	3.27	200	150
Calcium, Ca Hardness	mg/L	0.02	1.45	0.78	75	50
Magnesium, Mg Hardness	mg/L	1.36	2.41	2.49	NA	0.20

Table 4.3 continuous

Parameter	**Unit**	**Mean Value**			**WHO 2011**	**NSQDW Max. Permissible**
		S6	S8	S9		
Total Hardness, CaCO3	mg/L	3.04	0.97	1.90	200	150
Calcium, Ca Hardness	mg/L	1.03	0.17	0.41	75	50
Magnesium, Mg Hardness	mg/L	2.01	0.80	1.49	NA	0.20

Table 4.4: Comparison of physiochemical parameter (Hardness) of Samples water quality with WHO and NSDWQ drinking water guidelines

Parameter	**Unit**	**Mean Value**			**WHO 2011**	**NSQDW Max.Permissible**
		S11	S12	S14		
Total Hardness, CaCO3	mg/L	0.98	1.30	3.58	200	150
Calcium, Ca Hardness	mg/L	0.46	0.54	0.00	75	50
Magnesium, Mg Hardness	mg/L	0.52	0.76	3.58	NA	0.20

Table 4.4 continuous

Parameter	Unit	Mean Value			WHO 2011	NSQDW Max. Permissible
		S15	S16	S18		
Total Hardness, CaCO3	mg/L	1.80	1.79	3.20	200	150
Calcium, Ca Hardness	mg/L	0.69	0.45	1.23	75	50
Magnesium, Mg Hardness	mg/L	1.11	1.34	1.97	50	0.20

3.2 *Discussion of Results*

The discussion of the study results is presented below.

3.2.1 *Bacteriological Quality of Water Samples*

The WHO recommends that, for water to be considered no risk to human health, the total coliform bacteria, faecal coliform and E. coli in water sample should be zero, WHO:2008–[53]. The Nigeria Standard for Drinking Water Quality (NSDWQ) recommends a maximum of ten (10) total coliform counts, NSDWQ:2010-[54]. In this study the Total coliform bacteria count of the water samples from all the hand dug wells are positive when compared to WHO recommendations but some of the samples were negative particularly samples S3, S4, S5, S6, S7, S8, S12, S13, S14, S16, S17, S19 tested negative to Total Bacteria Count while the remaining samples tested positive.The values ranged from 1-134 cfu/100 ml total coliform counts. Sample S10 was the highest at 134 cfu/100ml while S17 was the least at 1 cfu/100ml.The high total coliform count is clear indication of faecal contamination. The figure 2 below shows the samples relationship with the WHO and NSDWQ recommendations for total coliform bacteria count.

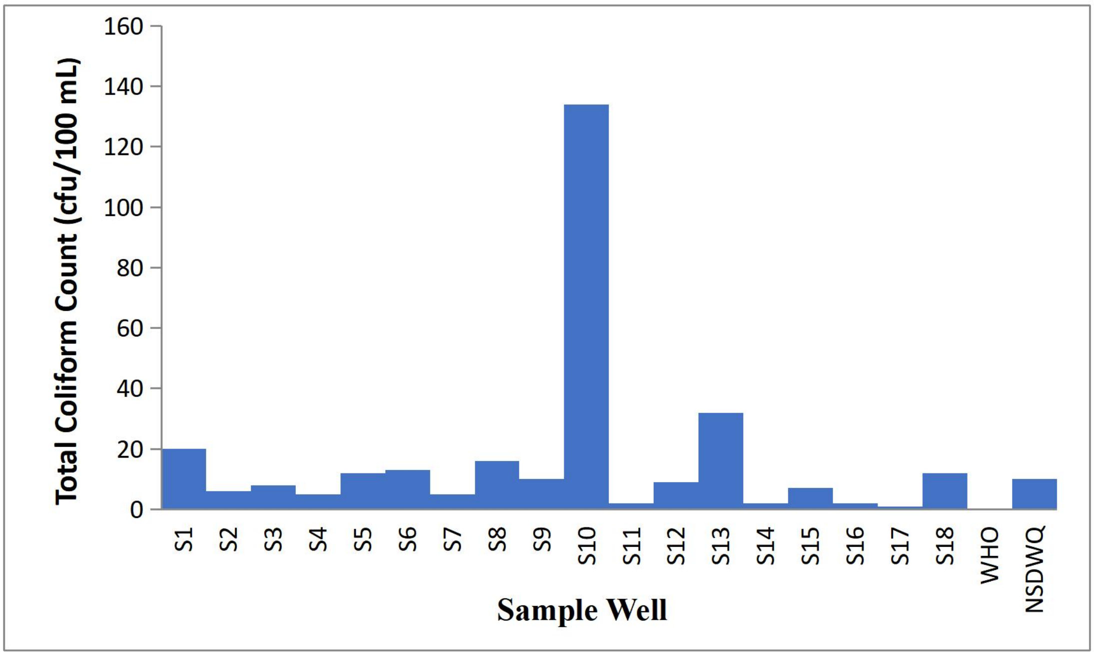

Figure 2. Bacterial coliform count variation in the sampled hand-dug wells

3.2.3 *Comparison of Physiochemical Parameters of the sampled Hand–dug well water quality with WHO and NSDWQ Drinking Water Guidelines*

It can be seen from Tables 4.1-4.4 that most of the physiochemical parameters of all the hand dug wells were within the WHO: 2011–[55] and NSDWQ: 2010–[54] permissible values. However, there were a few deviations from the recommendations.

pH

It is the measure of acidity or alkalinity of the water. The pH of most drinking water lies within the range of 6.5 – 8.5 [56]. Usually it has no direct impact on consumers and it is one of the most important operational water quality parameters [52]. The pH values of all the samples were in conformity to the two standards except samples S1 and S2 which were not within standard range recommended. The low pH values recorded could be as a result of the faecal contamination to these wells. The samples show that water within the metropolis is neither acidic nor alkaline, except the aforementioned samples that were slightly alkaline. It may be concluded that the pH of the water samples collected from the metropolis falls within the acceptable limits for drinking.

Electrical Conductivity

The conductivity of water is a measurement of its capacity to carry electric current. It is directly connected to the water's overall dissolved salt concentration. This is the case because the salts can conduct electric current proportionally to their concentration and can dissociate into positive and negative ions. Conductivity may be affected by human activity. Because of the nitrate and phosphate content, sewage and farm runoff can increase conductivity. Road runoff may also contain salt and other substances that ionize water. The 300µS/cm conductivity limit for drinking water is advised by the WHO (2006).

When comparing the Electrical Conductivity, EC of the samples with the WHO and NSDWQ it was deduced that all were within the recommended range. Sample S6 had the least EC Value at 100 µS/cm while sample S7 had the highest value at 1100 µS/cm slightly above NSDWQ recommendation of 1000µS/cm, it was also the only sample (S7) that exceeded the NSDWQ prescription. Thus the conductivity values of water obtained from the metropolis are within the limits set by both the Nigerian regulatory agency as well as that of WHO.

Total Dissolved Solids, TDS

The TDS test serves as a warning sign for potential water quality issues [51]. In people who drink water with TDS levels above 1000 mg/l, there have not been any harmful physiological effects, according to WHO (2006). WHO, however, suggests the latter's low level as a TDS reference standard. According to Kempster et al. [56], a critical TDS value of 2450 mg/l is the point at which it is reasonable to expect some long-term health issues as a result of excessive concentrations of dissolved particles in drinking water.

The TDS values of the samples were mostly within the prescribed guidelines, only samples S4, S7, S12 and S15 were slightly above the recommended value of 500 mg/L. TDS is not a direct measure of a specific element or contaminant but is an indicator of the potential for water quality problems [51]. According to WHO in 2006 [52], there has not been any deleterious physiological reactions occurring in persons consuming drinking water that have TDS values in excess of 1000mg/l. Sample S6 had the least TDS value of 90 mg/L while the highest value of 710 mg/L was recorded for S7. It may be concluded that the water samples from the hand dug wells have satisfied the requirement of the regulatory authorities as far as total dissolved solids are concerned.

Free Chlorine

Chlorides are present in all sources of drinking water supply and wastewater, usually in the form of metal salts. This standard was developed due to potential aesthetic issues with water taste and the fact that increased levels can promote corrosion of pipes and fittings [51] Free chlorine is naturally present in the environment, but high levels of chlorine can also be caused by sewage from septic tanks, storm water runoff, salt water, cleaning solutions and other industrial solutions . For free chlorine, all samples were within the acceptable limits specified by the NSDWQ, except sample S7, which had a concentration of 0.60 mg/L, which was well above 0.25 mg/L.

Lead

From the result shown in tables 4.2-4.3, the lead Pb content exceeded the permissible limit of 0.01 mg/L provided by NSDWQ with the exceptions of Samples S1, S2, S3, S4, S6, and S11 which are below the limit. Sample S14 and S15 recorded the highest lead content at 0.26 mg/L. High content of lead causes adverse health effects such as Cancer, interference with Vitamin D metabolism, affect mental development in infants, toxic to the central and peripheral nervous systems [54].

Total Hardness, (TH)

Calcium salts in solution and, to a lesser extent, magnesium salts are responsible for the overall hardness of water. The equal amount of calcium carbonate (CaCO3) per liter of water is used to indicate how hard the water is, however the test actually evaluates the multivalent positively charged ions such as calcium, magnesium, manganese, and iron. Although it is possible that corrosion issues could be related to water with very low water hardness, people often notice aesthetic difficulties with the water when the overall hardness is above 160 mg CaCO3/l [51]. Hardness levels above 200 mg/l may cause scale deposition depending on the pH and alkalinity, especially after heating. Soft water is defined as having less than 75 mg/l of CaCO3 and hard water as having more than 150 mg/l [52].

All of the tested samples' Hardness parameters were found to be within the range recommended by the WHO and NSDWQ for drinking water. Less than 61 mg/L of hardness is regarded as soft water, 61–120 mg/L as moderately hard, 121–180 mg/L as hard, and more than 180 mg/L as very hard [48]. As a result, it is possible to conclude that the water in the city is soft based on all of the samples taken from it. The highest value was 3.86 mg/L, while the lowest was 0.97 mg/L. The overall hardness of the water from the hand-dug wells, according to Appiah and Momende [57], ranged between 38.7-259 mg/l. Less than 50% of the WHO maximum allowed threshold of 500 mg/l was present in the majority of the hand-dug wells.

Calcium

In the crust of the earth, calcium occurs naturally and in great quantities. It is a significant and plentiful element in the human body, and a sufficient intake is necessary for healthy and normal growth. The most significant component creating water hardness is Ca. Increased risks of osteoporosis, nephrolithiasis (kidney stones), colorectal cancer, hypertension and stroke, coronary artery disease, insulin resistance, and obesity have been linked to inadequate calcium intakes. Most of these illnesses are treatable, but not all of them are. Due to the absence of strong evidence linking calcium to these disorders, estimates of calcium requirements have been made based on bone health outcomes, with the aim of maximizing bone mineral density [52]. All of the samples were nonetheless well below the threshold limits of 50 mg/L and 75 mg/L advised by NSDWQ and WHO, respectively, when the calcium hardness of all the samples taken from the city was compared with the WHO and NSDWQ permitted limits. S14 had the lowest calcium value of 0.00 mg/L, whereas sample S2 had the highest calcium value of 1.45 mg/L.

Magnesium

In intracellular fluid, magnesium cations are widely distributed. About 350 biological enzymes use it as a cofactor, many of which are involved in energy metabolism. It is necessary for appropriate vascular tone and insulin sensitivity and is also involved in protein and nucleic acid production. Roughly 60% of the body's reserves, or about 25 g, reside in the bone. Because only a small fraction of the total body burden is in blood or other bodily fluids, and because it might vary, it is challenging to estimate. All samples had magnesium hardness levels that were higher than the NSDWQ standards of 0.20 mg/L. Although too much magnesium can give water a harsh taste, it usually has no health risks, and consumption can be dependent on what consumers find acceptable [54]. The sample S14 included the highest amount of magnesium, 3.58 mg/L, while the sample S11 contained the lowest amount, 0.52 mg/L. The WHO's recommended limit for magnesium in drinking water is 50 mg/L, but the NSDWQ recommended 0.20 mg/L. Reduced insulin sensitivity, raised levels of C-reactive protein (a pro-inflammatory marker that is a risk factor for coronary heart disease), endothelial dysfunction, and enhanced vascular responses are all linked to low magnesium levels. Hypertension, coronary heart disease, type 2 diabetes, and metabolic syndrome have all been linked to low magnesium levels.

3.3 *Spatial Representation of Parameters using GIS*

The spatial distribution of bacteriological and physicochemical analysis of groundwater samples collected from the six districts of Bauchi metropolis are shown in Fig. 3-11. The total bacteria coliform count ranges from 1-134 cfu/100 ml as in Fig 3. It can be observed that from Fig. 4 that the pH ranges between 5.9 and 7.1. The Electrical Conductivity of the samples collected was in the range of 100-1100 µS/cm as presented in Fig 5. From the parametric analysis, total dissolved solids were in the range of 90-710 mg/L as shown in Fig 6. Fig 7 showed that free chlorine ranged from 0.00 mg/L to 0.06 mg/L. The lead contents ranged between 0.00 mg/L and 0.26 mg/L as in Fig 8. Total hardness was in the range of 0.97-3.86 mg/L as in Fig 9 while calcium and magnesium were in the range of 0.00-1.45 mg/L and 0.52-3.58 mg/L respectively as shown in Figs 10 and 11. All these are shown as computed using Arc GIS application.

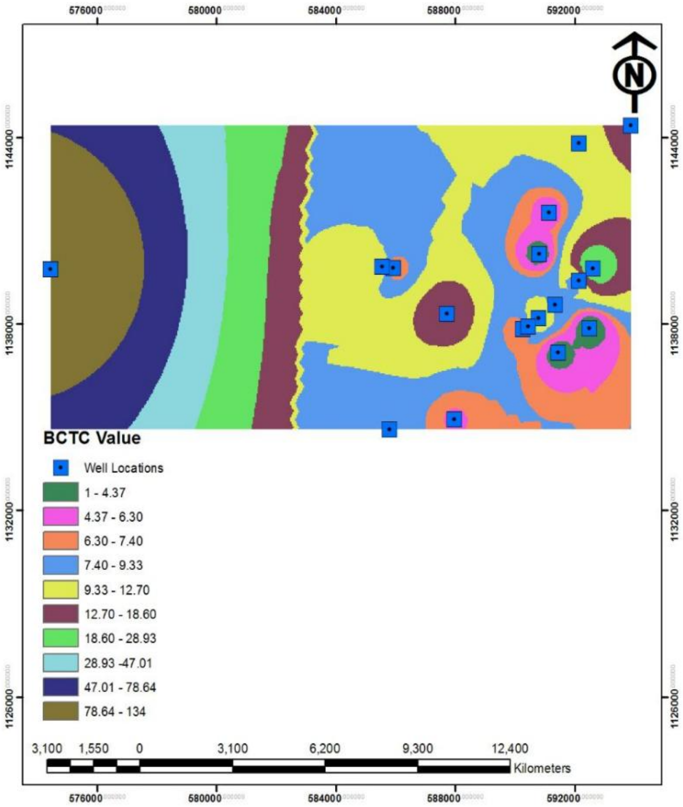

Figure 3. Spatial variation representation of TBC parameter

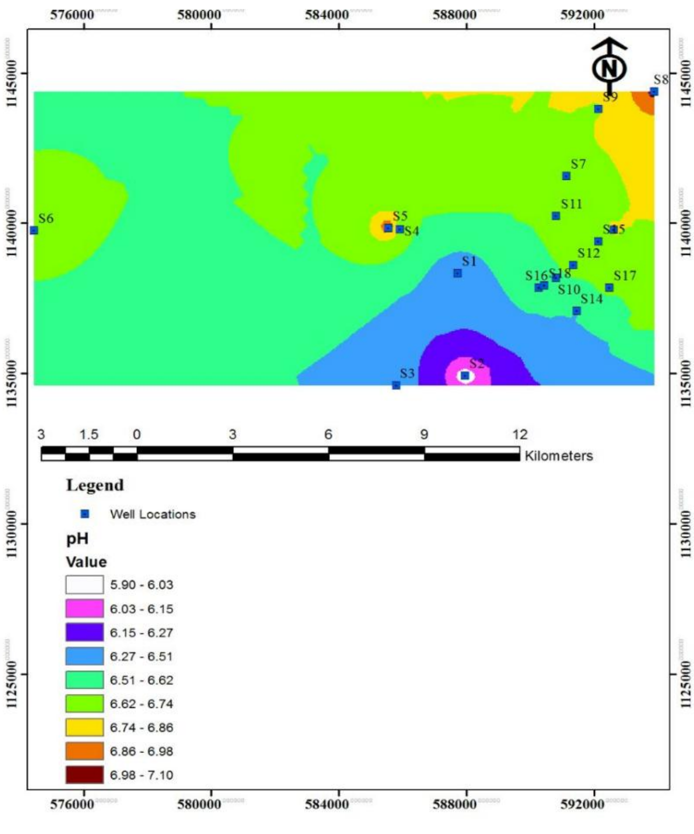

Fig. 4: Spatial variation representation of pH parameter

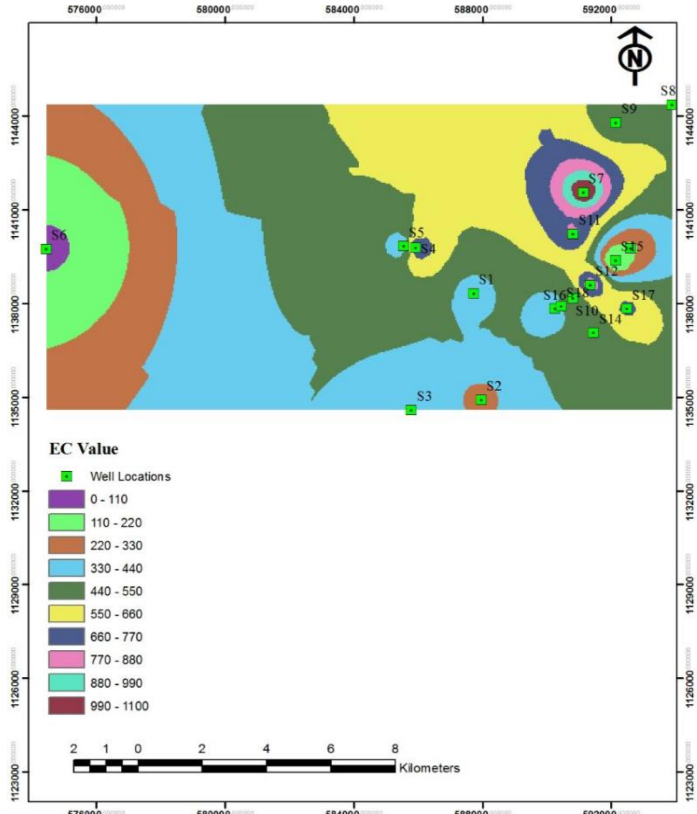

Fig. 5: Spatial variation representation of EC parameter

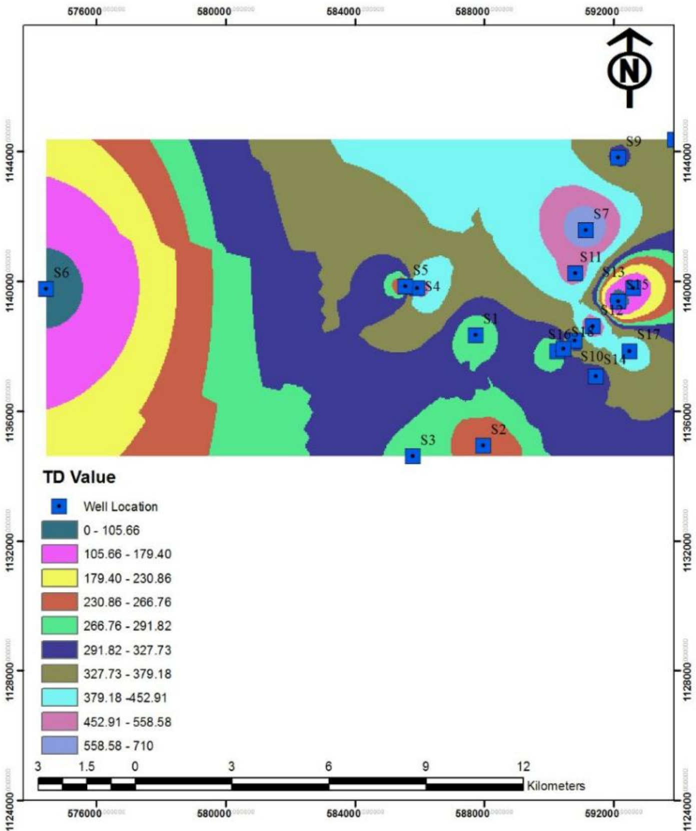

Fig. 6: Spatial variation representation of TDS parameter

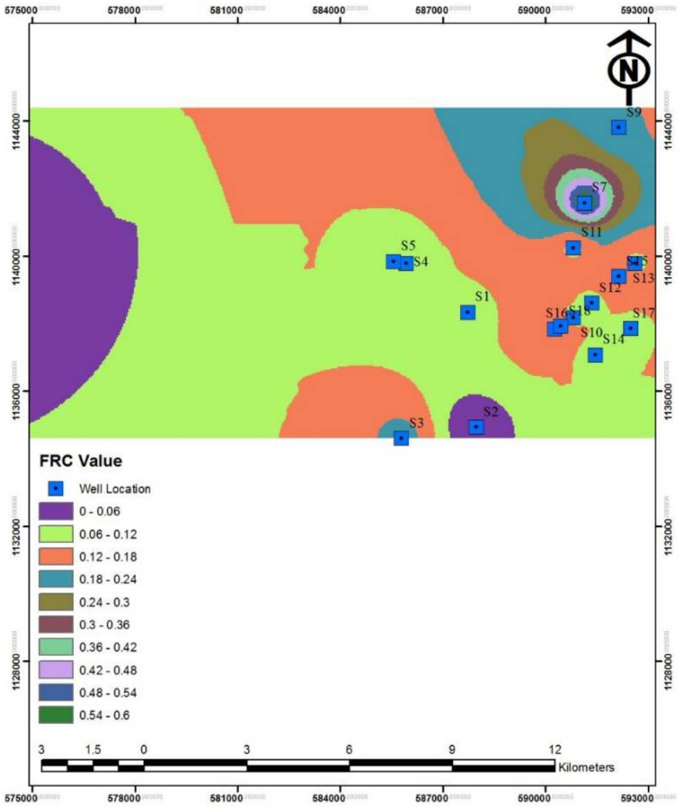

Fig. 7: Spatial variation representation of Free Chlorine parameter

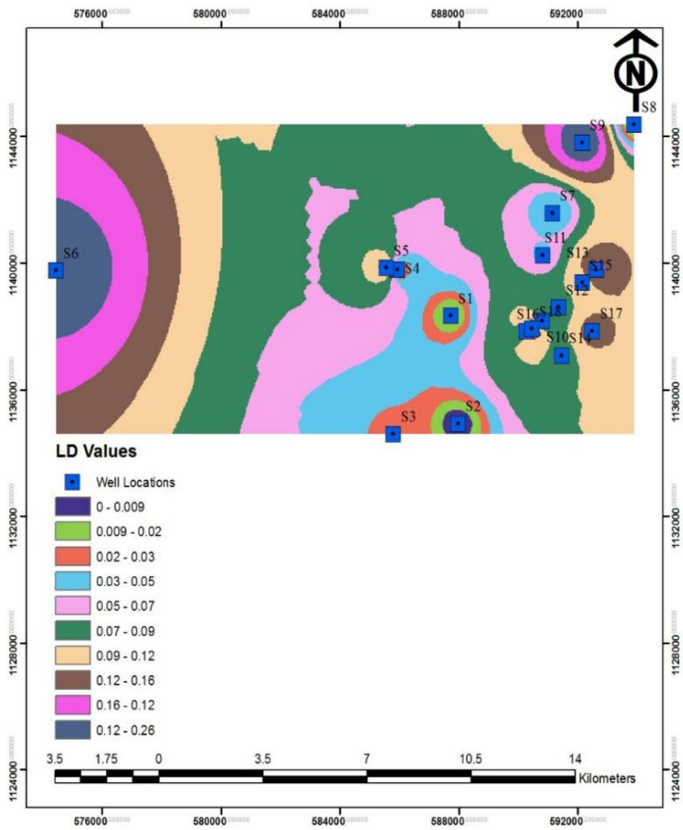

Fig. 8: Spatial variation representation of lead parameter

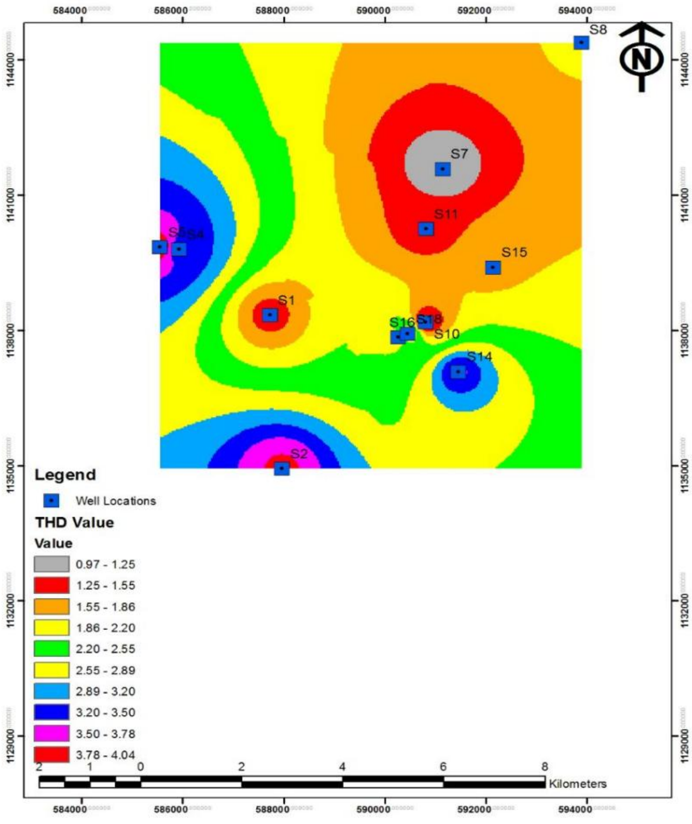

Fig. 9: Spatial variation representation of Total Hardness parameter

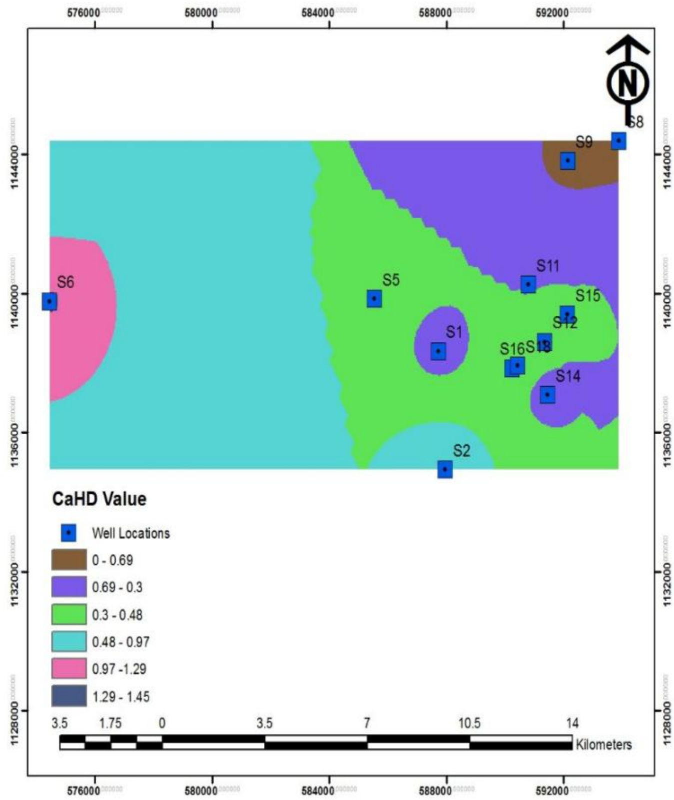

Fig. 10: Spatial variation representation of Calcium parameter

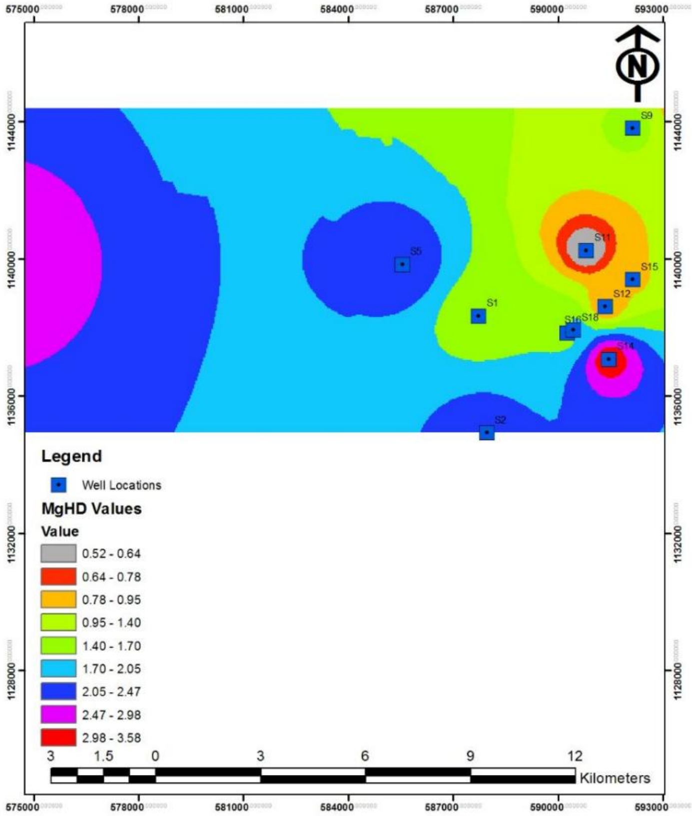

Fig. 11: Spatial variation representation of Magnesium parameter

4. Conclusion

Thus, the following conclusions were drawn from the study.

The quantitative aspect of bacteriological analysis presented above indicated that all the tested samples were positive to Total Bacteria Count in the laboratory when compared to WHO Standard. When compared to NSDWQ Standard samples S3, S4, S5, S6, S7, S8, S12, S13, S14, S16, S17 tested negative to Total Bacteria Count while the remaining samples tested positive. Sample S10 was the highest at 134 cfu/100ml while S17 was the least at 1 cfu/100ml.

Parallel to the tests on pH only samples S1and S2 were not within the standard recommended range.

All the samples were within the limits prescribed by the two standards except sample S7 slightly above the limit at a value of 1100 μS/cm.

All Water samples were within the allowable limits for total hardness and are considered to be soft.

In general as a district, samples drawn from Birshi ward showed considerable conformity to standard limits except for their low pH values as shown in the result table.

The GIS representation clearly shows the areas with the high and low presence of the tested parameters within the metropolis for better information and choice of healthy and quality water for easy accessibility.

It is recommended that further analysis be carried out on other parameters and spatially represented using GIS so as to offer valuable information for reliable management of water resources.

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