Assessing Groundwater Quality In Katsina State, Nigeria

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ABSTRACT

Groundwater quality is crucialto the determination of the water's suitability for drinking, domestic, agricultural and industrial purposes. The suitability of groundwater for the different intents depends on its intrinsic quality. Secondary data of some groundwater samples from seventy borehole locations across Katsina State was obtained from the state's Rural Water Supply and Sanitation Agency (RUWASA). Elevenphysico-chemicalparameters (pH, total dissolved solids (TDS), total hardness (TH), electrical conductivity (EC), chloride, iron, manganese, sulphate, total alkalinity, fluoride and nitrate) of the samples from borehole locations were used to compute Water Quality Index (WQI) with a view to assessing the suitability of the groundwater for human consumption. The results show WQI values for the entire Katsina State range from 18.05 to 60.76, representing excellent and good water quality. Samples from twenty-nine Local Government Areas (LGAs) have average WQI values lower than 50 thereby representing excellent water quality while samples from the remaining five LGAs have WQI values greater than 50 thereby representing good water quality. The results show about 85% of groundwater in Katsina State has excellent water quality while the remaining 15% have good water quality.

Keywords: *Groundwater, Water Quality Index, Drinking Water, Excellent Quality Water*

I. INTRODUCTION

Groundwater has increasingly been the major source of fresh water in many parts of the world in recent times. Its usage spans through domestic, industrial water supply and irrigation all over the world. Groundwater accounts for more than a third of municipal and industrial supply and services some 40 percent of the planet's irrigated agriculture[1]. Groundwater in comparison with surface water has long been regarded as the pure form of water. This is as a resultof purification of the former in the soil column through anaerobic decomposition, filtration and ion exchange. Consequently causing the excessive consumption of groundwater in rural and semi-urban areas all over the world [2].

Groundwater quality is crucial to the determination of the water's suitability for drinking, domestic, agricultural and industrial purposes. The suitability of groundwater for the different intents depends upon its intrinsic quality which reflects inputs from the atmosphere, soil and rock weathering, as well as from anthropogenic activities [3]. The value of groundwater does not only lie in its widespread occurrence and availability but also in its consistent good quality [4], [5]. Groundwater is degraded when its quality parameters are altered beyond their natural variations by the introduction or removal of certain substances [6], [7]. Once pollution enters the subsurface environment, it is has been estimated that it may remain concealed for many years, and in no time get dispersed over wide areas of groundwater aquifer and rendering groundwater supplies unsuitable for consumption and other uses [8]. Again, once the groundwater is contaminated, its quality cannot be restored by stopping the pollutants from the source. It is therefore essential to routinely monitor the quality of groundwater and to chart ways and means to protect it [9].Groundwater must therefore be meticulously managed to maintain its purity within standard limits being a fragile and important source of drinking water, [2].

Water quality index (WQI), a technique for rating water quality is an effective tool to assess spatial and temporal changes in groundwater quality and communicate information on the quality of water to the concerned citizens and policy makers [10], [11]. WQI is defined as a rating reflecting the composite influence of different water quality parameters, which is calculated from the point of view of the suitability of groundwater for human consumption [10]. WQI has been successfully applied to assess the quality of groundwater in the recent years as it serves in the understanding of water quality issues by integrating complex data and generating a score that describes water quality status. Basically, WQI aims at giving a single value of water quality of a source reducing great number of parameters into a simpler expression and enabling easy interpretation of monitoring data [12].

With the use of secondary data of some groundwater samples from 70 borehole locations obtained from the Rural Water Supply and Sanitation Agency (RUWASA), Katsina State, this work attempts to compute WQI with a view to assessing the groundwater suitabilityfor human consumption.

II. WATER QUALITY INDEX

Horton (1965)[13] initially developed WQI in the United States by choosing 10 most commonly used water quality variables such as dissolved oxygen (DO), pH, coliforms, specific conductance, alkalinity and chloride. This has been widely applied and accepted in European, African and Asian countries [14]. The assigned weight reflected significance of a parameter for a particular use and has considerable impact on the index. Following this, a new WQI similar to Horton's index was developed by the group of Brown in 1970. This was based on weights to individual parameter [15]. In recent times, many adjustments have been put up for WQI concept through various scientists and experts[16], [17]. A general WQI approach [18] is based on the most common factors, which are described in the following three steps:

1. Parameter Selection: This is carried out by judgment of professional experts, agencies or government institutions that is determined in the legislative area. The selection of the variables from the 5 classes namely oxygen level, eutrophication, health aspects, physical characteristics and dissolved substances, which have the considerable impact on water quality, are recommended [19].
2. Determination of Quality Function (curve) for Each Parameter Considered as the Sub-Index: Sub-indices transform to non-dimensional scale values from the variables of its different units (ppm, saturation percentage, counts/volume etc.).
3. Sub-Indices Aggregation with Mathematical Expression: This is frequently utilized through arithmetic or geometric averages.

Several number of water quality indices have been formulated by different national and international organizations and these have been applied for the assessment of water quality in particular areas. Examples include Weight Arithmetic Water Quality Index (WAWQI), National Sanitation Foundation Water Quality Index (NSFWQI), Canadian Council of Ministers of the Environment Water Quality Index (CCMEWQI), Oregon Water Quality Index (OWQI) and Scottish Water Quality Index (SWQI) [20], [21].A number of researchers across the globe developed WQI models based on weighing and rating of different water quality parameters [22], [23]. Most water quality indices rely on normalizing, or standardizing, data parameter by parameter according to expected concentrations and some interpretation of 'good' versus 'bad' concentrations. Parameters are often then weighted according to their perceived importance to overall water quality and the index is calculated as the weighted average of all observations of interest (e.g., [25]-[29].

There is no globally accepted composite index of water quality, the UNEP GEMS/Water programme has however selected the Canadian Water Quality (CWQI aka CCMEWQI) as the model to follow in developing the global water quality index. This model was selected as it requires the use of a benchmark or guideline which allowed for comparison of values to the World Health Organisation's Drinking Water Quality Guidelines. To assess the robustness of these guidelines, comparisons with drinking water quality guidelines was conducted with those currently in place in the European Union, Australia and USA. In line with the use of the aforementioned guidelines, many researchers and agencies however adopt the local (national) standards for the development of the water quality index.

III. MATERIALS AND METHODOLGY

Study Area

The study is focused on Katsina State. The state is located between latitude 11° 08' North and 13° 22' North and longitude 6° 52' East and 9° 20' East. Katsina State was created in 1987 from the defunct Kaduna State. It spans a total area of approximately 23,983 km^2. The state is bounded in the East by Kano State, in the West by Zamfara State, in the South by Kaduna State and in the North by the Niger Republic. The State is made up of 34 local government areas with a total population of 5,801,584 in 2006 [30] and projected to be 9,105,589in 2016.

Figure1: The Map of Katsina State and Local Government Areas

Katsina State is characterised by the tropical wet and dry climate i.e. tropical continental climate designated as Aw climate by Koppen. Rainfall is mainly between May and September with its peak in August. Average annual rainfall is about 700mm with a general highly variable pattern of rainfall. This can bring about severe and widespread droughts that can impose serious socio-economic constraints [31]. The mean annual temperature ranges from 29 ºC – 31 ºC. The highest air temperature normally occurs in April/May and the lowest in December through February. Evapo-transpiration is generally high throughout the year. The highest amount of evaporation occurs during the dry season.

Two major rivers namely; River Gada and Karadua dominate other few perennial rivers and streams in the State.

These rivers flow over the basement complex, thus are characterized by rapids and falls. They flow into the Rima and Sokoto Rivers which ultimately drains into the Niger River [32]. Above the basement complex rocks of the State predominantly are ferruginous tropical red and brown soils. Eroded weathered rocks and sand drifts composed of unconsolidated sands on the interfluves and upper slopes form the parent materials of the soil. The lateritic drift soil of the State is coarse and tends to be of low to medium fertility [33]. The southern part of the State iscovered by soils of ferruginous type derived from basement complex and old sedimentary rocks. These soils are distinguished by a marked differentiation of horizons. The northern part of the State is however characterised by brown and reddish brown weakly-developed soils. The vegetation is sparse and as such does not provide much litter, but the plant roots that decay in the soil are responsible for much of humus in the soil. These soils possess high water and nutrient retention capacities which could make them very productive with adequate water supply.

Methodology

Results of chemical analyses of groundwater samples from 70 borehole locations were obtained from Rural Water Supply and Sanitation Agency (RUWASA), Katsina State.The major cations and anions were analysed using Atomic Absorption Spectrophotometer (AAS) and Ultra Violet Spectrophotometer (UVS), respectively while electrical conductivity (EC) and pH measurements were taken in-situ using standard equipment. The dates of the samples range between 2004 and 2016. For this project, eleven parameters namely; pH, total dissolved solids (TDS), total hardness (TH), electrical conductivity (EC), chloride, iron, manganese, sulphate, total alkalinity, fluoride and nitrate were obtained for each of the samples (see table 1). The standards for drinking purposes as recommended by Nigerian Industrial Standard (NIS: 554: 2007) [34] form the basis for the calculation of WQI. There are few steps for computing WQI:

- As indicated in table 2, specific weights are assigned to the water chemical parameters according to their relative significance in the overall quality of water for drinking. The most significant parameters have a weight of 5 and the least significant a weight of 1. Nitrate is estimated to play a prominent role in groundwater quality for drinking purposes [9] hence maximum weight of 5 is assigned this parameter whereas the total hardness is the least harmful (among all) to ground water quality for drinking purposes and the weight of 2 is given to it (table 2).

- Compute the relative weight ***(Wi)*** by using the following equation:

$$W_i = \frac{w_i}{\sum_{I=1}^{n} w_i} \qquad Equation\ 1$$

Where, W_i is the relative weight, w_i is the weight of each parameter and n is the number of parameters. Calculated relative weight (W_i) values of each parameter are also given in table 2.

- Calculate a quality rating scale (q_i) for each parameter which is assigned by dividing its concentration in each water sample by its respective standard.
- According to the guidelines laid down in the NIS and the result multiplied by 100.

$$q_i = (C_i/S_i) * 100 \qquad Equation\ 2$$

Where q_i is the quality rating, C_i is the concentration of each chemical parameter in each water sample, and S_i is the Nigerian drinking water standard for each chemical parameter in mg/L according to the guidelines of the NIS 554, 2007.

- Determine SI_i(Sub index)for each chemical parameter which has been calculated from the following equation

$$SI_i = W_i * q_i \qquad Equation\ 3$$

- Finally, compute WQI for each sample by using the following formula:

$$WQI = \sum SI_i \qquad Equation\ 4$$

The computed WQI values are classified into five types, “excellent water” to “water unsuitable for drinking” (see table 3) [35], [9].

However, having computed the WQI values for all the samples, the average WQI for LGAs having more than one location samples were further computed. Each LGA therefore has one value for the WQI. Also, available data for the computation of WQIwas for 28 LGAs while the WQI for the remaining 6 LGAs were interpolated from the average of the WQI of the bordering LGAs.

Table II: Nigerian Standards, weight (w_i) and calculated relative weight (Wi) for each parameter

Parameters	Si(Nigeria)	Weight (wi)	Relative Weight (Wi)
PH	8.5	4	0.09756
TDS (mg/l)	500	4	0.09756
TOTAL HARDNESS (mg/l)	150	2	0.04878
CONDUCTIVITY (μs/cm)	1000	4	0.09756
CHLORIDE (mg/l)	250	3	0.07317
TOTAL IRON (mg/l)	0.3	4	0.09756
MANGANESE (mg/l)	0.2	4	0.09756
SULPHATE (mg/l)	100	4	0.09756
TOTAL ALKALINITY (mg/l)	200*	3	0.07317
FLOURIDE (mg/l)	1.5	4	0.09756
NITRATE (mg/l)	50	5	0.12195
TOTAL		41	1.00000

*Nigerian Standard not available

Table III:Water quality index range and water quality description for drinking

WQI	CLASS	WATER QUALITY

<50	I	Excellent
50-100	II	Good
100-200	III	Poor
200-300	IV	Very poor
>300	V	Unsuitable

IV. GIS OPERATIONS

A shapefile of the 34 LGAs of Katsina State was extracted from the Administrative map of Nigeria (Source: OSGOF). Fields representing the WQI value and WQI class were created and populated for each of the LGAs in the attribute table respectively.

V. RESULTS AND ANALYSIS

The results of the average water quality index and class of the samples of the thirty-four LGAs are given in Table 4 and Figure 2. Generally, the computed WQI values for the entire Katsina State ranged from 18.05 in Mashi LGA to 60.76 in Musawa LGA. This range of values represent classes I (excellent water quality) and II (good water quality). Samples from twenty-nine LGAs have average WQI values lower than 50 thereby representing excellent water quality while the samples from the remaining five LGAs have values greater than 50 thereby representing good water quality. This implies that about 85% of the entire state has excellent water quality while the remaining 15% have good water quality. The five LGAs of good water quality are Batagarawa, Ingawa, Jibia, Kusada and Musawa. The sample from Dangani, Musawa LGA with high concentration of Iron (Fe) contributed immensely to the average WQI for the LGA.

Figure 2: Map of Katsina State showing water quality based on average WQI for the 34 LGAs.

Although, the WQI sums up the different considered physico-chemical attributes of the groundwater samples, a brief description of these important attributes is also presented as follows.

pH

Generally, water with a pH < 7 is considered acidic and with a pH > 7 is considered basic. Most groundwater systems are characterised by a pH range of 6 to 8.5. Majority (59%) of the samples have pH values < 7 showing they are acidic. The average pH of the samples shows a slightly acidic value of 6.86. The low pH value in the

Table IV: Average water quality index and class of the samples from the 34 LGAs of Katsina State

S/N	LGA	AVE WQI	WQI CLASS	WATER QUALITY
1	Bakori	33.287	I	Excellent
2	Batagarawa	53.325	II	Good
3	Batsari	45.370	I	Excellent
4	Baure	31.386	I	Excellent
5	Bindawa	34.355	I	Excellent
6	Charanchi	45.922	I	Excellent
7	Dandume	43.254	I	Excellent
8	Danja	20.495	I	Excellent
9	Danmusa	42.475	I	Excellent
10	Daura	18.840	I	Excellent
11	Dutsi	38.558	I	Excellent
12	Dutsin-M	37.436	I	Excellent
13	Faskari	40.835	I	Excellent
14	Funtua	45.673	I	Excellent
15	Ingawa	56.216	II	Good
16	Jibia	53.286	II	Good
17	Kafur	31.953	I	Excellent
18	Kaita	24.794	I	Excellent
19	Kankara	43.545	I	Excellent
20	Kankiya	32.959	I	Excellent
21	Katsina (K)	40.025	I	Excellent
22	Kurfi	49.941	I	Excellent
23	Kusada	51.757	II	Good
24	Mai'Adua	19.457	I	Excellent
25	Malumfashi	37.079	I	Excellent
26	Mani	41.406	I	Excellent
27	Mashi	18.053	I	Excellent
28	Matazu	30.572	I	Excellent
29	Musawa	60.759	II	Good
30	Rimi	26.139	I	Excellent
31	Sabuwa	42.044	I	Excellent
32	Safana	49.103	I	Excellent
33	Sandamu	19.010	I	Excellent
34	Zango	48.366	I	Excellent

groundwater of the study area can be attributed to the dominant acidic sandy-clayey soils and plausibly the influence of fertilizers like ammonium sulphate and super phosphate in agriculture [36]. An abnormal pH value of 11.5 is noticed in the sample from Katsina LGA (Faruwa). High pH value in some instances could be attributed to the presence of considerable amount of sodium, calcium, magnesium, carbonate and biocarbonate ions [37].

Total Dissolved Solids (TDS)

TDS content is typically considered a major factor which determines the use of groundwater for any purpose [38]. The samples show a TDS concentration range of 20 to 858 mg/l. Average TDS value is given as 234.3 mg/l. About 94% of the samples exhibit TDS values within the permissible limit (500mg/l). The remaining 6% with TDS values higher than 500 mg/l are samples from Funtua LGA (Hadiqatul Quran, Zaria Rd), Jibia LGA (Tsayau), Mani LGA (Makau) and Zango LGA (Madaka II). Three of these LGAs are situated in the northern part of the state.

Total Hardness (TH)

The samples show hardness in concentration range of 16 to 480 mg/l. The average hardness of the samples is given as 94.6 mg/l. Results show that 84% of the samples fall within the Nigerian Standard permissible limit of 150mg/l. The classification of groundwater (Table) based on Total Hardness (TH) show that 47% fall in the soft water category, 39% fall in the moderately hard water category, 13% fall in the hard water category and 1% falls in the very hard water category [7].Going by the Nigerian Standard the maximum allowable limit of TH for drinking is 150 mg/lwhile the most desirable limit as recommended by WHO guidelines is 100mg/l.

Table V:Groundwater quality for drinking based on hardness

Water Class	No. of Water Samples	Percentage	Total Hardness as $CaCO_3^-$ (mg/l)
Soft	33	47	0-75
Moderately Hard	27	39	75-150
Hard	9	13	150-300
Very Hard	1	1	>300

Electrical Conductivity (EC)

EC values range from 41.6 to 1740 µs/cm for the total samples with an average value of 479.4 µs/cm. As expected, the samples with high TDS values; Funtua LGA (Hadiqatul Quran, Zaria Rd), Jibia LGA (Tsayau), Mani LGA (Makau) and Zango LGA (Madaka II) also exhibit the same for EC. These two parameters are directly related to each other [39]. Two samples from Safana LGA and one sample from Danmusa LGA also show high EC values. Generally nutrient enrichment as a result of fertilizer applications to farmlands might have enhanced TDS which in turn increases the EC in the listed areas. Large variations in EC are mainly attributed to anthropogenic activities. EC generally increases along a groundwater flow path because of the combined effects of evaporation, ion exchange, and topographic conditions [40]. Electrical Conductivity permissible limit by the Nigerian Standard is given as 1000 µs/cm. About 93% of the samples fall within the limit.

Chloride

Chloride is a natural compositionof all types of waters. Chloride ion is the most prevalent natural form of the element chlorine and is extremely stable in water. Chloride content of the samples ranged from 7 to 220 mg/l. This range falls below the 250mg/l guideline limit for drinking water by the Nigerian Standard and WHO. The chloride in groundwater may be from diverse sources such as weathering, leaching of sedimentary rocks and soil, domestic and municipal effluents [41]. Also, the agricultural application of potassium (K) as a plant nutrient commonly causes chloride contamination of recharging shallow groundwater [42].

Iron and Manganese

Iron (Fe) and Manganese (Mn) are natural occurring metallic elements in soils, rocks and minerals. Groundwater in the aquifer comes in contact with these solid materials and dissolves them, thereby releasing their constituents, including Fe and Mn to the water. Fe concentration in the samples are in the range 0 to 2 mg/l. Majority of the samples are within the 0.3 mg/l permissible limit except for three samples with 0.5 mg/l at Kurfi LGA (KwantamawaDutsinma), 0.8 mg/l at Ingawa LGA (KuranKazau) and 2 mg/l at Musawa LGA (Dangani) respectively. Mn appears to be absent in about 79% of the samples while remaining 21% are within 0.1 mg/l which is below the permissible 0.2 mg/l of the Nigerian Standard.

The dissolution extent of Fe and Mn in groundwater is dependent on the amount of oxygen in water and to a minor extent, upon its level of acidity. If the groundwater is oxygen poor, iron (and manganese) will dissolve more readily, particularly if the pH of the water is on the low side (slightly more acidic). This might explain the metals concentration in the samples. Usually, the concentration of dissolved iron (and manganese) in drinking water is relatively small.

Sulphate

Sulphate concentration in the samples ranged from 10 to 220 mg/l with an overall average of 44.5 mg/l. Majority of the samples are within the 100 mg/l permissible limit except for four samples with 110 mg/l at Kankara LGA (Bela), 160 mg/l at Charanchi LGA (Barangizo), 180 mg/l at Safana LGA (Luggawa Gora) and 220 mg/l at Ingawa LGA (KuranKazua) respectively. Sulphates are a combination of sulphur and oxygen and are a part of naturally occurring minerals in some soil and rock formations that contain groundwater. The mineral dissolves over time and is released into groundwater. Sulphate concentration in the range of 10-15 mg/l may not require any rich sulphate source, the interaction of rain water with ground surface is enough to explain this much concentration. The use of fertilizers as ammonium sulphate for example suggests the sulphate concentrations in the samples more particularly the samples with the high concentration values. Sulphate is a nuisance that usually do not pose a health risk at concentrations found in domestic water supplies [44].

Fluoride

Fluoride is a common constituent of groundwater. Fluoride in groundwaterin most cases is contributed by the host rocks which are naturally rich in fluoride [43]. Natural occurrences are linked to various types of rocks and to volcanic activity. The samples exhibit low level of fluoride in the range 0 to 0.5 mg/l with an overall average of 0.1 mg/l. All samples are therefore below the permissible limit of 1.5 mg/l by WHO and Nigerian Standard. The acidic nature (pH <7) of the water might be suggestive of the low fluoride concentration as high-fluoride groundwaters are mainly associated with a sodium-bicarbonate water type and relatively low calcium and magnesium concentrations and such water types usually have high pH values (above 7) [45].

Total Alkalinity

Generally, the alkalinity of natural waters may be due to the presence of one or more of a number of ions. These include bicarbonates, carbonates and hydroxides. Alkalinity in most natural surface and groundwater is mainly derived from the dissolution of carbonate minerals, and from CO_2 present in the atmosphere and in soil above the water table. Three carbonate species (H_2CO_3, HCO_3^- and CO_3^{2-}) contribute to total alkalinity, their relative proportions being dependent on pH and temperature. At near-neutral values of pH, dissolved bicarbonate (HCO_3^-) is the dominant ion. A significant contribution from CO_3^{2-}, and other anions, emerges only at pH levels greater than approximately 9.0. The alkalinity content of the samples spans between 18 and 393 mg/l with an average of 128.4 mg/l. About 81% of the samples exhibit alkalinity values within the permissible limit of 200 of the Nigerian Standard while the remaining 19% fall outside the limit. The average pH of the samples suggests HCO_3^- as the main contributor to the total alkalinity in the study area. Although unlikely in this situation, it should be noted that in polluted waters, other negative ions like PO_4 and NO_3 may contribute to alkalinity [46], [47].

Nitrate

Nitrate is the most important nutrients in an ecosystem. Nitrate concentration in the total samples ranged from 0 to 50 mg/l. The average concentration is given as 10.3 mg/l. The highest concentration of 50 mg/l is seen in Katsina LGA (Tundun Wada). Varying concentrations of nitrates found might be suggestive of how much of fertilizer and manure applications are been used for agricultural purposes in the different areas. None of the samples exceeds the permissible limit of 50 mg/l.

VI. CONCLUSIONS

Eleven physico-chemical parameters (pH, total dissolved solids (TDS), total hardness (TH), electrical conductivity (EC), chloride, iron, manganese, sulphate, total alkalinity, fluoride and nitrate) obtained from the results of chemical analyses of groundwater samples from 70 borehole locations in Katsina State were used for the computation of water quality index (WQI). The resultant WQI values ranged from 18.05 in Mashi LGA to 60.76 in Musawa LGA, representing excellent to good water quality. Twenty-nine LGAs have water of excellent quality while the other five LGAs have water categorised as good quality. This implies that about 85% of the entire state has excellent water quality while the remaining 15% have good water quality.

The application of the WQI approach to groundwater is to provide a simple and valid method for expressing the results of several parameters so as to assess the groundwater quality. This was further incorporated into GIS for easier understanding, presentation and analysis. The spatial distribution map generated for the WQI could be useful for planners, water quality managers and decision makers for initiating groundwater quality monitoring, development and management in the study area.

REFERENCES

[1] FAO. Food and Agriculture Organization.

[2] Kannan, N. and Joseph, S. 2009. Quality of Groundwater in the Shallow Aquifers of a Paddy Dominated Agricultural River Basin, Kerala, India. World Academy of Science, Engineering and Technology, (52): 475-493.

[3] Shanmugasundharam, A., Kalpana, G., Mahapatra, S.R., Sudharson, E.R, Jayaprakash, M. 2017. Assessment of Groundwater quality in Krishnagiri and Vellore Districts

in Tamil Nadu, India.Applied Water Science (2017) 7:1869–1879.DOI 10.1007/s13201-015-0361-4.

[4] Rajmohan, N., Elango, L., Ramachandran, S. and Natarajan, M. 2000. Major ion correlation in groundwater of Kancheepuram region, south India.Indian J Environ Protection 20(3):188–193.

[5] UNESCO. 2000. Groundwater Pollution. International Hydrological Programme.

[6] Ramesh, R. 2001. Point and Non-point sources of Groundwater Pollution: Case Studies along the East Coast of India. Capital Publishing Company, New Delhi, India, 107p.

[7] Todd, D. K. 2001. Groundwater Hydrology, 2nd Edition, John Wiley & Sons Ltd. Singapore, pp. 334.

[8] Nagarajan R, Rajmohan N, Mahendran U, Senthamilkumar S (2010)Evaluation of groundwater quality and its suitability for drinking and agriculture use in Thanjavur city, Tamil Nadu, India. Environ Monit Assess. 171:289–308.

[9] Ramakrishnalah, C.R; Sadashivalah C. and Ranganna G, 2009. Assessment of water quality index for the groundwater in TumkurTaluk , Karnataka state , India, E Journal of chemistry, 6(2), pp.523-530.

[10] Mishra, S.P. and Patel, R.K. 2001. Study of the pollution load in the drinking water of Rairangpur, a small tribal dominated town of North Orissa. Indian J. Environment and Ecoplanning.5 (2):293-298.

[11] Tiwari, T.N. and Mishra, M.A. 1985. A preliminary assignment of water quality index of major Indian rivers.Indian J. Environmental Protection. 5: 276-279.

[12] Singh P.K, Tiwari A.K, Panigarhy B.P, and Mahato M.K., Water Quality Indices used for Water Resources Vulnerability Assessment using GIS Technique: A Review, International Journal of Earth Science and Engineering, 6(6-1): 1594-1600, (2013).

[13] Horton, R.K., An index number system for rating water quality, J. Water Pollu. Cont. Fed., 37(3). 300-305. 1965.

[14] Tyagi, S., Sharma, B., Singh, P, Dobhal, R. 2013. Water Quality Assessment in Terms of Water Quality Index.American Journal of Water Resources, 2013 1 (3), pp 34-38. DOI: 10.12691/ajwr-1-3-3.

[15] Brown, R.M. and McClelland, N.I. 1970. Deininger, R.A. and Tozer, R.G., Water quality index-do we dare. Water Sewage Works, 117(10).339-343.

[16] Bhargava, D.S, Saxena, B.S. and Dewakar, R.W. 1998. A study of geo-pollutants in the Godavary river basin in India.Asian Environ., 12. 36-59.

[17] Dwivedi, S., Tiwari, I.C. and Bhargava, D.S. 1997. Water quality of the river Ganga at Varanasi, Institute of Engineers, Kolkota, 78, 1-4.

[18] Fernandez, N., Ramirez, A. and Solano, F., Physico-chemical water quality indices - a comparative review. RevistaBistua. ISSN 0120-4211. Available at http://redalyc.uaemex.mx/src/inicio/ArtPdfRed.jsp?iCve=90320

[19] Dunnette, D.A. 1979. A geographically variable water quality index used in Oregon", J. Water Pollu. Cont. Fed., 51(1). 53-61.

[20] Lumb, A., Halliwell, D. and Sharma, T. 2002. Canadian water quality index to monitor the changes in water quality in the Mackenzie river–Great Bear.Proceedings of the 29th Annual Aquatic Toxicity Workshop, (Oct. 21-23), Whistler, B.C., Canada.

[21] Chaturvedi, M.K. and Bassin, J.K. 2010. Assessing the water quality index of water treatment plant and bore wells, in Delhi, India, Environ. Monit.Assess., 163. 449-453.

[22] UNEP GEMS. 2007. Global drinking water quality index development and sensitivity analysis report. United Nations Environment Programme Global Environment Monitoring System/Water Programme. 58 p. (www.gemswater.org).

[23] Kavitha, R. and Elangovan, K. 2010. Ground water quality characteristics at Erode district, Tamilnadu India. International Journal of Environmental Science, 1(2): pp. 145-150.

[24] Alobaidy, A. M.J.,Abid, H.S. and Maulood, B.H. 2010. Application of water quality index for assessment of Dokan lake ecosystem, Kurdistan region, Iraq.Journal of Water Resource and Protect, 2: pp. 792-798.

[25] Pesce, S.F. and Wunderlin, D.A. 2000. Use of water quality indices to verify the impact of Cordoba City (Argentina) on Suquia River.Water Research 34: 2915-2926.

[26] Stambuk-Giljanovik, N. 2003. Comparison of Dalmation water evaluation indices.Water Environment Research 75(5):388-405.

[27] Sargaonkar, A. and V. Deshpande. 2003. Development of an overall index of pollution for surface water based on a general classification scheme in Indian context. Environmental Monitoring and Assessment 89:43-67.

[28] Liou, S.M., Lo, S.L. and Wang, S.H. 2004. A generalised water quality index for Taiwan.Environmental Monitoring and Assessment 96: 35-32.

[29] Tsegaye, T., Sheppard, D., Islam, K.R., Johnson, A., Tadesse, W., Atalay, A., and Marzen, L. 2006. Development of chemical index as a measure of in-stream water quality in response to land-use and land cover changes. Water, Air, and Soil Pollution 174: 161-179.

[30] National Population Census, NPOPC 2016. Population by Sex.Url:/hhtp://www.population.gov.org/files//nationalfinal.pdf. Assessed; 15th March 2016.

[31] Nagarajan R, Rajmohan N, Mahendran U, Senthamilkumar S (2010) Evaluation of groundwater quality and its suitability for drinking and agriculture use in Thanjavur city, Tamil Nadu, India. EnvironMonit Assess 171:289–308

[32] Yaro, A. & El-Ladan, I.Y. 2012. The Effect of Urban Run-Off Water and Human Activities on Some Selected Physio Chemical Properties of River Ginzo, in Katsina Local Government, Katsina State.Katsina.Journal of Natural and Applied Sciences, Vol. 2, no. 2, pp. 52-61.

[33] Ibrahim, Y.E., Nuraddeen, A.M. &Abubakar, A.R. 2014. Factors Affecting Soil Quality Maintenance in Northern Katsina State, Nigeria.Science World Journal, Vol. 9, no. 4, pp. 39-46.

[34] NIS-554-2007. Nigerian Standard for Drinking Water Quality Standard Organisation of Nigeria.

[35] Sahu, P. and Sikdar, P.K. 2008. Hydrochemical Framework of the Aquifer in and around East Kolkota Wetlands, West Bengal, India.Environmental Geology, 55, 823-835.

[36] Appelo, C.A.J. and Postma, D., 2005. Geochemistry, Groundwater and Pollution, 2nd edition.Balkema publishers, Leiden, the Netherlands, 404p.

[37] Rao, D.K., Panchaksharjah, S., Pati, B.N., Narayana, A. and Raiker, D.L.S., 1982. Chemical Composition of Irrigation Waters from Selected Parts of Bijapur District, Karnataka, Mysore.J. Agric. Sci., 16: 426-432.

[38] Nordstrom, P.L., 1987. Groundwater resource of the antlers and Travis peak formations in the outcrop area of North Central Texas. Texas Water Development Board, Report 298, 280p

[39] Mishra, S.P. and Saksena, D.N., 1993. Planktonic fauna in relation to physico-chemical characteristics of Gauri Tank at Bhind, M.P. India.Advances in Limnology.Narendra Publishing House.New Delhi, pp. 57- 61.

[40] Toth, J. 1999. Groundwater as a geologic agent: an overview of the causes, processes and manifestations. Hydrogeol J 7:1–14.

[41] SarathPrasanth S.V., Magesh, N.S., Jitheshlal, K.V., Chandrasekar, N. 2012. Evaluation of groundwater quality and its suitability for drinking and agricultural use in the coastal stretch of Alappuzha District, Kerala, India. Appl Water Sci 2(3):165–175.

[42] Bohlke, J.K., 2002. Groundwater recharge and agricultural contamination.Hydrogeol J., Vol.10, pp. 153–179. doi:10.1007/s10040- 001-0183-3.

[43] Brindha, K. and Elango, L. (2011) Fluoride in Groundwater: Causes, Implications and Mitigation Measures. In: Monroy, S.D. (Ed.), Fluoride Properties, Applications and Environmental Management, 111-136.

[44] Rajankar, P.N., Gulhane, S.R., Tambekar, D.H., Ramteke, D.S. &Wate, S.R. 2009. Water Quality Assessment of Groundwater Resources in Nagpur Region (India) Based on WQI. E-Journal of Chemistry, Vol. 6, Issue 3, pp. 905-908.

[45] Brunt, R., Vasak, L. &Griffioen, J. 2004. Fluoride in Groundwater: Probability of Occurrence of Excessive Concentration on Global Scale. International Groundwater Resources Assessment Centre (IGRAC). Report nr. SP 2004-2.

[46] Dutta, J., Chetai, M., SarmahBaruah, J.P. and Misra, A.K. 2010. Assessment of Drinking Water in Different Small Tea Gardens of Sonitpur District (Assam), India. Archives of Applied Science Research, 2010, 2 (5):226-238.

[47] NAS, 1974. Water quality criteria.Nat. Acad. Sci., 23 (1972): 105p.

Table I: Water samples and their chemical parameters.

				GROUNDWATER QUALITY PARAMETER									
LGA	LOCATION	DATE	PH	TDS mg/l	TOTAL HARDNESS mg/l	CONDUCTIVITY Us/cm	CHLORIDE mg/l	IRON mg/l	MANGANESE mg/l	SULPHATE mg/l	TOLTAL ALKALINITY mg/l	FLOURIDE mg/l	NITRATE mg/l
BAKORI	UNGUWAR DAHIRU MOSQUE	2010	6.8	78	51	165.2	40	0.1	0	20	114	0.1	6.62
BAKORI	GIDAN DOSA	2016	6.7	311	71	648	70	0.1	0	40	162	0.1	12.29
BATAGARAWA	KADAFAWA	2005	7.4	173	186	363	30	0.24	0.1	60	207	0.3	12
BATSARI	KORAMAR KAURA	2013	7.3	481	62	995	40	0.1	0	40	186	0.1	0
BATSARI	KABOBI	2014	7	432	68	897	40	0.1	0	30	186	0.1	13.29
BAURE	DORAWA GOMA	2005	6.6	39	78	82.4	30	0.3	0	60	51	0.5	8
BAURE	MAIBARA	2013	6.4	120	81	192	40	0.1	0	30	87	0.1	8.86
BINDAWA	BINDAWA	2013	6.8	202	93	233	40	0.1	0	25	102	0.1	12.24
BINDAWA	TAMA	2005	7	186	159	390	50	0.16	0.1	60	195	0.1	12
BINDAWA	FARU	2007	5	31	36	65.3	20	0.1	0	70	30	0.1	10
BINDAWA	BINDAWA NURSERY	2013	7.2	297	22	622	40	0.1	0	40	66	0.1	8.86
CHARANCHI	CHARANCI	2013	6.6	144	93	222	70	0.1	0	20	87	0.1	12.98
CHARANCHI	BARANGIZO	2005	7.4	229	207	479	20	0.12	0.09	160	222	0.4	10
DANJA	DAN DANGA PRY SCH	2009	7.4	58	39	121.6	20	0.05	0	10	48	0.06	4.48
DANJA	RAFIN SABO PRY SCH	2009	7.3	53	78	111.2	20	0.09	0	20	66	0.06	4.84
DANMUSA	GOBIRAWA	2006	5.5	154	71	325	20	0.2	0.1	25	66	0.1	10
DANMUSA	YANTUMAKI FORESTRY	2013	7	349	44	727	30	0.1	0	50	114	0.1	8.86
DANMUSA	GANDUN SARKI YANTUMAKI	2013	6.5	114	39	112	30	0.1	0	20	48	0.09	8.86

DANMUSA	RUGAR GYADA	2006	5.7	415	480	1063	130	0.3	0.1	30	120	0.3	20
DUTSIN-M	FAFARAWA DABAWA	2013	7.9	253	90	529	111	0.13	0	10	87	0.12	10.24
DUTSIN-M	SHEMA RESIDENCE	2011	7.1	220	93	463	70	0.1	0	30	162	0.1	12.62
FUNTUA	GDSS FUNTUA	2006	6	51	48	108.7	30	0.1	0	15	57	0.1	8
FUNTUA	HADIQATUL QURAN ZARIA RD	2011	6.9	606	121	1240	220	0.18	0	40	279	0.14	30.64
INGAWA	RURUMA HEALTH CTR	2010	7.2	238	99	498	80	0.12	0	25	102	0.1	12.48
INGAWA	KURAN KAZAU	2016	6.5	266	48	558	40	0.8	0	220	96	0.08	12.29
JIBIA	BUGAJE	2007	6.1	284	120	598	7	0.1	0	20	90	0.2	20
JIBIA	TSAYAU	2005	7.9	511	156	1056	70	0.11	0.1	70	354	0.2	14
KAITA	RADI	2007	6.8	61	96	128.3	20	0.1	0	20	90	0.1	5
KAITA	BILISKORE	2006	5.5	142	126	299	40	0.1	0	10	52	0.1	5
KANKARA	BELA	2014	6.7	294	28	614	40	0.1	0	110	114	0.1	13.29
KANKIYA	KANYAN MAINA	2006	6.3	177	165	373	20	0.1	0	13	180	0.2	10
KANKIYA	HEALTH TECHNOLOGY	2007	6.9	151	60	318	50	0.1	0	50	60	0.1	10
KATSINA	DUTSEN SAFE MOSQUE	2007	6.1	114	102	241	20	0.1	0	20	51	0.1	15
KATSINA	TUNDUN WADA	2006	6.5	327	93	685	110	0.1	0	70	96	0.1	50
KATSINA	RAHAMAWA	2015	6.8	482	82	996	40	0.1	0	30	216	0.1	0
KATSINA	KOFAR SORO	2010	6.1	328	141	681	70	0.14	0	20	183	0.12	20.86
KATSINA	GANA JIGWA	2012	6.8	102	84	68	20	0.12	0	30	75	0.05	8.96
KATSINA	FARUWA	2005	11.5	397	216	828	30	0.12	0.02	60	252	0.2	15
KATSINA	SANDAMU	2006	7.4	196	84	414	60	0.2	0	30	189	0.1	7
KATSINA	GRA	2006	6.6	46	18	99.3	30	0.1	0	50	27	0.1	4
KURFI	LAMBO	2005	7.8	142	243	303	20	0.26	0.1	80	168	0.2	9
KURFI	BIRCI	2006	7.3	456	285	946	70	0.3	0.1	10	393	0.2	20
KURFI	KWANTAMAWA,DU TSINMA	2012	6.6	121	66	117	30	0.5	0	30	78	0	10.24
KURFI	BACCI	2004	7.7	114	72	241	50	0.06	0.04	50	132	0.1	7

KUSADA	KUSADA TWN	2006	7.3	351	129	733	40	0.3	0.1	55	246	0.2	15
KUSADA	SABON GARIN DANGAMAU 2	2010	7	255	135	533	30	0.1	0	20	282	0.1	8.86
MAI'ADUA	SHEKIYAL MOSQUE MAIADUA	2010	6	20	36	41.6	20	0	0	20	30	0.05	0
MAI'ADUA	MULUDU PRY SCH	2016	6.5	87	42	183	40	0.08	0	70	73	0.08	0
MALUMFA SHI	KWARSU	2010	6.9	179	111	375	40	0.14	0	20	189	0.12	12.42
MANI	GUNKI	2007	6.5	161	57	341	30	0.1	0	20	69	0.1	10
MANI	KWARKWADA	2007	7.3	238	30	499	20	0.1	0	20	33	0.1	20
MANI	MUSAWARA FULANI	2007	6.3	221	60	477	40	0.2	0.1	30	75	0.2	10
MANI	MAKAU	2014	6.1	858	69	1740	60	0.2	0	50	252	0.15	8.86
MANI	KUGABO	2013	7.1	251	20	545	40	0.1	0	50	42	0.1	8.86
MANI	SHAISKAWA	2005	7.7	219	186	462	30	0.14	0	70	237	0.2	10
MASHI	SABON SARA	2014	6.2	56	16	110	30	0.05	0	30	18	0	8.86
MATAZU	ADUWA,MATAZU	2014	6.1	441	35	915	40	0.12	0	30	174	0.1	NIL
MATAZU	BADOLE	2006	7.5	200	66	476	60	0.2	0	50	39	0.1	5
MATAZU	GIDAN ALHAJI LAWAL MATAZU	2015	6.8	48.4	45	96.8	11.99	0.01	0	20	22	0.1	0.22
MUSAWA	M/MUSAWA	2006	7.6	200	84	433	80	0.1	0	50	171	0.1	7
MUSAWA	DANGANI	2005	7.2	124	72	261	20	2	0.02	90	111	0.3	3
MUSAWA	UNG. GIDE	2006	7.4	178	141	396	60	0.2	0.1	50	120	0.1	10
RIMI	RUKUDA	2014	6.4	119	21	251	30	0.1	0	40	66	0.1	0
RIMI	TURAJI	2011	6.8	140	69	294	40	0.1	0	35	57	0.1	8.86
SAFANA	MARINA	2013	6.8	490	66	1000	90	0.12	0	25	252	0.1	8.86
SAFANA	KUNAMAWA	2004	7.7	200	135	441	60	0.04	0.02	70	240	0.1	5
SAFANA	LUGGAWA GORA	2016	7.2	487	87	1008	90	0.1	0	180	186	0.12	13.39
SAFANA	UNGUWAR RIMI	2013	6.8	260	99	546	110	0.14	0	15	120	0.14	10.24
SANDAMU	CHADI	2015	6	87	21	182	20	0.1	0	30	24	0.05	0
ZANGO	MADAKA II	2015	6.5	589	97	1000	40	0.1	0	50	120	0.1	8.86