Assessment of Chemical Quality of Water from Shallow Alluvial Aquifers in and around Badeggi, Central Bida Basin, Nigeria

A.A. Sidi[1], N.M. Waziri[1], A.T. Maji[2], I.A. Okunlola[3], A. Umar[2], S.H. Waziri[1]

Abstract

The chemical composition of water from shallow alluvial aquifers on the River Gbako flood plain, Badeggi, Central Bida Basin, Nigeria has been investigated with the aim of assessing the impact of intensive agricultural activity on the chemical quality of groundwater; the main source of potable water in the area. A total of 23 samples made up of eighteen (18) from hand dug wells, two (2) from boreholes, two (2) river water and one (1) from a spring were collected. Analyses for major cations and anions were conducted at the National Cereals Research Institute (NCRI) Badeggi, Nigeria using standard water analyses procedures. The results show cations concentrations are within drinking water limits set by the World Health Organization and Nigerian Standard for Drinking Water Quality. The order of abundance of cations is Ca>Na>K>Mg. The concentration of most anions are within acceptable limits, except for phosphate, nitrate and sulphate whose elevated levels in the water may be an indication of the impact of intensive fertilizer application on water chemistry. Two hydrochemical facies, namely, Ca (HCO^-_3) type and Na (HCO^-_3) were recognized. Overall, the water of quality in Badeggi and its environs has not been adversely affected by anthropogenic factors. However, continued monitoring is recommended as a means of protecting these flood plain aquifers from potential contamination.

Keywords: Bida Basin, Water quality, Alluvial aquifers, Hydrochemistry

[1] Department of Geology, Federal University of Technology, Minna
[2] National Cereals Research Institute, Badeggi
[3] Department Chemical and Geological Sciences, Al-Hikmah University, Ilorin

1   Introduction

Groundwater chemically evolves by interacting with aquifer minerals or internal mixing among different groundwater flow paths in the subsurface [1, 2]. The chemical composition of ground water is regulated by various factors, which include atmospheric inputs, mineral weathering through water-rock interaction, anthropogenic activities and biogeochemical process [3]. Depending on the geological environment, natural movement, recovery and utilization, the overall quality of groundwater depends largely on the soil zones on which the movement occurs. Mahmut *et al.*[4] discovered that soil, a main component of the terrestrial ecosystem is a habitat for great number of organisms and it is perhaps the most endangered component of our environment open to influences from a variety of different pollutants arising from human activities.

Groundwater contamination occurs as a result of various anthropogenic activities subject to the degree of vulnerability of the aquifer to such activity [5]. The potential pathway taken by these contaminants are mostly through the environment [6].Ground water pollution could be from lithogenic or anthropogenic sources such as agricultural practices. Millions of tons of fertilizers, herbicides and pesticides for example, are used annually around the world to boost crop production. A number of the chemicals used are highly toxic and can enter into the groundwater system and pollute the aquifer. Contamination of soils, stream sediment and surface water can result in poor drinking water quality, pollution of aquifer system, high cost for alternative water supplies and potential health problems. The implication of groundwater pollution is of serious concern.

Badeggi community in Katcha Local Government Area (LGA) of Niger State Nigeria is prominent in rice cultivation utilizing rich alluvial soil and stream sediment of Rivers Gbako and Musa. Groundwater serves as a source of water for irrigation agriculture and for domestic usage in the communities in and around the catchment domain of the alluvial plains. Understanding hydrochemical processes in alluvial aquifers of this basin is a baseline for studying the groundwater chemistry of the area.

Intensive agricultural activities are usually practiced in this area. The application of fertilizer, pesticides, insecticides, and manure to boost agricultural production and for research experimentations within the research field may possibly contaminate the soils, sediments and groundwater. NCRI Badeggi and the surrounding communities have had a long history of rice cultivation which involves the use of chemicals to boost the agricultural produce. The aim of this research therefore is to assess the impact of agricultural practices on water (surface and ground) in and around the NCRI, Badeggi.

2   The Study Area

The area of study is located in the South of Bida, Central Nigeria. It lies within latitude $09^{\circ}03'00''$N and $09^{\circ}06'00''$N and longitude $006^{\circ}05'00''$E and $006^{\circ}9'00''$E (Figure 1). Geomorphologically, the study area is mainly low lying and slopes towards the banks of river Gbako. River Gbako is the major surface water body in the area. The flood plain of the river is extensive with average uniform elevation across the study area. Topographical map of the area (Figure 1) shows the geomorphology of the area with alluvial plains of river Gbako extending to about three (3) kilometres from both sides of the River channel. Average elevation in the area is 75m above sea level from the data obtained with a hand held Geographical Positioning System (GPS) device.
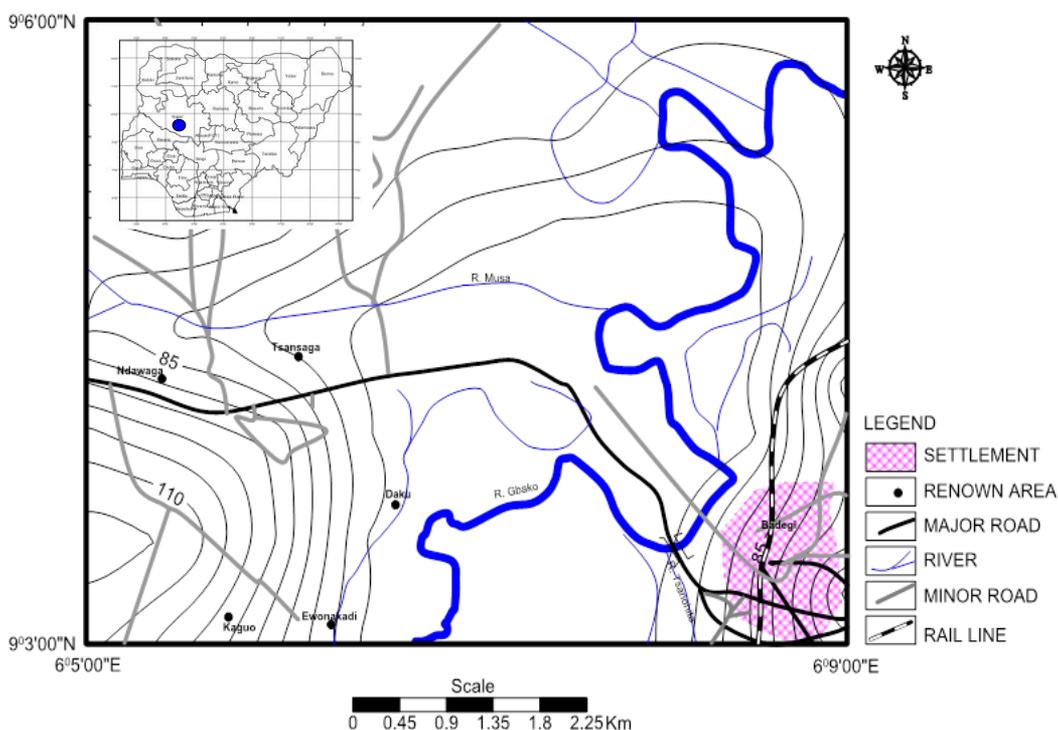

Figure 1 Location and Drainage map of the study area.

The mean annual average temperature of the area ranges between 33^{0}C to 34^{0}C. Two distinct seasons are prominent in the area, dry and rainy seasons. Between April and October is the rainy season while dry season commences around November and ends around March. The rainy season is characterized by heavy down pours accompanied by ground water infiltration and percolation. Average annual rainfall ranges between 900.6 to 1340.4 mm (NCRI Agro Met, 2014). The vegetation of the area belongs to the savannah type with few trees distributed across the area. Extensive agricultural practices are carried out in the area utilizing

the rich alluvial deposits of River Gbako. Cereal crops are usually cultivated and rice is the most prominent. Other land use activities around the area are fishing and grazing.

Two types of aquifers are identifiable in the area; one is semi-confined but locally confined in some places, while the other is unconfined. The first is most widespread and occupies about 80% of the land area, while the second is limited to small portions of the central and northern part of the basin [7, 8]. The unit aquifer (Nupe Sandstone) spreads over a large area within the Middle Niger Basin. At Mokwa area the average thickness is about 28m. The aquifer at the southern part of River Niger spreads as a belt along the basement complex boundary. This belt runs from Jebba in the north-west to Lokoja in the south-east having a maximum width of 30km [9].

3   Research Methodology

3.1   Field Geological Mapping

Geological mapping of the study area was conducted. It involves the descriptive and structural studies of the rocks in the area using a topographical map on a scale of 1:25,000 as base map. With the aid of the topographical map the study area was easily navigated and accessible. Geographical Positioning System (GPS) *etrex Garmin* and compass-clinometer were used during the field work for proper location of places on the map. Observations and field descriptions of rocks and geological features in the study area were recorded in the field note book. Images of geological features were also captured in the field with a portable digital camera. Detailed stratigraphic studies was not undertaken as the area of study is a flood plain that lacks lithological exposure.

3.2   Water Sampling and Field Measurements

A total of 23 water samples made up of eighteen (18) samples from domestics hand dug wells, two (2) samples from irrigation bore holes, two (2) river water samples and one (1) spring water sample were collected across the entire area of study. The samples were filtered and collected in pre-cleaned onelitre plastic bottles. Two samples were collected from each well for cation and anion analyses. The samples for cation analysis were immediately acidified with nitric acid (HNO_3). The physical parameters measured in the field were temperature (T), pH, Electrical conductivity (EC) and total dissolved solid (TDS) using HANNA pH meter and EC/TDS meter s258236. The samples were immediately transported to the Central Services Laboratory at National Cereal Research Institute (NCRI) Badeggi, Nigeria for chemical analysis.

3.3 Laboratory Analysis of Water

The chemical analyses were carried out the Central Services Laboratory, NCRI, Badeggi, Nigeria using standard water analysis techniques [10]. The Methods for the different cations and anions analyses are summarized in Table 1.

Table 1 Summary of the analytical methods used in this study

S/No.	Parameter	Method of Analysis
1	Cl^-, HCO_3^-	Titrimetry
2	PO_4^{3-}, NO_3^-	Colorimetric
3	SO_4^{2-}	Turbidometry
4	K^+, Na^+, Ca^{2+}, Mg^{2+}, Fe	Atomic Absorption Spectrometry

4   Results and Discussion

The concentration of major cations and anions for all samples were obtained from the laboratory analysis. Hydrogeochemical facies of the water was produced using Piper Diagram. Results of the laboratory analysis of the water are presented in Tables 2 and 3.

4.1 Physico-Chemical Characteristics

The pH values of water samples varied from 5.0 to 6.0 with an average value of 5.6 indicative of acidic water. The pH values of the water samples fall below the World Health Organization [11] limits for drinkable water of 6.5 to 9.5 and 6.5 to 8.5 specified by Nigerian Standard for Drinking Water Quality [12]. The source of acid in the water could be contributions from dissolved carbon dioxide and organic acids (fluvic and humic acids) which are derived from decay and subsequent leaching of plants materials [13]. Confirmation of this statement can be made from the fact that the area of study is an intensive agricultural area and decay of plants materials over time could have contributed to the acidity of the water in the area. The impact of low water pH is corrosion of water carrying metal pipes which could lead to release of toxic metals such as zinc, lead, cadmium, iron and mercury.

Total dissolved solid (TDS) ranges from 36 to 129 with average of 89.88 mg/l (NSDWQ Limit; 500 mg/l). The electrical conductivity (EC) values in the water

samples average 141 mS/cm. Both parameters (EC) and (TDS) are within the 2004 (WHO and NSDWQ) limits of drinkable waters. The low values of TDS and EC could be indicative of low mineralization or the continuous recharge of the ground water aquifer with rainfall which causes dilution. Sometimes low (EC) and (TDS) can also suggest that input of salts from anthropogenic sources of pollution is minimal as was observed in the analytical results of the water samples. Figure 2 shows the relationships among the physical parameters of the water of the alluvial aquifers of River Gbako around Badeggi.

Table 2 Physical parameters in water of Badeggi area, central Bida Basin

Code	pH	EC (µS/cm)	TDS (mg/L)	T (^{o}C)
BDW2	5.73	200.00	128.00	31.01
BDW3	6.05	90.00	57.00	30.50
BDW4	5.34	57.00	36.00	30.00
BDW5	5.23	64.00	40.00	30.50
BDW6	5.56	59.00	37.00	28.00
BDW7	5.38	70.00	44.00	30.50
BDW8	5.37	90.00	57.60	30.00
BDW9	5.39	230.00	147.00	33.00
BDW10	5.64	150.00	96.00	33.00
BDW11	5.31	150.00	96.00	30.00
BDW13	5.53	170.00	108.00	27.00
BDW14	5.37	160.00	102.00	28.00
BDW15	5.02	140.00	89.00	28.00
BDW16	5.39	160.00	102.00	31.00
BDW19	5.86	120.00	76.00	28.00
BDW20	5.84	70.00	44.80	30.00
BDW21	5.58	83.00	53.11	28.00
R.Gbako	5.42	100.00	64.00	28.00
R.Mussa	5.79	280.00	179.00	31.00
Spring	5.74	300.00	192.00	28.00

Table 3 Concentration of anions and cations in water from Badeggi area, central Bida Basin (mg/l)

Code	K^+	Na^+	Ca^{2+}	Mg^{2+}	Fe	Cl^-	SO_4^{2-}	NO_3^-	PO_4^{3-}	HCO_3^-
BDW2	12.80	23.00	22.30	1.16	5.53	22.70	12.34	ND	295.93	200.00
BDW3	5.00	10.00	7.30	1.16	5.53	39.77	9.49	2.28	21.70	40.00
BDW4	37.10	43.20	42.30	1.16	5.87	69.52	24.19	ND	16.27	50.00
BDW5	47.20	50.40	38.20	1.38	5.53	83.81	28.74	ND	67.80	70.00
BDW6	45.90	52.50	34.61	1.38	5.22	25.05	8.45	ND	21.70	100.00
BDW7	5.10	7.80	45.72	1.38	5.53	25.05	8.45	0.17	32.54	110.00
BDW8	7.00	18.80	41.91	1.38	5.53	38.77	15.34	8.56	81.36	40.00
BDW9	6.90	13.40	40.34	1.62	5.53	26.42	11.18	10.2	51.53	50.00
BDW10	5.00	6.50	39.23	1.38	5.22	11.84	12.09	10.83	455.62	120.00
BDW11	4.20	13.20	36.42	1.62	5.23	17.30	25.36	12.3	299.05	190.00
BDW13	3.00	26.40	33.74	1.62	5.22	37.35	25.36	ND	168.14	120.00
BDW14	3.20	30.50	31.22	1.38	5.22	10.93	9.49	11.12	ND	200.00
BDW15	5.10	19.90	31.11	1.63	5.23	19.13	13.26	ND	21.70	100.00
BDW16	37.70	35.50	12.14	1.62	4.87	20.24	146.55	12.52	273.12	180.00
BDW19	37.70	35.50	12.15	1.82	5.23	55.22	26.66	ND	56.95	120.00
BDW20	17.20	23.00	27.02	1.63	5.23	36.44	17.04	6.53	157.30	160.00
BDW21	4.00	20.70	26.80	1.82	4.87	4.56	4.42	9.23	32.54	120.00
R.Gbako	7.40	14.60	23.94	1.82	4.87	19.13	11.70	6.24	363.41	130.00
R.Mussa	4.20	13.10	23.13	1.60	4.87	20.04	1.22	8.30	62.30	60.00
Spring	20.40	46.80	16.02	1.82	5.23	72.88	1.81	1.690	100.50	150.00

Table 4 Summary Statistic of the Parameters Analyzed in the Water of Badeggi in mg/l

	K^+	Na^+	Ca^{2+}	Mg^{2+}	Fe	Cl^-	SO_4^{2-}	NO_3^-	PO_4^{3-}	HCO_3^-
Number of samples	23	23	23	23	23	23	23	15	22	23
Minimum	2.71	6.51	7.31	1.15	4.53	4.56	1.22	0.17	16.27	30
Maximum	47.21	52.51	45.71	1.82	5.86	83.81	146.55	12.52	455.62	200
Range	44.51	46.1	38.41	0.66	1.33	79.25	145.33	12.35	439.35	170
Mean	14.27	23.27	28.94	1.52	5.24	31.65	19.68	8.12	136.72	110
Standard deviation	15.26	14.36	10.44	0.21	0.34	20.86	28.69	3.96	130.12	52.48

A

B

C

D

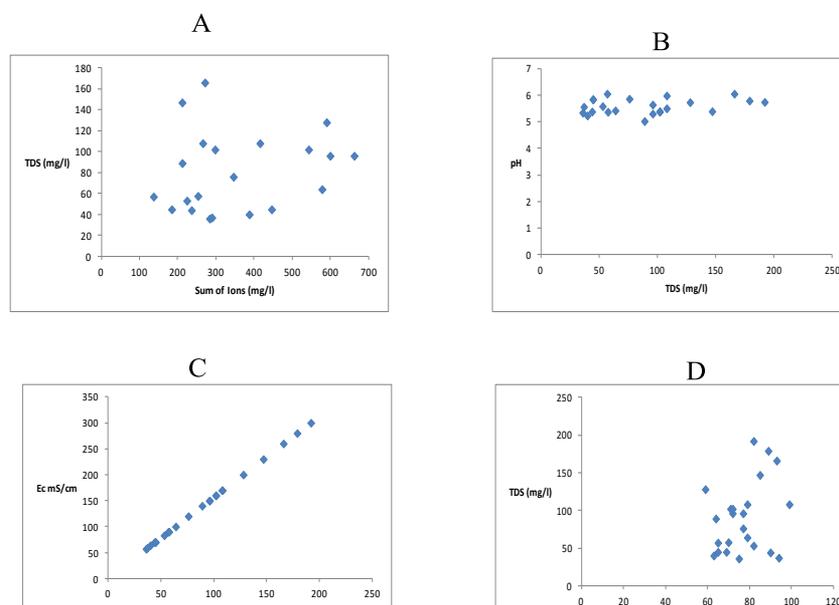Figure 2 Relationship between Physical Parameters in theWater of the Alluvial Aquifers of River Gbako. A= TDS against Sum of Ion. B=pH against TDS. C= Ec against TDS. D= TDS against Elevation.

Average temperature value of the water samples is 29.6^{o}C with minimum and maximum temperature values of 27°C and 33°C respectively. Characteristic temperature values of the water is uniformly distributed with slight variations observed in some water wells, high water temperatures was observed in most of the water wells within Badeggi township. The natural background temperature of waters in the tropics is usually between 22 to 29°C [14]. High temperature conditions for waters could encourage the growth of micro-organisms which can alter the odour, taste and colour of the water [6]. Water in the study area did not however show any questionable odour, taste or colour.

4.2 Cations in the Water

The major cations in the water sample shows sodium (Na) and Calcium (Ca) as the dominant in the water samples. The mean concentration of (Na) in the water sample is 23.3mg/l with minimum of 6.50mg/l and maximum of 52.50mg/l. Calcium (Ca) has mean concentration of 28.94mg/l with minimum and maximum concentration of 7.30mg/l and 45.70mg/l respectively. Potassium (K) minimum and maximum concentration is 2.70mg/l and 47.20mg/l respectively with mean concentration of 14.3mg/l. Magnesium (Mg) concentration averages 1.5mg/l with minimum values of 1.16mg/l and maximum value of 1.8mg/l.

The order of abundance of cations in the water is thus Ca>Na>K>Mg. The cations are distributed in the groundwater without any particular pattern, however, a decrease in concentrations of some elements towards the channels of River Gbako and River Mussa signifying active mixing of groundwater system with the Rivers Mussa and Gbako. This is confirmed by the characteristic chemistry of rivers water and that of the wells sited in the flood plains of River Gbako.

Weathering of silicate materials may also have contributed to the concentration of cations in the waters of the study area. The silicates are the chief constituents of clays and soils. Thus the cations concentration in the water were derived through this process as groundwater chemically evolves by interacting with aquifer minerals or internal mixing among different groundwater flow paths in the subsurface [1, 2].

The analysed cations are however, within the 2004 WHO limits for drinking water quality of Ca = 200 mg/l, K= 200mg/l, Mg =150 mg/l and Na = 200 mg/l respectively. The Cations (Ca, K, Na, Mg) are essential component of the water and important for human health and metabolism and should be available in normal drinking water. High concentration of these elements outside the permissible limits in groundwater can have adverse health impact on man.

4.3   Anions in the Water

The anions analyzed in the water samples are HCO_3, Cl, NO_3, PO_4, SO_4, preference was given to this analyzed anions because their high concentration in groundwater could signifies anthropogenic activities.

Nitrate (NO_3) concentration in the water samples are within the NSDWQ limits for drinkable water of 50mg/l and WHO of 45mg/l.   The sources of nitrate in the area of study can be linked to the application of fertilizer to agricultural soils in the area of study. Nolan *et al.* [15] argued that nitrate concentrations in the range of 13 to 18 mg/l are considered to indicate anthropogenic input. Wells BDW10, BDW11, BDW14, Rivers Mussa and Gbako have been observed to have concentration of NO_3 close to Nolan's standard indicative of anthropogenic input. River Mussa was observed to have high concentration of nitrate than River Gbako the reason been that River Mussa is close to the intensive agricultural area than River Gbako. More of the fertilizer is washed into River Mussa than River Gbako. Elevated concentration (>50 mg/l) of nitrate in water are an indication that the waters are at risk of pollution [16]. The levels of nitrate in water are of particular importance for use in drinking. Studies have shown that high nitrate in water can lead to blue baby syndrome or infantile methemoglobinaemia, urinary tract diseases [17]. Adelana*et al.* [18] suggested that chronic exposure to high levels of nitrate in drinking water may have adverse effects on the cardiovascular system.

The chloride concentration in the water of the study area is within the WHO and NSDWQ limits of 250mg/l. The minimum and maximum concentrations of chloride are 4.5mg/l and 83.8mg/l respectively. The sources of the chloride in the water could be contribution from atmospheric inputs from rainfall recharge or even to a large extent from agricultural activities within the area of study. The moderate concentrations of chloride in the water suggest moderate inputs of anthropogenic contribution to ground water chemistry of the area. Water with chloride in excess of drinking water standards can be used for irrigation and some types of livestock can drink water that has chloride concentration as high as 4000mg/l [6].

Sulphate (SO_4^{2-}) concentration in water of the area of study is within the 2011 WHO [19] limits of drinking water. Minimum concentration of SO_4^{2-} in the water is 1.2mg/l while the maximum concentration is 146.6mg/l. Only BDW16 shows SO_4^{2-} level above NSDWQ limits of 100mg/l. However, SO_4^{2-} occurs naturally in geologic materials (rocks, soil). In sedimentary basins highest abundance of SO_4^{2-} is in gypsum and anhydrites. The main anthropogenic source of SO_4^{2-} in the study area is input from agrochemicals applied in farming rice. Also low level of SO_4^{2-} concentration could be as a result of removal by bacteria [20].

All the water samples have shown elevated concentration of phosphate (PO_4^{3-}) beyond the Federal Ministry of Environment Effluent (FMEE) limits of 5mg/l. The minimum and maximum phosphate concentration is 16.3 and 455.6mg/l respectively. Of particular interest is in the spring water, River Gbako, River Mussa, wells BDW2, BDW10, BDW11, BDW13, BDW16, andBDW20 which exhibited high phosphate concentration. Intensive application of fertilizers in the study area is adding phosphate to the soil which gradually leaches to the underlying alluvial aquifers from which groundwater resource is exploited. Domagalski and Johnson [21] observed that long term over application of manure and chemical fertilizers can contribute to phosphorus movement into the groundwater system. Bicarbonate (HCO_3^-) concentration in the area has a minimum and maximum concentration value of 30 and 200mg/l respectively. Bicarbonate in the water could have originated from water dissolving CO_2 from the atmosphere and soil.

4.4   Hydrochemical Facies

Results of major ion chemistry of the water samples were plotted on a Piper diagram. The concentration of 8 major ions (Na^+, K^+, Mg^{2+}, Ca^{2+}, Cl^-, CO_3^{2-}, HCO_3^- and SO_4^{2-}) are represented on a trilinear diagrams by grouping the (K^+ with Na^+) and the (CO_3^{2-} with HCO_3^-), thus reducing the number of parameters for plotting to 6. On the piper diagram, the relative percentages of the cations and anions are plotted in the lower triangles, and the resulting two points are extended into the central field to represent the total ion concentration. The degree of mixing between waters can also be shown on the piper diagram. Two water types were

recognized in the area of study. They are Ca (HCO3) type and Na (HCO3) type (Figure 3).
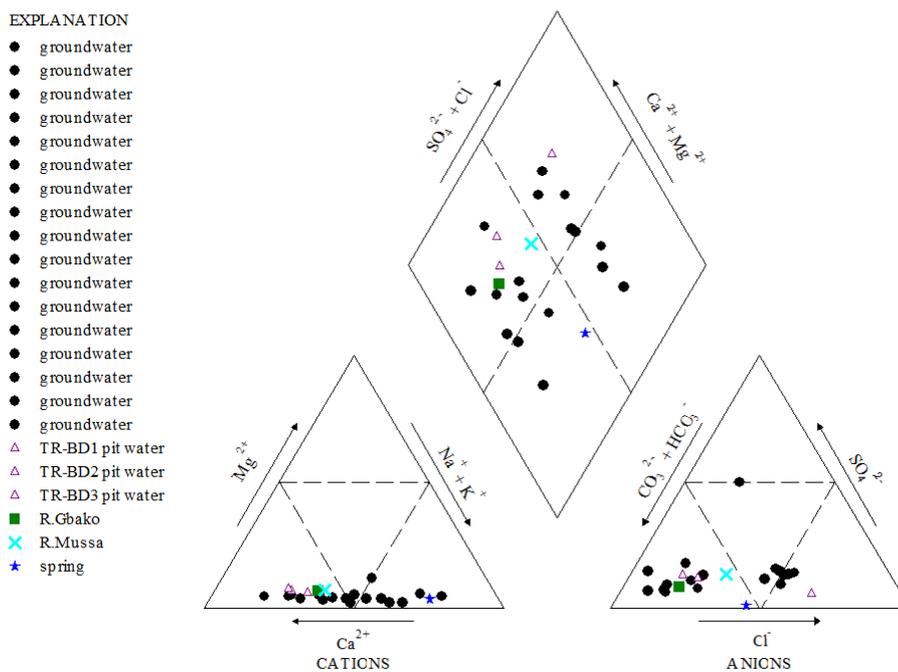

Figure 3 The Hydrochemical Facies of the Water of the Alluvial Aquifers of River Gbako.

5   Conclusion

Laboratory analysis of the water and sediments in the study area shows various chemical compositions. Generally, the water from the alluvial aquifers of Gbako River around Badeggi is acidic with pH values ranging between 5.0 and 6.0. All the cations analysed in the water were found to be within the permissible limits of WHO and NSDWQ, while their source in the water is probably mainly from natural geological process of rock weathering. Fe concentration is however high in the area with values ranging from 4.87 to 5.87 mg/l which is far above the 0.3 mg/l of permissible limits of WHO and NSDWQ. Iron is not of health concern at levels causing acceptability problems in drinking-water, but may affect acceptability of drinking water.

Anions analysed in the water are within the WHO and NSDWQ permissible limits with the exceptions of phosphate, nitrate and sulphate which were above the desirable limits, thus indicating anthropogenic contribution from agricultural practices in the area. The risks associated with consumption of water contaminated

with these contaminants are urinary track diseases, blue baby syndrome or infant methermoglobinaemia. Groundwater quality monitoring and evaluation should be carried out often in the study area to monitor the trend of contaminant mobility in the area.

References

[1] Domenico, P. A. (1972). *Concept and Models in Groundwater Hydrology*.New York,Mcgraw-Hill.

[2] Wallick, E.I., &Toth, J. (1984).The Role of Regional Gravity flow in the Chemical and Thermal Evolution of Groundwater. Proceedings of the first Canadian/American conference on hydrogeology, Bantt Salta.

[3] Kangjoo, K., Natarajan, R., Hyun, J. K., Seok, H. K., Gab, S.H., Seong T.Y...Sang, H.L. (2005). Evaluation of Geochemical Processes Affecting Groundwater Chemistry Based on Mass Balance Approach. *Geochemical Journal, 4, 301*-309.

[4] Mahmut, C., Ekiv, S., Marina, V.,Frontasyeva, T. S.,& Svetlana, D. (2006).Heavy Metal Pollution of Surface Soil in the THRACE RegionTurkey. *Environmental Monitoring and Assessment*, 119, 545-556.

[5] Ahmed, F. A. (2012). Groundwater Pollution Threats of Solid Waste Disposal in Urban Kano Nigeria.Evaluation and Protection Strategies. Unpublished PhD Thesis, University of Manchester, UK.

[6] Bakari, A. (2014). Hydrochemical Assessment of groundwater Quality in the Chad Basin around Maiduguri, Nigeria. *Journal of Geology and Mining,* 6(1), 1-12.

[7] Shekolo, P. D (1990).Development and Maintenance of Groundwater Resources Bida-Basin Case Study. A Paper Presented at International Seminar on Hydrology, Maiduguri.

[8] Olaniyan, I. O., &Oyeyemi, S. M. (2008). Geophysical exploration for groundwater potential at HayinDanmani area of Kaduna, Nigeria.*Global Journal of Engineering and Technology,* 1(4), 413-418.

[9] Polservice (1979). A Pre-drilling Hydrogeological Investigation Report, Area XVII: A Study Sponsored by Federal Ministry of Water Resources, Nigeria.

[10]APHA, (1998). Standard Methods for the Examination of Water and Waste Water (20th Ed.).Washington, DC, American Public Health Association.

[11]WHO (2004).Guidelines for Drinking Water Quality 3rdEdn 1, Recommendation, Geneva, 2004.

[12] NSDWQ NIS 544: 2007. Nigerian Standard for Drinking Water Quality. Nigerian Industrial Standard.

[13] Langmuir, D. (1997). *Aqueous Environmental Chemistry*. Upper Saddle River, Prentice Hall.

[14] Stumn, W., Morgan, J. I., (1981).*Aquatic Chemistry: an Introduction Emphasizing Chemical Equilibria in Natural Waters*. New York, Wiley Interscience.

[15] Nolan, B.T.,Hitt, K. J., Ruddy, B.C. (2002). Probability of Nitrate Concentration of Recently Recharged Groundwater in the ConterminousUnited State*. Environmental Science Technology*, 36, 2138-2145.

[16] Atabey, E. (2005). TibbiJeolojisempozyamKitabi 11.*Medical geology symposium book.*

[17] Wasik, E., Bahdziewic, Z. J, Blasszczyk, M. (2001).Removal of Nitrates from Groundwater by Hybrid Process of Biological Denitrification and Microfiltration membrane. *Process Biochem.,* 37, 57-64.

[18] Adelana, S. M., Olashehinde, P. I., &Vrbka, P. (2003).Isotope and Geochemical Characterization of Surface and Subsurface Waters in theSemi-Arid Sokoto Basin, Nigeria. *African Journal of Science Technology* 4(2), 80-89.

[19] WHO (2011). Guideline for Drinking Water Quality (4th edn), World Health Organization.

[20] Freeze, R. A., &Cherry, J. A. (1979). *Groundwater*. Eaglewood Cliffs, NJ, Prentice Hall.

[21] Domagalski, J. L., Johnson, H. (2012). Phosphorus and Groundwater: Establishing links between Agricultural Use and Transport to Streams. *U.S Geological Survey Fact Sheet* 2012-300.