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Assessment of groundwater quality using factor analysis in Mararaba-mubi area, Northeastern Nigeria

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Abstract

Analytical results of 23 water samples from surface water and groundwater reveal that the surface water is contaminated by nitrate. The mean concentration of nitrate from the surface water samples is 106 mg/l. The results further reveal that the different water sources are contaminated with respect to phosphate and coliform bacteria. Phosphate concentrations reveal a mean value of 19.6 mg/l in the surface water and a mean value of 13 mg/l in the groundwater samples. Coliform reveal an average of 9 in the surface water and an average of 25 number counts in the groundwater samples. The major fault zone in the area is responsible for the contaminant migration. Correlation between the chemical parameters reveal strong to perfect correlation, moderate and weak correlation. The correlation between coliform and chemical parameters indicates negative correlation. Principal component analysis on the chemical parameters reveals three

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factors (1, 2 and 3) that account for about 76.04% of the total variance. The plotting of the factor loadings reveals that natural mineralization, denitrification and sulphate reduction are the major processes responsible for the modification of the groundwater chemistry in the area.

Keywords: water source. Contaminant, factors, correlation, chemical parameters

1 Introduction

Animal and human wastes, the application of chemical fertilizer and manure can play a significant role in promoting the migration of pathogens and increase in nitrate concentration in surface and groundwater. High nitrate concentration in groundwater is known to cause acute condition known as ‘blue-baby syndrome’ among other health related problems (Fan and Steinberg, 1996; Townsend et al., 2003). The World Health Organization’s recommended limit of nitrate in drinking water is 45mg/l (WHO, 1984) and that drinking water should contain zero coliform while the Nigerian Standard for drinking water quality, NIS: 2007 recommend 50 mg/l. Bacteriological pollution of drinking water can lead to typhoid, dysentery, diarrhea, viral hepatitis, amoebiasis and schistosomiasis. In crystalline areas, thin surficial deposits and fractures can render groundwater vulnerable to contamination. High groundwater velocities can lead to rapid transport rates and hence widespread contaminant migration (Levison and Novakowski, 2009). The main objectives of this study are to determine the impact of agriculture on surface and groundwater quality and to identify the hydrogeochemical processes responsible in the modification of groundwater quality.

Agricultural practices could have negative impacts on surface water and groundwater in terms of the degradation in water quality especially in rural based settings. The effects of agriculture on groundwater quality had been investigated by Mawdsley et al (1995), Hamilton and Helsel (1995), Oeneme et al (1998), BÕhlke (2002), Dong-chan et al (2007), Levison and Novakoski (2009), Priyan (2009) and Rai and Dubey (2009). As groundwater flows from the recharge area towards the discharge area, modification of the groundwater chemistry occurs due to chemical reactions. Runnels (1993) revealed that as groundwater migrates from the recharge area, it becomes more saline and contains various chemical components. In rural settings characterized by intensive agricultural activities may significantly contribute to the modification of groundwater quality. These sources can be washed by surface run off into surface water which may ultimately recharge groundwater since they are hydraulically connected. Nitrogen (N) and phosphorus (P) are indispensable inputs for the sustainability of agriculture. However, nutrient losses have a number of environmental consequences. Nitrogen and phosphorus can negatively affect the quality of soils, groundwater, surface water, and the atmosphere (Schröider et al., 2004).

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2 Description of the Study Area

The study area is Mararaba-Mubi: It is located between latitudes $10^0$17’N to $10^0$21’N and longitudes $13^0$8’E to $13^0$12’E (Figure 1) and covers an area of about 56.2 Km^2. It has a population of about 3,596 (NPC, 1991). The area is accessible through the Hong-Mararaba road, Michika- Mararaba road and Maraba-Mubi road. The area is characterized by undulating topography and drained largely by Rivers

Mayo Lope and Mbawa. The area has a mean annual rainfall of 871mm and mean minimum and maximum temperatures of 14.4^{0}C and 31.9^{0}C, respectively.

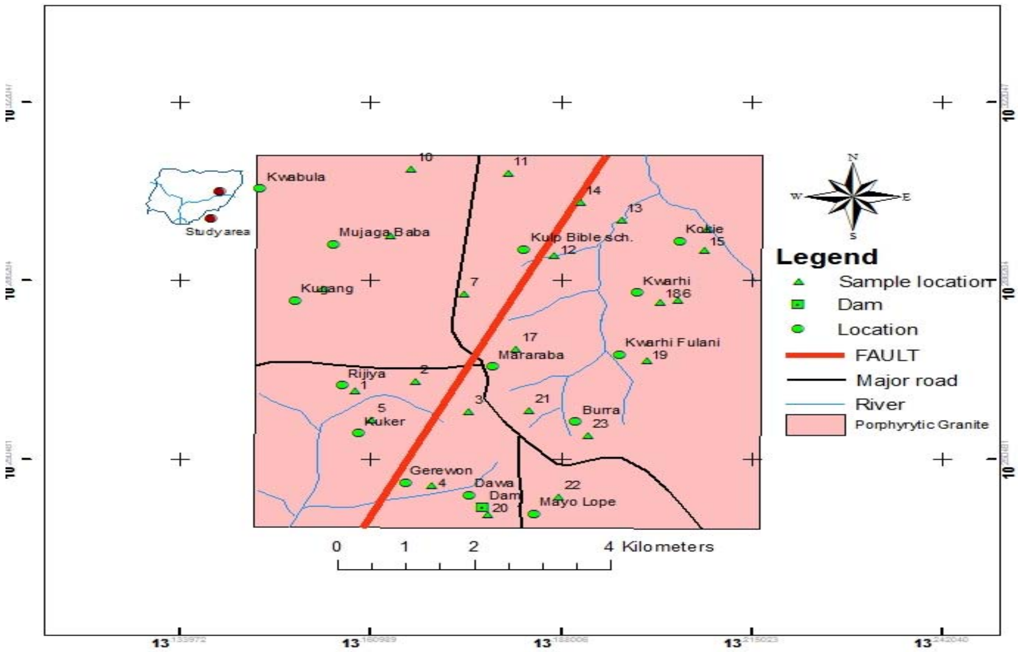

Figure 1: Geologic Map of the study area

The major occupation of the people is agriculture, and crops such as rice, maize, groundnuts and millets are grown. The land use in the area is dominantly use for agriculture and the season last for 5 months. Sources of water supply to the people are through ponds, streams, hand-dug wells and boreholes. These sources of water supplies are unreliable as the sources have been found to have questionable quality. Since farming is the major occupation of the people, chemical fertilizers such as Nitrogen Phosphorus Potassium (NPK), urea and manure are widely applied on agricultural farm lands to improve crop yield thereby compromising the quality of the water sources. The degradation of the water sources due to the anthropogenic activities does not cause any concern to the rural farmer as he is not made to be aware of the negative impacts of his actions on the sources of water supply.

2.1 Geology and Hydrogeology of the area

The study area is underlain by porphyritic granite (Figure 1). The porphyritic granite belongs to the Pan African older granites of the Nigerian basement complex (Rahman, 1988). Texturally, they are differentiated into (1) Large crystals (phenocrysts) and (2) phaneritic (coarse-grained). They consist predominantly of quartz, feldspars and mica. Rahman (1988) described the contact between the Pan African granites and the host rock as intrusive gradational and replacive while the contact between the older granite suite are both sharp intrusive and also intrusive gradational. It has also been recognized by Oluyide (1988) that the Pan Africa granites are characterized by distinctive layering which are normally aligned parallel to north-north easterly basement lineaments. The major deformational feature across the study area is a NE-SW trending fault which runs from Madagali in the NE to Wuro Sambo in Girei in the SW. The NE-SW sets are probably strike slip faults, with the north easterly one displaying dextral sence of movement. These faults have been interpreted by Oluyide (1988) as resulting from transcurrent movements. The major fault cut across Kulp Bible College, Mararaba and Gerewan areas. The yields of boreholes in the area could not be obtained due to lack of borehole data. However, borehole yields in the area can also be comparable to borehole yields in the basement complex areas of Nigeria. According to Offodile (2002) borehole yields in the Nigerian basement complex rocks range from 1 l/s to 2 l/s, and up to 4l/s in fractured zones. Figure 2 reveals that groundwater flow, occurs from Kuker and Pilefu in the SW and flows toward the LCCN Church, and also flows from Kwarhi Pri. Sch. towards LCCN Church and Gurva Yashi in the NW. Other flow zones occur from Mayo Lope and Burra in the SE and flows toward the LCCN Church. Groundwater flow also takes place from Mararaba and Kworhi areas and flows toward the Bible School and Wuro Ardo areas. The major discharge area covers the LCCN, Bible College and Wuro Ardo areas. It can be observed from the position of the major fault in the area (Figure 1) that the regional groundwater flow is towards the fault zone. This implies that the fault zone in the area is the major source of groundwater recharge. It can also be deduced from the fault zone that stream flow in the area is structurally controlled as the rivers/streams aligned parallel to the fault zone.

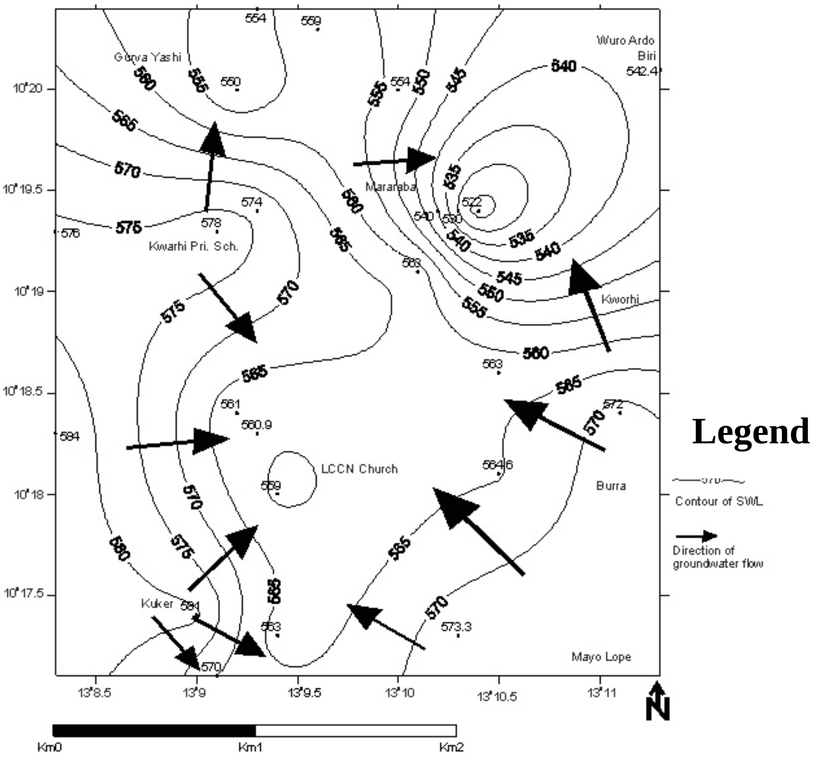

Figure 2: Hydraulic head distribution in weathered overburden aquifer

3 Method of Investigation

A total of Twenty three (23) water samples were collected for this investigation in rainy season period (Figure 1) with 14 samples collected from hand-dug wells, 7 samples from boreholes and 2 samples were collected from the surface water bodies. The plastic containers used for the collection of the water samples were rinsed with the samples to be collected according to Barcelona et al (1985) method.

Water samples were collected from the discharge of existing hand-dug wells and boreholes according to Chilton (1992) method. Field parameters such as electrical conductivity (Ec), TDS and pH were determined in the field using digital conductivity meter (HACH KIT) (Model 44600) for Ec and TDS while pH was determined using HANNA pH meter (Model HI 28129). The samples were analyzed chemically using HACH spectrophotometer (Model DR/2400, USA) and titrimetric method using digital titrator (HACH) (Model 16900). The chemical parameters analysed include TH, Na^+, K^+, Ca^{2+}, Mg^{2+}, HCO_3^-, SiO_2 and PO_4^-. Bacteriological analysis was carried out using membrane filtration method according to WHO (1985). The analyses were carried out at the laboratories of Adamawa State Water Board, Yola and Department of Microbiology, Federal University of Technology, Yola laboratories. All the samples for chemical analysis were carried out within 48 hours of collection while samples for bacteriological analysis were carried out within 24 hours of collection. However, it was not possible for some samples to be analyzed within 24 hours of collection due to logistic problems. The samples were store in refrigerator and were analyzed within 48 hours. The sample containers used for the collection of samples for bacteriological analysis were sterilized for 15 hours in an autoclave. Depths to water levels were measured from hand-dug wells and boreholes using water level sounder for the purpose of constructing the hydraulic head distribution in the area. The geologic map of the study area scanned and imported into Arc GIS version 9.2 and was georeferenced and digitized. Surfer 7.0 was used to create grid-based maps for nitrate concentrations, coliform and hydraulic head fields.

3.1 Multivariate statistical analysis

The principal component analysis (PCA) is a multivariate statistical technique employed for the purpose of data reduction with a view to determining the sources of elements and their controlling factors. The PCA depends upon the fact that the variables in a data set are usually partially-to-strongly correlated and it transforms that data set into an uncorrelated one; define by a new set of variables- the principal components. The first principal component is such that the projections of the given points onto it have maximum variance, the second principal component has the variance subject to being orthogonal to the first; the third principal component has the maximum variance subject to being orthogonal to the first and second components and so on (Hotelling, 1933, Gnanadesikan, 1977). The multivariate statistical technique therefore relates variables into principal associations (factors) based on their mutual correlation coefficients and these associations may be interpreted in terms of mineralization, lithology and environmental processes (Nton et al., 2007). The application of the analysis has proved useful in the interpretation of hydrogeological data as revealed by many workers such as Bakalowiez, 1994; Aruga et al., 1995; Elueze et al., 2001). The multivariate analysis was carried out using the statistical package for Social Sciences Software (SPSS).

4 Results

Table 1 indicates that Ec values reveal average of 293.4µS/cm for surface water and average of 260.7 mg/l for groundwater samples.

TDS reveal mean values for both surface water and groundwater as 188 mg/l and 172.3 mg/l, respectively. TH reveals mean values for both surface water and groundwater as 84.8 mg/l and 89.3 mg/l, respectively. pH values reveal average of 7.3 for surface water samples and a mean value of 7.1 for the groundwater samples. The results of the cations indicate that sodium, potassium, calcium and magnesium mean values of 34.8 mg/l, 10 mg/l, 49.9 mg/l and 34.8 mg/l for surface water samples. In the groundwater samples, the cations reveal mean values of 38 mg/l, 4.9 mg/l, 49.3 mg/l and 37.9 mg/l, respectively. The results of the anions indicate that sulphate indicate average of 34.8 mg/l, chloride 49.9 mg/l and bicarbonate 231.5 mg/l for surface water samples. In the groundwater samples, the anions reveal average values of 20.4 mg/l, 43.4 mg/l and 227.7 mg/l respectively.

Table 1: Summary of physical, chemical and bacteriological data from the study area

	Gw		Sw					
Parameters	Range	Mean	Range	Mean	Over all range	Over all mean	WHO (1993)	NIS:554:2007
Ec	75.5-550	260.7	75-490	282.5	75-550	262.6	1500	1000
TDS	50-366	172.3	50-326	188	50-366	173.7	1000	500
pH	6.5-7.7	7.1	7.2-7.5	7.3	6.5-7.7	7.1	6.5-9	6.5-8.5
Sulphate	12-36.3	20.4	31.8-37.8	34.8	12-37.8	22	400	100
Chloride	16.7-81.8	43.4	10.7-89	49.9	10.7-89	44	200	250
Nitrate	20.9-69.7	44.1	106	106	20.9-106	49.5	45	50
Coliform	3-90	25	7-10	9	3-90	23	0-3	10
TH	59.6-163	89.3	47.6-122	84.8	47.6-163	88.9	500	150
Sodium	24.8-79	38	18.9-50.6	34.8	18.9-79	37.7	200	200
Potassium	3-8.9	4.9	9.9-10	10	3-10	5.4	200	
Calcium	29.8-86.4	49.3	28.6-71.1	49.9	28.6-86.4	49.3	200	
Magnesium	24.8-79	37.9	18.9-50.6	34.8	18.9-79	37.7	150	
Bicarbonate	112-402	227.7	103-360	231.5	103-402	228	600	
Carbonate	1-5	2.5	6.4-7	6.7	1-7	3		
Silica	1.1-16.6	7.5	2-12.4	7.2	1.1-16.6	7.4	60*	
Phosphate	6.9-19.9	13	19.1-20	19.6	6.9-20	13.6	10*	

Ec= Electrical conductivity, TDS=Total dissolved solids, TH= Total hardness

*WHO, 1998, NIS= Nigerian Industrial Standard.

Nitrate concentrations in the surface water bodies gave values of 106 mg/l each. Coliform number counts in the groundwater samples gave average values of 9 and 25 for surface water. Phosphate concentrations in surface water and groundwater gave averages of 19.6 mg/l and 13 mg/l, respectively. The total hardness of the surface water samples has an average of 84.8 mg/l while the groundwater samples reveal average of 89.3 mg/l. The surface water samples reveal average silica concentrations of 7.2 mg/l and 7.5 mg/l for groundwater samples.

5 Discussion of Results

The mean values of the physical parameters reveal that Ec, TDS, TH and pH from the surface water and groundwater are below WHO maximum permissible limit and NIS: 554 standard limit. The mean concentration values of the cations are also below the maximum permissible limit of WHO and NIS: 554 standard limit. The anions mean concentration values also fall below the WHO maximum permissible limit and NIS: 554 standard limit. Nitrate concentrations from the surface water bodies exceeded the maximum permissible limit and NIS: 554 standard limit while nitrate concentrations from the groundwater samples are below the WHO maximum permissible limit and NIS: 554 standard limit

The high nitrate concentrations in the surface water bodies could be associated with the use of chemical fertilizers notably the NPK fertilizer, use of manures on agricultural farm lands and decomposition of organic matter. These sources of plant nutrients are washed into the surface water bodies from the surrounding agricultural farm lands. The water from the different sources is contaminated with respect to coliform. According to WHO (1993), drinking water should contain zero coliform. The sources of coliform could be associated with animal and human wastes. The water from the different sources also reveals phosphate contamination as the mean values exceeded the WHO maximum permissible limit. The high concentration of phosphate could be associated with the use of NPK fertilizer and organic decomposition. The surface water quality in the area has been affected by phosphate, nitrate and coliform bacterial contamination while the groundwater quality is affected by phosphate and coliform bacterial contamination. These sources of contamination could be as a result of the application of chemical fertilizer, manures and sewage effluent. The surface water is most affected by nitrate contamination which could be responsible for the elevated concentrations of Ec and TDS over the groundwater values. Figure 3 indicates that the nitrate plumes are associated with surface water. Both plumes are located at Awa Dam and River Mbawa, and reveal concentrations of 106 mg/l. The Awa Dam is a locally constructed Dam use to supply water to animals. Hence, the geological, geotechnical and engineering factors were not considered in the construction of the Dam. The high nitrate concentration in the Dam is an indication of inflow of surface water containing chemical fertilizers and manures applied on farm lands. Figure 3 shows that the nitrate plume flows down gradient with the plume decreasing in concentration to about 70 mg/l at Matakom. This shows that people living around the Dam area down to Matakom may consume water of high nitrate concentration. At the River Mbawa, the plume decreases in concentration towards the Matakom area. The Awa Dam and River Mbawa are sources of groundwater recharge in the area and therefore may impact high nitrate into groundwater considering the crystalline nature of the area characterize by fractures and thin overburden in some places. Figure 4 shows coliform distribution with the major plume occurring at Pilefu. This plume appears to be located in the recharge zone (Figure 2) and this decreases down gradient into a small plume having coliform number counts of 15 towards the western portion of the study area. The second plume occurs at Kwarhi Pri. Sch. having coliform number counts of 70. This appears to be located in the discharge zone (Figure 2), and could represent the infiltration of recharged surface water characterized by high coliforms probably derived from the use of manures and sewage from homes. Figure 2 reveal that groundwater flow occurs towards the northeastern part and therefore the coliform plume flows down gradient and decreases to a small plume having coliform number counts of 5 located between Mararaba and Kworhi areas. Concentrations of calcium, potassium, sulphate, nitrate and chloride have also been elevated which could be due to application of potash and nitrogen-based fertilizers (NPK).

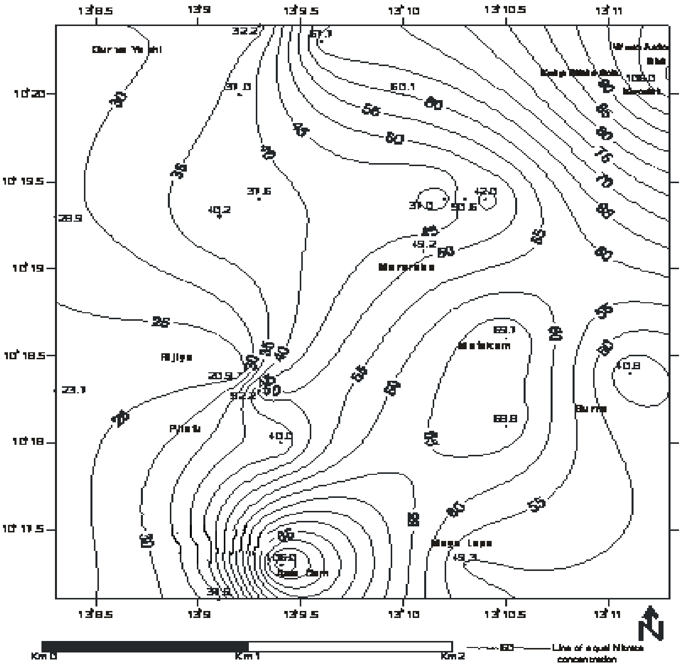

Figure 3: Nitrate distribution in the study area

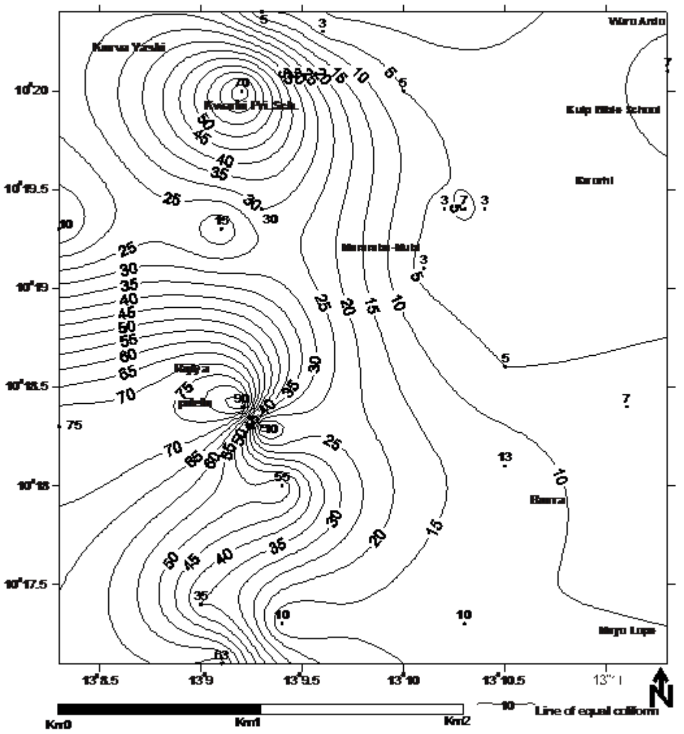

Figure 4: Distribution of coliform in the study area

The elevated concentrations of chloride, sulphate and nitate could also be linked to the dissolution of salts of Cl, NO_3 and SO_4 incorporated in the commercial fertilizers. The mean concentration of silica from the different water sources also fall below the WHO (1998) standard limit.

5.1 Correlation analysis

Fifty four parameters were correlated and the results are shown in Table 2. For example, the following parameters TH and EC, TH and TDS have strong correlation coefficient ranging 0.859 to 0.862. According to Adams et al (2001), Samples showing correlation coefficients of $r>0.7$ are considered to be strongly correlated, where as $r>0.5$-0.7 shows moderate correlation. The strong to perfect correlation between the chemical parameters is an indication of common source.

5.2 Identification of hydrogeochemical processes

Principal component analysis on chemical data shows three factors which explain about 76.04% of the total variance (Table 3). Principal component analysis has been widely applied in the interpretation of hydrogeochemical data (Evans et al., 1996; Cameron, 1996; Adams et al., 2001). For factor loadings, a high loading was defined as greater than 0.75, and a moderate loading was defined as 0.40-0.75.

Loadings of less than 0.40 were considered insignificant (Evans et al., 1996). The three factors are 1, 2 and 3.

Factor 1 account for about 51.99% of total variance and is characterized by moderate to high loadings. Ec, TDS, TH, Na, Mg, NO_3 and Ca have high loadings while pH, sulphate, chloride, bicarbonate, SiO_2 and phosphate have moderate loadings.

Table 2: Results of correlation analysis of groundwater quality data in the study area

Parameters	Correlation coefficient	Correlation strength
TDS and pH	0.501	Moderate
TDS and Cl	0.542	Moderate
Cl and Ec	0.558	Moderate
Cl and TDS	0.542	Moderate
NO_3 and Ec	0.702	Moderate
NO_3 and pH	0.748	Moderate
NO_3 and Cl	0.565	Moderate
Coliform and pH	-0.649	Negative
Coliform and NO_3	-0.589	Negative
TH and Ec	0.859	Strong
TH and TDS	0.862	Strong
TH and pH	0.616	Moderate
TH and SO_4	0.494	Weak
TH and Cl	0.531	Moderate
TH and NO_3	0.544	Moderate
Na and Ec	0.661	Moderate
Na and TDS	0.656	Moderate
Na and pH	0.441	Weak
Na and Cl	0.475	Weak
K and NO_3	0.562	Moderate
Ca and Ec	0.865	Strong
Ca and TDS	0.871	Strong
Ca and pH	0.597	Moderate
Ca and SO_4	0.481	Weak
Ca and Cl	0.641	Moderate
Ca and NO_3	0.583	Moderate
Mg and Ec	0.660	Moderate
Mg and TDS	0.658	Moderate
Mg and pH	0.443	Weak
Mg and Cl	0.475	Weak
HCO_3 and Ec	0.509	Moderate
HCO_3 and TDS	0.527	Moderate
HCO_3 and pH	0.730	Moderate
HCO_3 and SO_4	0.571	Moderate
HCO_3 and NO_3	0.682	Moderate
SiO_2 and Ec	0.571	Moderate
SiO_2 and TDS	0.566	Moderate
SiO_2 and Cl	0.592	Moderate
PO_4 and Cl	0.489	Weak
PO_4 and NO_3	0.561	Moderate
Na and TH	0.890	Strong
Ca and TH	0.933	Strong
Ca and Na	0.744	Moderate
Mg and TH	0.890	Strong
Mg and Na	1.000	Perfect
Mg and Ca	0.743	Moderate
HCO_3 and Coliform	-0.460	Negative
HCO_3 and TH	0.566	Moderate
HCO_3 and Ca	0.593	Moderate

SiO_2 and TH	0.495	Weak
SiO_2 and Ca	0.546	Moderate
SiO_2 and HCO_3	0.533	Moderate
PO_4 and K	0.571	Moderate

Perfect 1 Strong 7 Moderate 34 Weak 8 Negative 3

Ec and TDS have loadings of 0.900 and 0.905, and control the overall mineralization while TH having a loading of 0.924 is controlled by availability of Ca and Mg. Ca having a loading of 0.925, and the high loading may be attributed to its abundance in the earth crust or as the byproduct of the weathering of feldspars, amphibole and pyroxenes. Nitrate having a loading of 0.773 could be associated with anthropogenic activities.

Table 3: Eigen values, percentage of variance explained and cumulative variance of principal components (PCs)

Parameters	Component		
	1	2	3
Ec	.900	-.066	.133
TDS	.905	-.059	.103
pH	.721	.202	-.405
Sulphate	.495	-.207	-.647
Chloride	.688	.132	.353
Nitrate	.773	.541	-.069
Coliform	-.580	-.264	.363
TH	.924	-.326	.033
Sodium	.757	-.503	.225
Potassium	.164	.791	.193
Calcium	.925	-.165	.072
Magnesium	.757	-.503	.224
Bicarbonate	.714	.235	-.457
Silica	.636	.059	.169
Phosphate	.450	.643	.378
Eigen value	7.80	2.21	1.40
% variance explained	51.99	14.74	9.31
% cumulative	51.99	66.73	76.04

Sodium and magnesium each have loading of 0.757 and sodium could be derived from the weathering of plagioclase feldspar, atmospheric dust washed by rain water and also through cation exchange process while magnesium is derived from the weathering of mafic minerals. Chloride has a loading of 0.688, and it is derived from anthropogenic sources or the source of chloride in the area could be from water trapped during magmatic activities (Juvenile water). pH, Silica and bicarbonate have loadings of 0.721, 0.636 and 0.714 respectively.

Silica represents the building block of rock forming minerals while the source of bicarbonate can be attributed to CO_2 charge recharge water (Tijani, 1994). The moderate loading of pH, SiO_2 and HCO_3 is related to natural mineralization. Among the cations, calcium has the highest loading followed by sodium and magnesium having equal loadings. Among the anions, bicarbonate has the highest loading. Considering the order of loadings of the ions, the groundwater in the area can be classified as Ca-HCO_3. Factor 1 also shows moderate loading with respect to phosphate and sulphate having loadings of 0.450 and 0.495 respectively. The possible sources of these contaminants in the area could be anthropogenic. The moderate loading of phosphate corresponds to correlation between measured concentrations of nitrate and phosphate ($r=0.561$).The possible sources of these contaminants could be from organic decomposition such as household solid wastes, animal and human wastes. Factor 1 also showed negative loading with respect to coliform of -0.580, which shows that coliform is not influenced by some of the contaminants that belong to the same factor such as phosphate, sulphate, chloride and nitrate. This is also buttressed by the correlation between measured coliform and NO_3 concentration ($r=-0.589$). Coliform however did not show any form of correlation between Cl and PO_4. Possible source of coliform could have been derived from sewage effluent and organic decomposition.

Factor 2 accounts for about 14.74% of the total variance. This factor revealed that potassium has high loading of 0.791; nitrate and phosphate have moderate loadings of 0.541 and 0.643. Sodium and magnesium however have equal negative loadings of -0.503. This is an indication that sodium and magnesium do not have effect on this factor. Sodium and magnesium revealed a perfect correlation between the measured sodium concentration and magnesium (r=1.000) (Table 3) which is an indication of a common origin. Factor 2 appeared to be related to contamination from agricultural inputs following the use of chemical fertilizers such as NPK, potash and manures. It represents a diffuse form of contamination. Correlation between the measured concentrations of nitrate, potassium and phosphate revealed positive correlation between NO_3 and K(r=0.562), and PO_4 and NO_3 (r=0.561). These positive correlations are indications of common source that is related to the application of NPK fertilizer.

Factor 3 accounts for about 9.31% of the total variance. This factor indicated negative loadings with respect to pH (-0.405), SO_4 (-0.647) and HCO_3 (-0.457). SO_4 and HCO_3 can result from the decomposition of organic matter based on the fact that sources of SO_4 such as gypsum and anhydrite may be unlikely in the area. Consequently these sources may be derived from the decomposition of waste materials. This underlying relationship is also indicated by the correlation of measured concentrations of HCO_3 and SO_4 (r=0.571), and HCO_3 and pH (r=0.730) which is an indication of common source. The negative loading of pH is apparently associated with SO_4 and HCO_3 due to organic decomposition, and the negative loadings of SO_4 and HCO_3 could be explained by the chemical reduction of SO_4 to H_2S while HCO_3 is increased. Factor 3 can therefore be ascribed as sulphate reduction. According to Wu and Weng (1988), SO_4 in groundwater could be reduced to H_2S during degradation of organics. Thus, the stronger the reducibility of the environment, the lower the concentration of SO_4, and then the more the concentration of HCO_3 will increase (Wen and Qin, 2007). The plots of factor loadings (Figures 5 and 6) illustrated these three factors. Figure 5 shows denitrification process and sulphate reduction. Figure 6 shows denitrification process and natural mineralization. In both cases, nitrate seemed to lag behind potassium and phosphate; this could be attributed to denitrification process.

Denitrification processes are as following:

$$^{4}/_{5}NO^{-}_{3} + CH_2O \rightarrow {}^{2}/_{5}N_2 + HCO_3^{-} + {}^{1}/_{5}H^{+}\,{}^{2}/_{5}H_2O \qquad (3)$$

According to Rodvang and Simpkins (2001), denitrification requires: (1) the presence of denitrifying bacteria; (2) the near absence of oxygen; and (3) an electron donor. Rodvan (2001) went further to state that heterotrophic denitrification uses organic carbon as an electron donor.

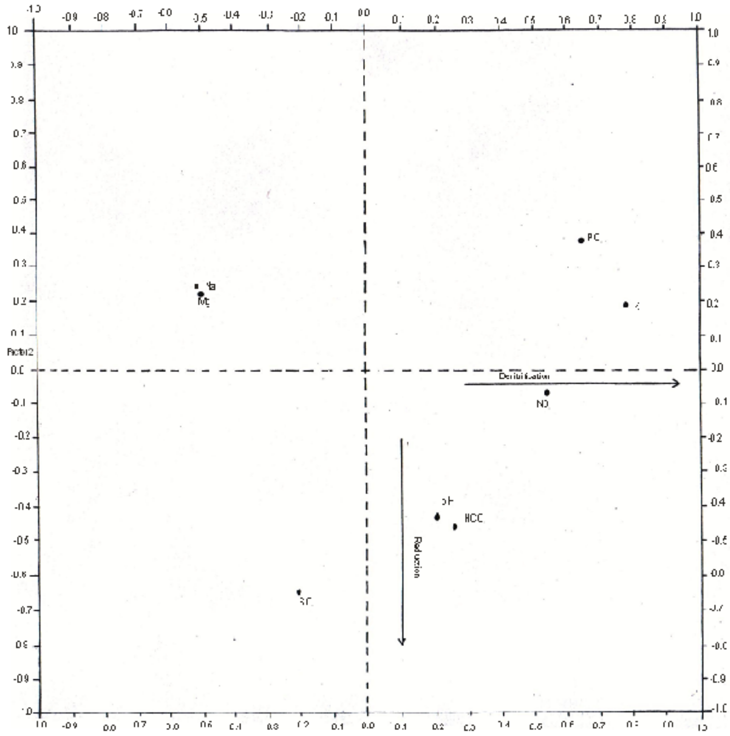

Figure 5: Factor loading diagram for factor 2 versus factor 3

It can be summarized from the fore going that;

1. Factor 1 consists of EC, TDS, TH, Na, Mg, NO_3, Ca, PH, SO_4, Cl^-, HCO_3^-, SiO_2 and PO_4. The factor is characterized by the highest loading with respect to Ca and moderate loading with respect to pH, SiO_2 and HCO_3^-.

This factor appears to be related to natural mineralization processes accompanied by increased Ca and alkalinity.

2. Factor 2 is characterized by highest loading with respect to K and moderate loading with respect to NO^-_3 and PO^-_4. This factor appears to be related to agricultural diffused form of contamination and is controlled by denitrification process.
3. Factor 3 is characterized by negative loadings with respect to pH, SO^{2-}_4 and HCO^-_3. This factor appears to be influenced by sulphate reduction processes.

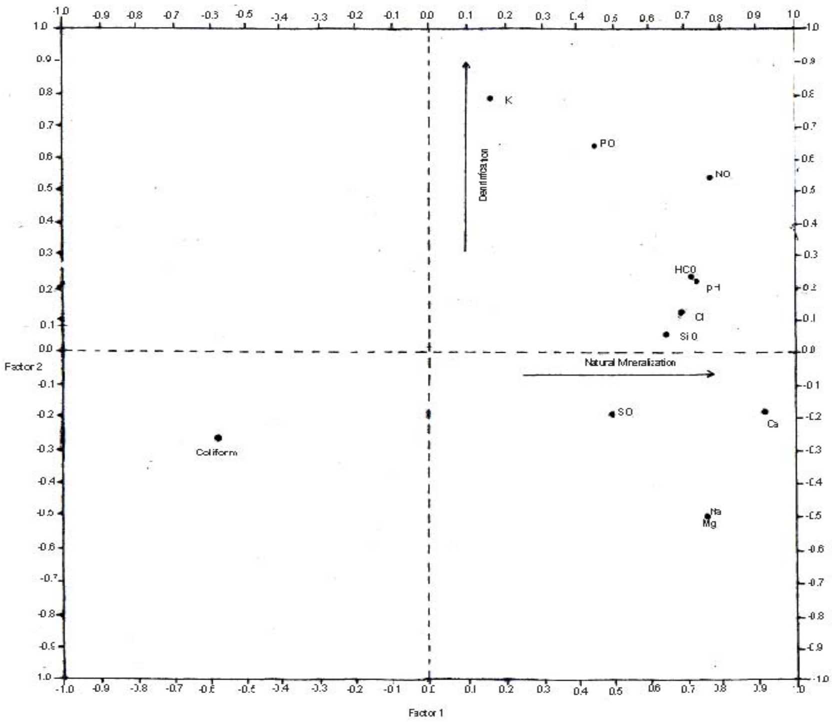

Figure 6: Factor loading diagram for factor 1 versus factor 2

6 Conclusion

The following conclusions can be drawn from this study:

1. Correlation of chemical data and WHO and NIS 554 standard limits indicated that the surface water is characterized by high concentration of nitrate which could be associated with the use of potash and nitrogen-based fertilizers (NPK), use of manures on agricultural farm lands and decomposition of organic matter.
2. The water from the different sources is also contaminated with respect to coliform bacteria and phosphate which could be associated with animal, human wastes, and use of chemical fertilizers (NPK).
3. The major fault in the area is responsible for the contaminant migration.
4. Correlation between the chemical parameters indicated strong to perfect correlation, moderate and weak correlation which is an indication of common source.
5. The correlation between coliform bacteria and some of the chemical parameters indicated negative correlation which is an indication that they are from different sources.
6. Principal component analysis on the chemical data revealed factors 1, 2 and 3 that explain about 76.04% of the total variance.
7. The plots of the factor loadings revealed natural mineralization, denitrification, sulphate reduction processes as being responsible for the modification of groundwater chemistry.
8. Controlled fertilizer application and manures on agricultural farm lands, and controlled waste disposal practice can minimize surface water and groundwater quality degradation in the area.

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