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Full Length Research Paper

Assessment of groundwater quality using water quality index and GIS in Jada, northeastern Nigeria

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Assessment of groundwater quality using WQI and GIS was carried out in Jada area. The results of 11 physic-chemical parameters were used for the calculation of WQI. The results indicated that WQI values ranged from 15-43, and thus indicated well to very good groundwater quality status. The geographical information system using the Inverse Distance Weighted method (IDW) delineated two groundwater quality zones into good and very good potential areas. The hierarchal cluster analysis identified anthropogenic contamination, natural mineralization, reverse cation exchange and cation exchange as the major processes controlling groundwater chemistry. It is recommended that regular groundwater quality monitoring should be encouraged as a strategy towards groundwater quality protection and conservation.

Keywords: WQI, GIS, cluster analysis, anthropogenic contamination, natural mineralization.

INTRODUCTION

The determination of groundwater quality for human consumption is important for the well being of the ever-increasing population (Ishaku, 2011). The supply of good quality water is one of the important component of groundwater protection and conservation strategies and therefore useful in the planning and management of groundwater. Groundwater quality depends on the quality of recharged water, atmospheric precipitation, inland surface water and subsurface geochemical processes (Reza and Singh, 2010; Vasanthavigar et al., 2010). The authors further stressed that temporal changes in the origin and constitution of the recharged water, hydrologic and human factors may cause periodic change in groundwater quality. Water pollution not only affects water quality but also threatens human health, economic development, and social prosperity (Milovanovic, 2007). Hence, evaluation of groundwater quality status for human consumption is important for socio-economic growth and development and also to establish data base for planning future water resource development strategies.

Water Quality Index (WQI) is an important technique for demarcating groundwater quality and its suitability for drinking purposes (Tiwari and Mishra, 1985). Assessment of groundwater quality through Water Quality Index (WQI) studies and spatial distribution of WQI utilizing GIS technology could be useful for policy makers to take remedial measures. GIS can be powerful tool for developing solutions for water resources problems to assess in water quality, determining water availability, understanding the natural environment on a local and/or regional scale (Swarna and Nageswara Rao, 2010). The geographical information system and WQI, which synthesizes different available water quality data into an easily understood format, provide a way to summarize overall water quality conditions that can be clearly communicated to policy markers (Strivastava et al., 2011).Therefore this study is focused on the results of physic-chemical analysis of various parameters for domestic use and development of WQI, and mapping of their spatial distribution using GIS techniques. The study is also aimed at determining the major processes controlling groundwater chemistry.

Description of the study area

The study area is Jada and environs; it is located between latitudes 8°43'N to 8°47'N and longitudes 12°06'E to 12°12'E (Figure 1), and covers an area of

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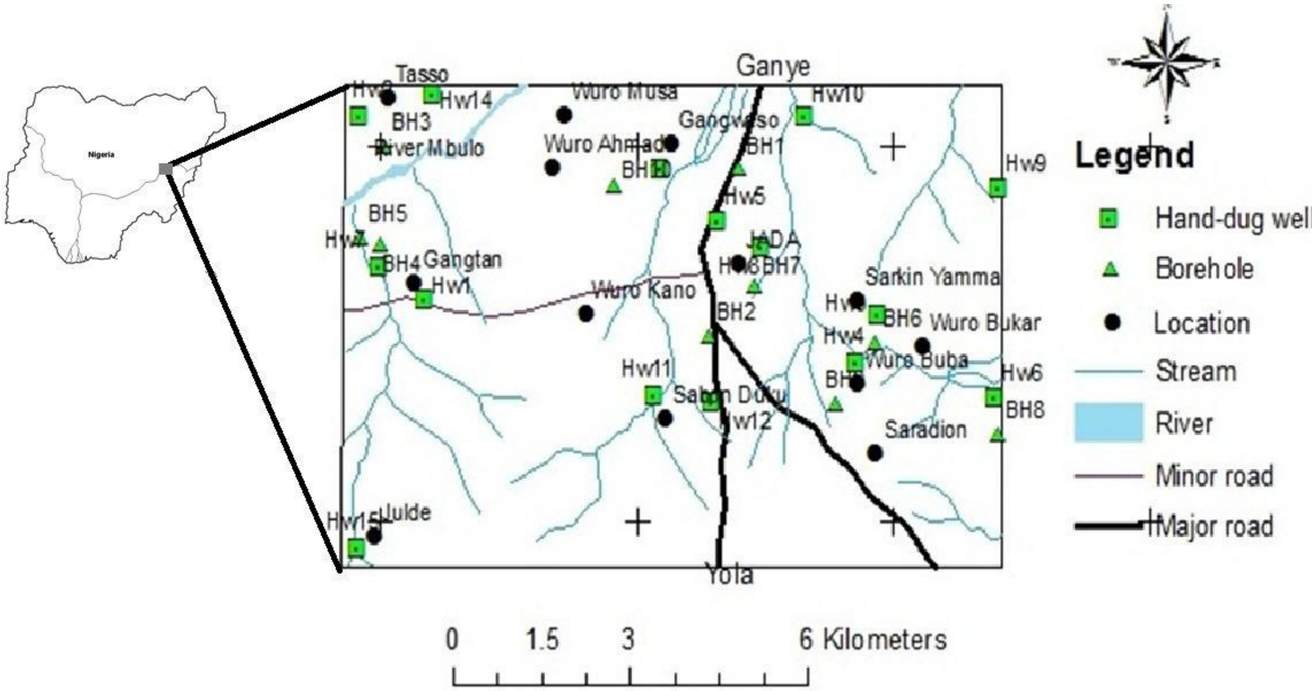

Figure 1. Map of the study area showing sampling points

about 92Km^2. The area is characterized by dry and rainy seasons. The rainy season commences in April and ends late October. The average rainfall is about 1750 mm, and mean annual evapo-transpiration of about 1200mm (Ogunbajo, 1978), and mean minimum and maximum temperatures of 15.2^{o}C and 39.7^{o}C (Adamawa State Diary, 2007). The major occupation of the people is agriculture and the area is characterized by rural setting. Sources of water supply are from hand-dug wells, shallow boreholes and streams. These sources of water supply are unreliable as the quality of the water is poor coupled with poor sanitary conditions. The type of waste disposal practice in the area is the open dump waste disposal system for household solid waste, and most residents use pit latrines. The main objectives of the present study involve analysis of water samples for physic-chemical parameters and development of Water Quality Index, and mapping of their spatial distribution using GIS techniques. The study is also aimed at determining the processes responsible for controlling groundwater chemistry. The area is underlain by the Precambrian Basement Complex rocks, and consists of the older granites, gneiss and mylonites (Figure 2). The older granites cover extensive parts of the study area such as Julde, SabonDuku, Wuro Buka and Wuro Musa areas. The gneissic rocks occur in the northwestern part, and underlie Gangton and Neso areas. The mylonite covers a small section of the area and covers the central portion of the study area. Analysis of borehole lithologic section revealed two aquifer system; these are the weathered overburden aquifer with thickness ranging from 6 m to 15 m with an average of 9 m and fractured basement aquifer having thickness ranging from 3 m to 18 m with an average of 12 m (Abubakar, 2010). Figure 3 indicates pockets of flow zones occurring in the study area. Groundwater flow takes place towards the northern part of the study area, and towards the northwestern and southern parts, respectively. Other flow zones take place from the recharge zones located around Saradion and extend towards the northern part of Wuro Buba. From the recharge zones groundwater flows towards Wuro Bukar and Sarkin Yamma, and flows toward Wuro Kano areas, respectively. The discharge areas include Wuro Musa and Tasso areas in the northwestern part and Wuro Kano in the central part of the study area.

MATERIALS AND METHODS

25 water samples were collected from the different water sources ten (10) samples from boreholes and fifteen (15) from hand-dug wells. The positions of the different water sources were determined using GPS. Before the collection of the samples, field parameters such as pH, EC and TDS 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). Bicarbonate was also determined in the field by titration using Sexana (1990) method. The samples were analyzed chemically using HACH spectrophotometer (Model DR/2400, USA). The samples for chemical analysis were carried out within 48 hours of

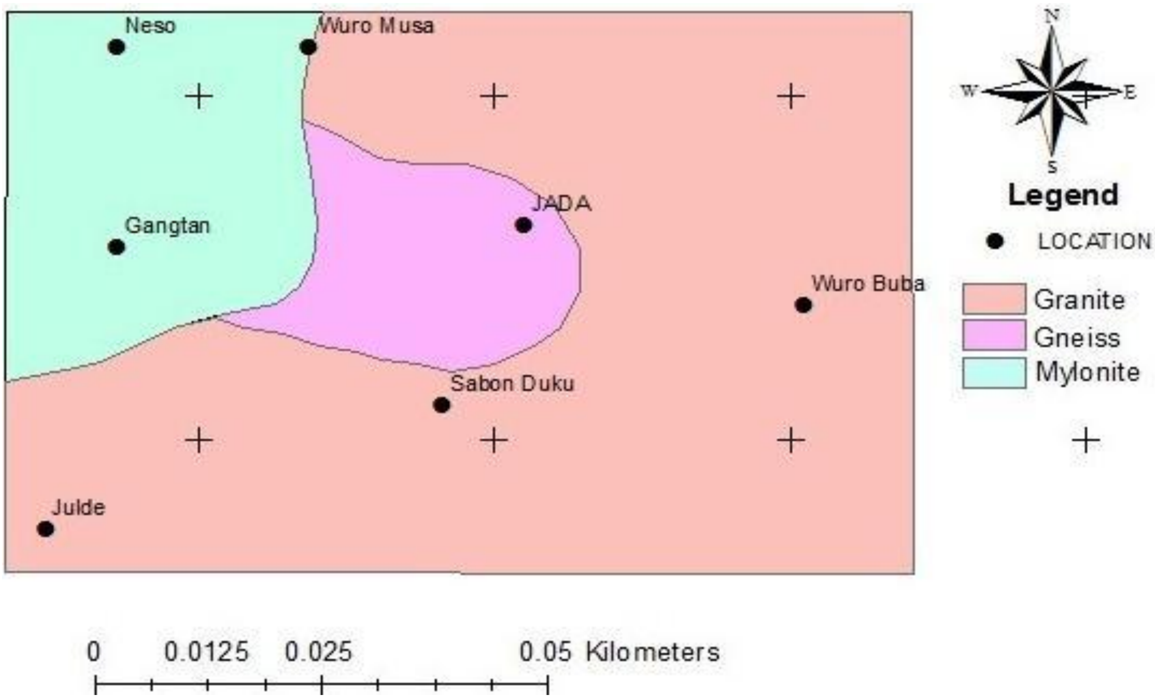

Figure 2. Geologic map of the study area

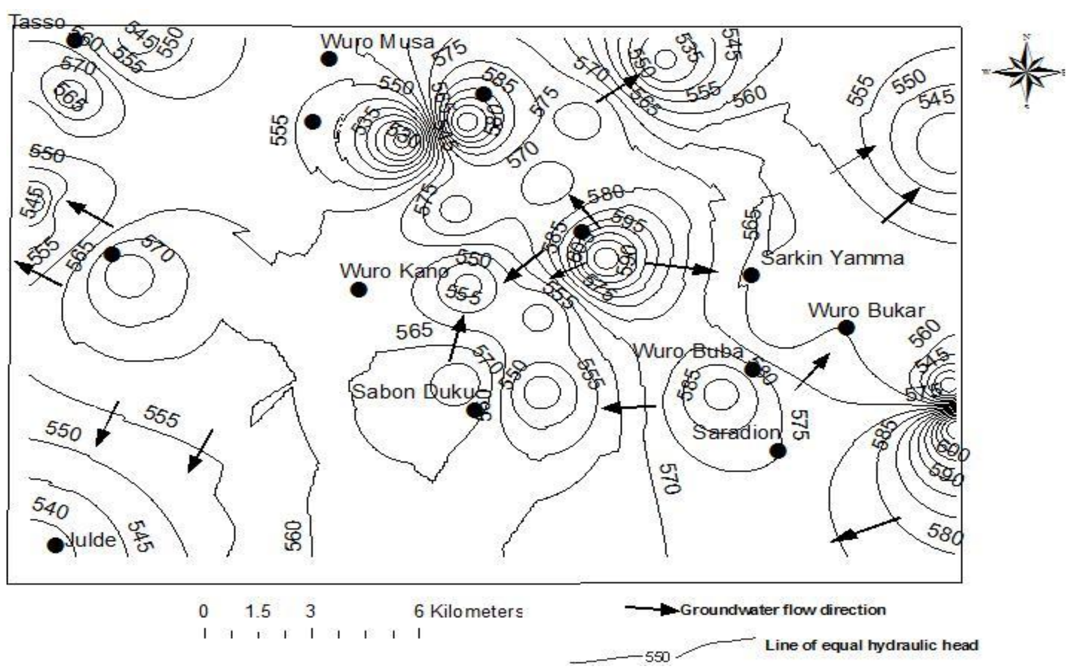

Figure 3. Hydraulic head distribution in unconfined aquifer in the study area.

Collection.

GIS Geo-data base

The map showing sampling points was scanned and imported into Arc GIS version 9.2 and was geo referenced and digitized. The sampling points were determined using GPS and transferred into the digitized map of the study area. The water samples were collected and analyzed for different physic-chemical parameters and then used for the calculation of WQI.The WQI values

Table 1. Relative weight of chemical parameters.

Chemical parameters	Standard permissible Value (s) (WHO, 2004)	Weight (wi)	Relative weight (Wi)
pH	6.5-8.5	4	0.09091
EC (µS/cm)	500	4	0.09091
TDS (mg/l)	500	4	0.09091
Sodium (mg/l)	200	2	0.04545
Potassium (mg/l)	200	2	0.04545
Calcium (mg/l)	75	2	0.04545
Magnesium (mg/l)	50	1	0.02273
Chloride (mg/l)	250	3	0.06818
Bicarbonate (mg/l)	500	3	0.06818
Sulphate (mg/l)	250	4	0.09091
Nitrate (mg/l)	50-70	5	0.11364
Iron (mg/l)	1.0	4	0.09091
Fluoride (mg/l)	1.5	5	0.11364
Phosphate (mg/l)	10	1	0.02273

$\sum wi = 44$ $\sum Wi = 1.000$

form the attribute data base creation function of Arc GIS 9.2 software. The different locations of the sampling points were imported into GIS software through point layer. Each sample point was assigned a unique code and stored in the attribute table. The geo-database was used to generate the spatial distribution maps of WQI. The present study used the Inverse Distance Weighting (IDW) method for spatial interpolation of WQI. Inverse Distance weighting (IDW) is an interpolation technique in which interpolated estimates are made based on values at nearby locations weighted only by distance from the interpolation location (Naoum and Tsanis, 2004)

Calculation of WQI

11 physico-chemical parameters consisting of EC, TDS, pH, Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, HCO_3^- and NO_3^- were considered in the calculation of WQI. Water Quality Index (WQI) calculation involve three stages. In stage 1, each of the 14 parameters has been assigned a weight (w_i) according to its relative importance in the overall quality of water for drinking purposes (Table 1). The maximum weight of 5 has been assigned to the parameter nitrate due to its importance in water quality assessment. Magnesium is given the minimum weight of 1 which indicates that, it may not be deleterious. In stage 2, the relative weight (W_i) is computed from the following equation (Ramakrishnaiah et al., 2009; Ishaku, 2011):

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \qquad (1)$$

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 (Wi) value of each parameter are also given in Table 1. Stage 3, a quality rating scale (q_i) for each parameter is assigned by dividing its concentration in each groundwater sample by its respective standard according to the guidelines by WHO and the result multiplied by 100 (Gebrehiwot et al., 2011):

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

Where, q_i is the quality rating, C_i is the concentration of each parameter in each water sample, and S_i is the WHO drinking water standard for each parameter.

For computing the WQI, the SI is first determined for each parameter, which is then used to determine the WQI as indicated by the following equation (Reza and Singh, 2010):

$$SI = W_i \times q_i \qquad (3)$$

$$WQI = \sum SI_i \qquad (4)$$

Where, SI_i is the sub index of ith parameter; q_i is the rating based on concentration of ith parameter and n is the number of parameters.

Hierarchal cluster analysis

Cluster analysis (CA) is a simple approach for classification of groundwater quality into two or more mutually exclusive unknown groups based on combination of interval variables (Hussein, 2004). The tool sorts out different objects into groups such that the degree of association between the objects is maximal if they belong to the same group (Hamzaoui-Azaza et al., 2009). The hierarchal cluster analysis according to Ward (1963) with squared Euclidean distances was applied to detect multivariate similarities in groundwater quality. The results are presented by dendrogram of the groups and

Table 2. Statistical summary of physical and chemical parameters in the study area

Parameters	Minimum	Maximum	Mean	Std. Deviation
pH	5.40	6.70	6.1600	.26458
EC	25.00	425.00	141.3040	114.02293
TDS	21.00	283.00	95.8600	75.01908
Calcium	4.00	63.70	20.8320	14.76939
Magnesium	5.80	52.30	19.1800	11.35114
Sodium	.01	1.90	.6141	.55608
Potassium	1.10	6.90	2.9400	1.40564
Bicarbonate	121.00	273.00	205.2000	31.90089
Sulphate	1.20	27.60	14.8800	5.66627
Chloride	5.00	57.40	20.8920	15.25292
Nitrate	1.40	20.70	9.2280	4.84686

Table 3. Computed values of GWQI in the study area

Code	GWQI	Remarks
BH1	20	Very good
BH2	22	Very good
BH3	23	Very good
BH4	24	Very good
BH5	20	Very good
BH6	24	Very good
BH7	42	Good
BH8	26	Good
BH9	22	Very good
BH10	27	Good
HW1	26	Good
HW2	28	Good
HW3	23	Very good
HW4	15	Very good
HW5	20	Very good
HW6	18	Very good
HW7	23	Very good
HW8	25	Very good
HW9	23	Very good
HW10	19	Very good
HW11	40	Good
HW12	43	Good
HW13	37	Good
HW14	22	Very good
HW15	24	Very good

BH=Borehole, HW=Hand-dug well, GWQI=Groundwater Quality Index

their proximity.

RESULTS AND DISCUSSION

Table 2 indicates that the average values of pH as 6.2 which indicates acidic condition of the groundwater samples. EC is a measure of salt content in water, and changes in its concentration signify water quality deterioration. The mean value of EC is 141.3 µS/cm which is below the desirable limit of WHO. TDS indicates the different types of mineral present in water, and from this study, it indicates an average value of 95.9 mg/l. The mean value of TDS is below the recommended limit of WHO. The cations indicate average as Ca^{2+} (20.8 mg/l), Mg^{2+} (19.2 mg/l), Na^{+} (0.6 mg/l) and K^{+} (2.9 mg/l) while the anions reveal average values as HCO_3^- (205.2 mg/l), SO_4^{2-} (14.9 mg/l), Cl^- (20.9 mg/l) and NO_3^- (9.2 mg/l), respectively. All the mean concentrations of the parameters are below WHO recommended limits. The mean values of the cations in order of abundance were $Ca^{2+}>Mg^{2+}>K^{+}>Na^{+}$ while the anions reveal order of abundance as $HCO_3^->Cl^->SO_4^{2-}>NO_3^-$.

The groundwater quality index assessed from the groundwater quality data values range from 15-43 (Table 3). Base on the standard classification (Table 4), the groundwater quality status ranges from good to very good. Figure 4 classifies the WQI values into two groundwater quality zones (Good to very good). The areas covered by the very good water quality are Tasso, Gangtan and Julde areas in the northwest and southwestern portion of the study area. Other areas covered by this zone occur in the

North east and southwestern parts, and covers areas such as Saradion, Wuro Buba, Wuro Bukar, Sarkin Yamma and extends to the Gangwaso area towards the north. The areas covered by the good water quality include Wuro Musa in the north and extends to Sabon Duku and extends to the extreme end of the southern parts of the study area. Figure 5 indicates that the higher values of WQI are associated with BH7, HW11, HW12

Table 4. Water quality classification standard

GWQI	Status
0-25	Very good
26-50	Good
51-75	Poor
>75	Very poor

Reza and Singh (2010)

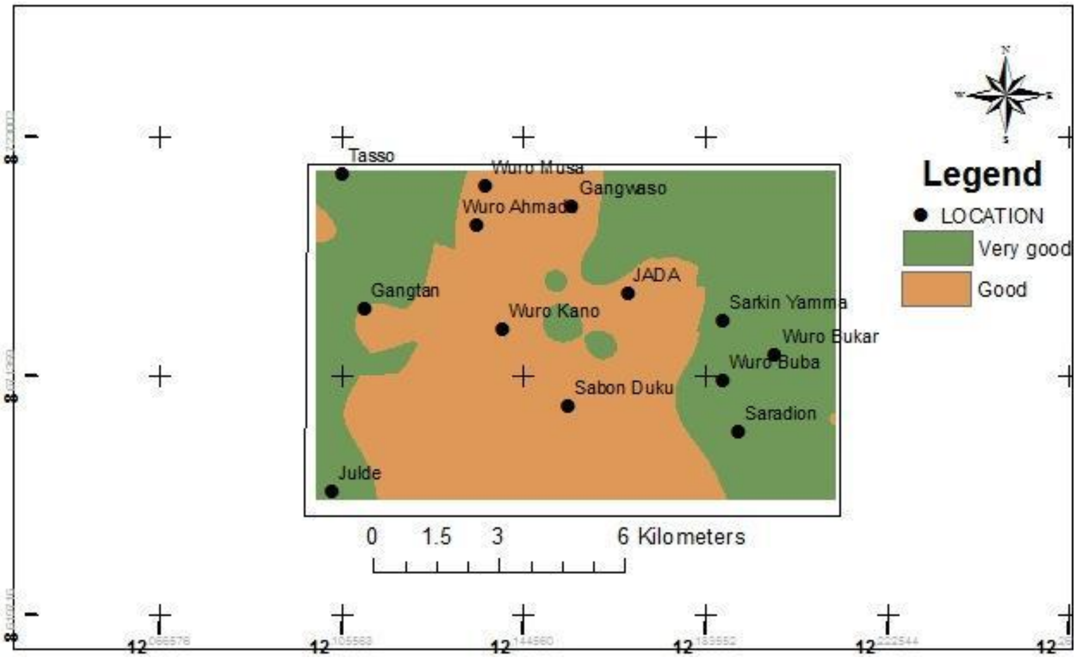

Figure 4. Spatial Distribution of Water Quality Index in the study area

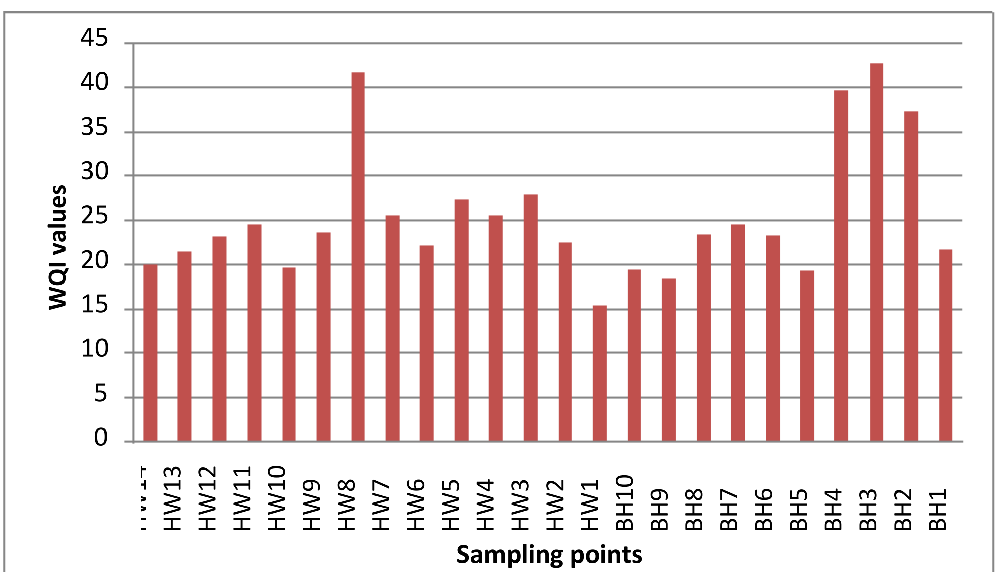

Figure 5. Water Quality Index of groundwater samples

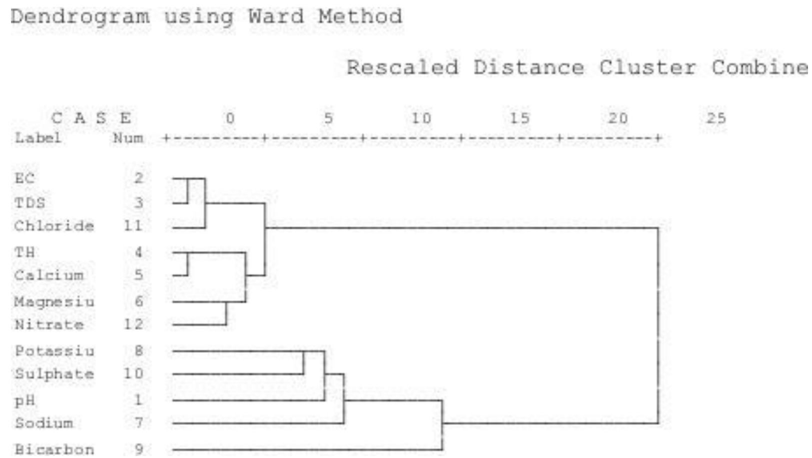

Figure 6. Dendrogram of groundwater samples

Table 5. Correlation of some physic-chemical parameters in the study area

	pH	EC	TDS	Calcium	Magnesium	Sodium	Potassium	Bicarbonate	Sulphate	Chloride	Nitrate
pH	1										
EC	.057	1									
TDS	.094	.990	1								
Calcium	.038	.812	.823	1							
Magnesium	.253	.738	.774	.604	1						
Sodium	.168	.150	.131	.109	.065	1					
Potassium	.310	.121	.125	.416	.290	.286	1				
Bicarbonate	-.151	-.287	-.275	-.435	-.149	.132	-.411	1			
Sulphate	.362	.208	.242	.029	.460	.155	.409	.052	1		
Chloride	-.104	.840	.853	.673	.590	.224	-.160	-.112	.032	1	
Nitrate	.139	.629	.687	.690	.688	.164	.440	-.164	.392	.470	1

and HW13, and have been found to be mainly due to pH, EC, calcium, magnesium, chloride, bicarbonate, sulphate and nitrate. The hierarchal cluster analysis was applied to identify the processes controlling groundwater chemistry. The dendrogram (Figure 6) displayed two clusters. Cluster 1 comprised of comprised of EC, TDS, chloride and calcium showing close similarities and included magnesium and nitrate in the same cluster. This cluster is interpreted as anthropogenic contamination which is related to indiscriminate house hold solid waste disposal, sewage effluent following the use of pit latrines by most residents and indiscriminate application of chemical fertilizer.

The cluster also indicates Ca-Mg-Cl facies, which resulted from reverse cation exchange. The presence of TDS in this cluster is an indication that the cations and anions influence TDS and thus increases the water's electrical conductivity (EC). At high TDS concentration, water becomes saline (Shahbazi and Esmaeili-Sari, 2009). The association of nitrate with chloride, calcium and magnesium is an indication that the sources of these ions are anthropogenic. Table 5 indicated positive correlation among the physic-chemical parameters ranging from 0.63 to o.99. This positive correlation is an indication of common origin. Cluster 2 consists of potassium, sulphate and pH showing close similarities and included sodium and bicarbonate in the same cluster. The cluster is interpreted as natural mineralization, and is controlled by cation exchange

CONCLUSION

The major findings of this study include the following:

The calculated WQI for the groundwater samples range from 15 to 43, and falls within the good to very good class. The geographical information system delineated the area into good to very good potential areas of groundwater quality and therefore proved as a useful tool in mapping groundwater quality.

Hierarchal cluster analysis identified anthropogenic contamination, natural mineralization, reverse cation exchange and cation exchange as the major processes controlling groundwater chemistry.

It is recommended that groundwater quality monitoring should be encouraged in order ensure groundwater quality protection and conservation.

REFERENCES

Adamawa State Diary (2007). Government Printing Press.

Abubakar MA (2010). Determination of the influence of geology and anthropogenic activities on groundwater quality of Jada area, Northeastern Nigeria. Final year research project, Department of geology, Federal University of Technol. Yola

Gebrehiwot AB, Tadesse N, Jigar E (2011). Application of water quality index to assess suitability of groundwater quality for drinking purposes in Hantebet watershed, Tigray, Northern Ethiopia. ISABB J. Food and Agric. Sci.1 (1):22-30

Ishaku JM (2011). Assessment of groundwater quality index for Jimeta-Yola area, Northeastern Nigeria. J. Geol. and Min. Res. 3(9): 219-231.

Hamzaoui-Azaza F, Bouhilila R, Gueddari M (2009). Geochemistry of Fluoride and Major Ion in the groundwater Samples of Triassic Aquifer (South Eastern Tunisia.Through Multivariate and Hydrochemical Techniques. J. Appl. Sci. Res. 5(11):1941-1951.

Hussein MT (2004). Hydrochemical evaluation of groundwater in the Blue Nile Basin, eastern Sudan, using conventional and Multivariate techniques. Hydrogeol. J., 12: 144-158

Milovanovic M (2007). Water quality assessment and determination of pollution sources along the Axios/Vardar River, Southeastern Europe. Desalination, 213: 159-173.

Naoum S, Tsanis IK (2004). Ranking of spatial interpolation techniques using a GIS-based DSS. Global Nest: the Int. J., 6(1), 1-20

Ogunbajo JS (1978). Climate A Geography of Nigerian Development. Heinemann Education Books (Nig). Ltd. Pp. 45-70.

Ramakrishnaiah CR, Sadashvaiah C, Ranganna G (2009). Assessment of Water Quality Index for the Groundwater in Tumkur Taluk, Karnataka State, India". E-J. Chem. **6**(2): 523-530.

Reza R, Singh G (2010). Assessment of Ground Water Quality Status by Using Water Quality Index Method in Orissa, India. World Appl. Sci. J. 9 (12): 1392-1397.

Sexana MM (1990). Environment: Water analysis, soil and air. 2nd ed. Agro Botanical (India), pp. 188

Shahbazi A, Esmaeili-Sari A (2009). Groundwater Quality Assessment in North of Iran: A case Study of the Mazandaran Province. World Appl. Sci. J. 5(Special Issue for Environment): pp. 92-97

Strivastava PK, Mukherjee S, Gupta M, Singh SK (2011). Characterizing Monsoon Variation on Water Quality Index of River Mahi in India Using Geographical Information System. Earth and Environmental Science Water Quality, Exposure and Health 2(3-4): 193-203, DOI: 10.1007/s 12403-011-0038-7

Swarna LP, Nageswara Rao K (2010). Assessment and Spatial Distribution of Quality of Groundwater in Zone II and III, Greater Visakhapatnam, India using Water Quality Index (WQI) and GIS. Int. J. Environ. Sci. 1(2):198-212.

Tiwari TN, Mishra MA (1985). A preliminary assessment of water quality index of major Indian rivers J. Environ. Protection. 5: 276-279.

Vasanthavigar M, Srinivasamoorthy K, Rajiv Gantha R, Vijayaraghavan K, Sarma VS (2010). Characterization and quality assessment of groundwater with special emphasis on irrigation utility: Thirumanimuttar sub-basin, Tamil Nadu, India. Arab .Geosci. J. DOI 10 1007/s12517-010-0190-6.

Ward JH (1963). Hierarchial grouping to optimize objective function. J. Am. Stat. Assoc., 69: 236-244.