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MULTIVARIATE STATISTICAL APPROACH FOR ASSESSMENT OF GROUNDWATER QUALITY AT HADEJIA-JAMAARE-KOMADUGU- YOBE BASIN, NIGERIA

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ABSTRACT

Assessment of the processes that control groundwater quality is significant for the sustainable development of water resources. Groundwater samples collected from the study area were appropriately analyzed in the laboratory. The study approach employed the use of multivariate statistical tools; Principal component and cluster analyses on the data, in order to understand the groundwater condition of the area, with a view to the concentration of different parameters in the water and other factors controlling the groundwater quality. Based on the Eigen value-one criterion, eleven (11) components were chosen after Varimax rotation. The first Varimax factor (VF1) contained strong factor loadings on Pb, Mo, Cd and Ni which account for 15.404% variance of the water quality data. The 2nd Varimax factor (VF2) has strong loadings on Electrical conductivity (EC), total dissolved solid (TDS), Cl and Temperature, with a variance of 14.068%. The 11 Varimax factors explained 81.91% of the variability of the water quality data. The strong loading for Pb, Mo and Cd could be due to industrial effluents. While the high loading for EC, TDS and Cl could be due to salinity build up in the area as a result of the intensive agricultural activities. These results suggest the possibility of effects of anthropogenic activities; industrial effluents and intensive application of agro-chemicals. There is need for proper discharge of industrial effluents and application of agro-chemicals.

Keywords: Multivariate statistical, Assessment, Groundwater quality, Hadejia-Jamaare-Komadugu-Yobe basin.

INTRODUCTION

Groundwater has been and will always be the most important resource to sustain life. However, there is general global concern about the sustainability of groundwater resources due to the impact of land use activities on its quality such as industrialization, urbanization and intensive agricultural activities.

According to Dogara et. al., (2007) the Hadejia-Jamaare-Komadugu-Yobe Basin (HJKYB) supports a population of more than 15 million people who directly or indirectly rely on its rivers for their activities; domestic supplies, irrigated farming, fishing, rearing of animals, transportation and industrial activities. A combination of many lingering factors has, over many years, led to serious degradation of the land and water resources in the basin. These factors include; increasing population; urbanization; severe deforestation; among others.

The increase in population leads to the generation of waste which if inappropriately disposed becomes a threat to the environment, including changes to water quality through both anthropogenic and natural mechanisms. These changes in water quality can be potentially dangerous as the conditions are no longer suitable for the survival of life (Bierman et. al., 2008 and Das et. al., 2009).

The discharge of effluents from agricultural, domestic and industrial sources into streams and river channels are considered to be compounding water quality problems as observed in areas around Hadejia and Nguru, because of widespread kidney and other renal problems in the area.

Statistical methods such as principal component analysis (PCA), hierarchical agglomerative cluster analysis (HACA) help in the interpretation of complex data sets, such as those involving a large number of parameters (Mustapha et. al., 2019).These multivariate statistical tools are useful techniques for simplifying and organizing large data sets in order to make useful generalizations. Multivariate techniques could streamline the data without much loss of information into a reasonably manageable data set (Das et.al, (2009). The PCA provides information concerning most significant parameters and data reduction with minimum loss of information. PCA, the first principal component is the linear combination of the variables with maximal variance which represents the largest variability of the original data set (Deb et. al., 2008). The second component is the linear combination with the next largest variability that it is orthogonal to the first components, etc. The HACA on the other hand, assembles objects based on the characteristics they possess (Kumar et. al., 2008; Kumar et. al., 2011 and Mustapha et. al., 2019).The technique classifies observations into groups, so that members of the same group are similar to each other and distinct from other groups. The similarities at which observations are merged are used to construct Dendogram that gives graphic representation, which indicates the linkages between the similarities of clusters. Cluster and Correlation Analysis can be run on the data to identify the interrelationship between the physicochemical characteristics of the samples. HCA can be used to assign groundwater monitoring sites, or individual samples from the sites, to distinct water-quality categories (Daughney, 2011).

The objective of the present study is to investigate the concentration of major and trace elements in groundwater of the Hadejia-Jamaare-Komadugu-Yobe basin, Nigeria, and to determine the characteristics of water quality in the study area using multivariate statistical method.

Study Area

The Hadejia-Jama'are-Komadugu-Yobe Basin is situated in the Sudan-Sahel-Guinea vegetation zones of northern Nigeria. It covers parts of Kano, Jigawa, Bauchi, Yobe, Plateau and Borno States (Figure 1). The study area is bounded by latitude $10^{o}00'$-$13^{o}00'$N and longitude $07^{o}25'$-$11^{o}00'$E, and has, a total area of approximately 84,138 $km^{2.}$ WRECA (1972).

The basin consists of triangular area in which the headwaters of the Hadejia River rises in Kano state and flows east by northeast along one side of the triangle. The Jamaare River also rises in northeast and flows north easterly along the other side of the triangle until it meets the Hadejia River in an extensive flood plain near the triangle's apex (Schultz (1976), East of Gashua, the system is known as the Yobe River and 100km farther east at

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Damasak it joins the Komadugu Gana and flows on into Lake Chad.

The lower part of the basin, in Yobe and Borno States, is the driest area of Nigeria, with the rainfall in some years barely adequate to enable the cultivation of millet (Diyam consultants, 1996).

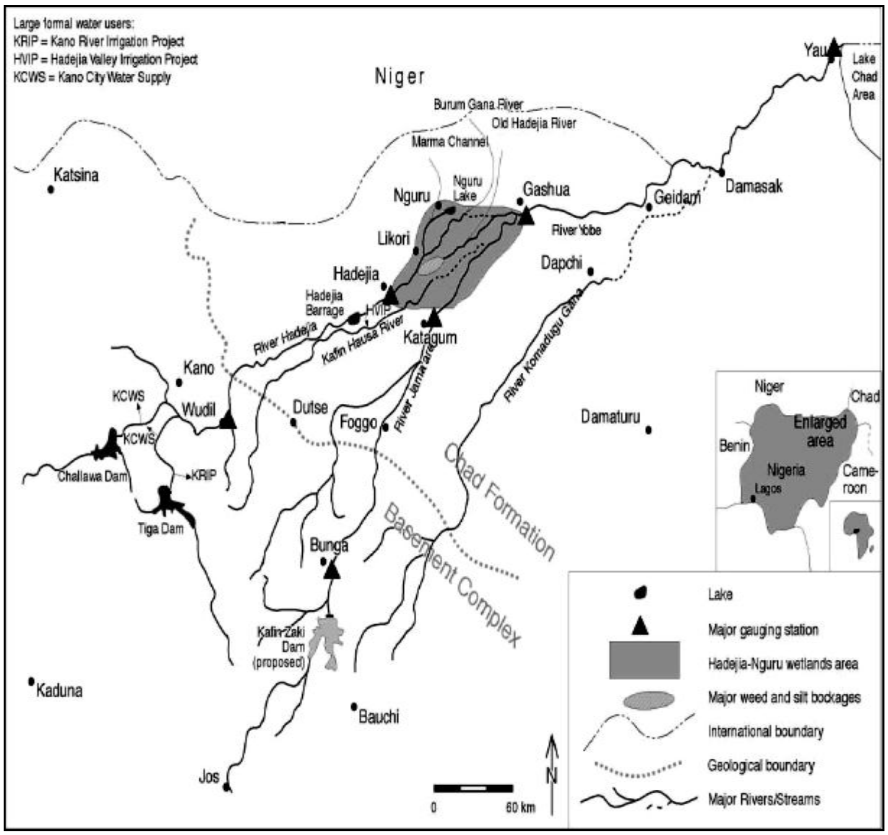

Figure 1: Catchment Map of the Study Area (After Goes, 2002)

MATERIALS AND METHODS

To understand the chemistry of groundwater in the study area; 81 groundwater samples were collected in clean 120 ml sampling polyethylene bottles using the APHA standard methods of groundwater sampling . P^{H}, temperature, TDS and conductivity were measured on site using conductivity meter Hanna HI 9811-5. This allowed an initial and quick assessment of water quality at the site of sampling. All analysis of cations was carried using Agilent 4210 MP-AES and anion was achieved using the titrimetric method. Descriptive and multivariate statistical analyses of the measured water quality parameters were done in order to understand their grouping, similarities and characteristics. These were achieved using SPSS Software Package and Minitab software for Principal Component Analysis and Cluster Analysis respectively.

RESULTS

The results of water quality assessments conducted at the Centre for Dry Land Agriculture Bayero University Kano and Pollution Control Laboratory Kano are presented in Tables 1.

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Table 1: Table 1: Descriptive Statistics of Water Parameters

Parameters	Mean	±Std. Dev.	Variance	Min.	Max.	Count
PH	7.94	7.03	49.43	5.7	9.1	81
Temperature	33.11	3.4	11.59	23.7	40.2	81
TDS	154.32	279.96	78379.85	20	2050	81
EC	322.1	557.31	310599.3	60	4090	81
NO3	0.33	0.41	0.17	0	2.46	81
NO2	0.21	0.27	0.07	0	1.85	81
NH4	0.08	0.19	0.03	0	1.5	81
SO4	30.34	29.9	894.18	2	200	81
Cl	11.57	15.41	237.58	0	96	81
HCO3	221.09	84.87	7202.53	0	561.2	81
P	3.47	1.83	3.33	-1.76	9.87	81
S	3.49	3.83	14.64	-8.64	13.54	81
Se	0.16	0.57	0.33	-0.01	4.3	81
Zn2+	0.4	0.72	0.52	0.02	5.9	81
Cd	1.26	7.93	62.89	0.18	71.74	81
Ca+	72.85	28.49	811.62	34.05	132.05	81
Fe3+	58.32	66.29	4394.46	0.29	381.23	81
Ba	0.3	0.16	0.03	0.08	0.84	81
Cu2+	0.2	0.1	0.01	-0.01	0.46	81
Ni	0	0.04	0	-0.02	0.36	81
As	0.41	0.3	0.09	-0.07	1.54	81
Co	0.02	0.02	0	-0.08	0.09	81
Pb	0.09	0.5	0.25	0.02	4.54	81
K+	9.4	13.27	176.04	0	79.55	81
Mo	-3.03	27.26	743.05	-245.33	0.02	81
Mg2+	1.83	0.93	0.87	0	6.74	81
Mn+	0.19	0.23	0.05	0.01	1.23	81
Na+	0.04	0.15	0.02	-0.8	0.45	81
Al	0.88	1.01	1.01	0.01	4.52	81

Principal Component Analysis (PCA) was used on the physicochemical data from the study area to identify the linear combination of parameters in order to understand the relationship between them. The PCA result is presented in Table 2.

Based on the Eigen value-one criterion, eleven (11) components were chosen after Varimax rotation. The 11 Variamax factors together explained 81.91% of the variance of the data. The Eigen value, Variance and Cumulative variance are shown in Table 2.

The first Varimax factor (VF1) contained strong factor loading on Pb, Mo, Cd and Ni. It account for 15.404% of the total variability of the water quality data. Even though the industries are not well developed in the area, but many are found localized in the urban centers, which are mostly unregulated in terms of management of discharges. The Pb and Cd may have originated from discharge of contaminants from these industries and from agricultural activities, through the use of pesticides and insecticides. The 2^{nd} Varimax factor (VF2) has strong loading for EC, TDS, Cl and Temperature with variance of 14.068%.

Table 2: Principal Component Analysis (PCA)

Parameters	VF1	VF2	VF3	VF4	VF5	VF6	VF7	VF8	VF9	VF10	VF11
Pb	0.995	-0.021	-0.039	-0.038	-0.041	0.004	-0.011	-0.033	-0.007	-0.017	0.001
Mo	-0.994	0.016	0.039	0.05	0.046	0.011	0.011	0.034	0.005	0.017	0.001
Cd	0.994	-0.013	-0.041	-0.055	-0.046	-0.006	-0.01	-0.034	-0.009	-0.016	-0.001
Ni	0.989	-0.032	-0.03	0.011	-0.023	-0.043	-0.016	-0.024	0.018	-0.058	-0.013
EC	-0.025	0.963	0.042	-0.104	-0.014	-0.028	0.055	0.009	-0.037	-0.014	0.012
TDS	-0.026	0.963	0.045	-0.098	-0.01	-0.03	0.055	0.01	-0.035	-0.014	0.014
Cl	-0.044	0.848	0.242	-0.033	0.037	0.106	-0.044	-0.059	0.095	-0.008	0.031
Temp	-0.073	-0.521	0.047	0.025	-0.048	-0.176	0.039	-0.076	0.476	-0.134	0.15
9NO$_2$	-0.031	0.064	0.920	-0.109	0.071	-0.012	-0.093	0.046	0.018	0.008	-0.115
NO$_3$	-0.038	0.031	0.873	-0.209	0.099	0.054	-0.166	0.072	0.06	0.02	-0.113
SO$_4$	-0.083	0.419	0.633	-0.069	-0.077	-0.074	0.056	-0.066	-0.033	0.136	0.205
HCO$_3$	-0.063	0.095	0.584	0.292	-0.26	-0.051	0.174	-0.018	0.006	-0.018	0.235
Cu	-0.227	-0.147	0.016	0.772	0.064	-0.265	-0.131	0.123	0.148	-0.109	-0.078
Ca	0.018	-0.063	-0.091	0.706	0.325	-0.036	0.268	0.08	0.297	0.001	-0.324
P	-0.056	0.127	0.187	-0.679	-0.04	-0.161	0.075	-0.04	0.154	-0.123	-0.088
Mg	0.188	-0.033	0.085	-0.549	-0.488	-0.168	-0.068	-0.048	-0.228	-0.146	0.381
K	-0.025	-0.005	-0.029	0.309	0.862	0.216	-0.04	0.035	-0.011	0.073	-0.122
Na	0.094	-0.022	-0.045	0.008	-0.838	0.122	-0.133	0.003	-0.123	0.025	-0.199
Co	0.053	-0.036	-0.004	0.19	0.116	0.876	0.062	-0.176	0.01	-0.059	-0.048
As	-0.166	0.18	-0.049	-0.327	-0.07	0.766	0.161	0.078	0.197	-0.021	0.02
Zn	-0.014	-0.045	-0.041	-0.13	0.109	0.007	0.848	-0.124	-0.126	-0.168	0.074
Ba	-0.037	0.13	-0.081	0.108	-0.006	0.223	0.801	0.148	0.15	0.099	-0.264
Fe	-0.077	-0.091	0.062	0.09	0.007	-0.121	-0.082	0.877	-0.069	-0.116	0.124
Mn	-0.053	0.195	-0.128	-0.012	-0.028	-0.106	0.179	0.662	0.218	0.316	-0.262
Al	-0.014	-0.082	0.255	0.38	0.151	0.352	-0.053	0.545	-0.201	-0.116	0.147
Se	-0.033	0.005	-0.048	-0.081	-0.143	-0.17	0.028	-0.002	-0.822	0.017	-0.09
NH$_4$	-0.012	-0.058	0.28	0.197	-0.059	-0.036	-0.009	0.009	0.006	0.803	0.157
S	-0.167	0.117	-0.321	-0.26	0.264	-0.071	-0.183	-0.054	-0.15	0.634	-0.02
P^H	-0.019	0.026	-0.025	-0.089	0.054	-0.004	-0.081	0.049	0.137	0.112	0.751
Eigen Value	4.467	4.08	2.922	2.629	1.942	1.677	1.432	1.309	1.157	1.124	1.014
Variance	15.404	14.068	10.075	9.066	6.697	5.783	4.939	4.515	3.989	3.876	3.497
Cum. Variance	15.404	29.472	39.547	48.614	55.311	61.094	66.033	70.548	74.536	78.412	81.91

The strong loading for EC, TDS and Cl could be due to salinity build up process in the area due to intensive agricultural activities. High concentration of TDS and Cl lead to salinity of the water. Barzegar (2017) has reported that, the process of salinity built-up is common in irrigational agricultural area, whereby there is constant accumulation of ions in the upper soil horizon which increases the salinity built-up especially when

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groundwater exploitation rate used for irrigation is higher than the recharge of aquifer systems. The 3rd Varimax factor (VF3) has higher loadings for NO_2, NO_3, SO_4 and $HCO_3$with variance of 10.075%. The HCO_3can be related to dissolution of carbonate minerals and atmospheric and soil CO_2. The NO_3concentration in groundwater is usually low but can reach higher levels due to leaching or runoff from agricultural land. The decomposition of organic materials may increase the concentration of NO_3. Anaerobic conditions may result in the formation of NO_2. The source of SO_4 in water is decaying organic matter through H_2S. It's an indicator of organic pollution in water especially in shallow aquifers. Other sources of SO_4 include fertilizers and from dissolution of sulfide minerals in some weathered rocks. The 4th Varimax factor (VF4) has higher loading for Cu, Ca, P and M. It accounts for 9.066% variance. Ca^{2+} is the dominant cation in the study area. High concentration of Ca^{2+} in parts of the study area could be attributed to weathering of basement rocks upstream of the basin. The 5th Varimax factor (VF5) contained strong factor loading on K and Na. These parameters could be related to weathering of silicates minerals of basement rocks upstream of the basin.

Additional concentration of K^+ could be from Potassium fertilizer due to agricultural activities in the area. The 6th Varimax factor (VF6) contained strong factor loading on Co and as with 5.783% variance. (As) occurs naturally in small amounts in sulphide deposits and in compounds of pesticides, where they can enter through water by application of pesticides. The 7th Varimax factor (VF7) has higher loadings for Zn and Ba at 4.939% variance. The 8th Varimax factor has strong loadings for Fe, Mn and Al at 4.515% variance. The 9th Varimax factor has a negative loading for Se at 3.989%. The 10th Varimax factor has a high loading for NH_4 and S at 3.876%. Lastly 11th Varimax factor has high loading for P^H at 3.497% variance.

Cluster Analysis using Hierarchical Agglomerated Analysis (HACA) was run on the data. Results of this analysis are presented in Figure 2, indicating two (2) main groups of clusters, followed by several subgroups. In Group 1; P, Cl, TDS, EC, NO_3, NO_2, SO_4, HCO_3, Se, Mg, Na, Cd, Pb and Ni are joined in the same group. The group is associated with parameters indicating organic and inorganic pollution. Those with highest similarity in the group are; TDS and EC, Cd, Pb and Ni, followed by NO_2 and NO_3.

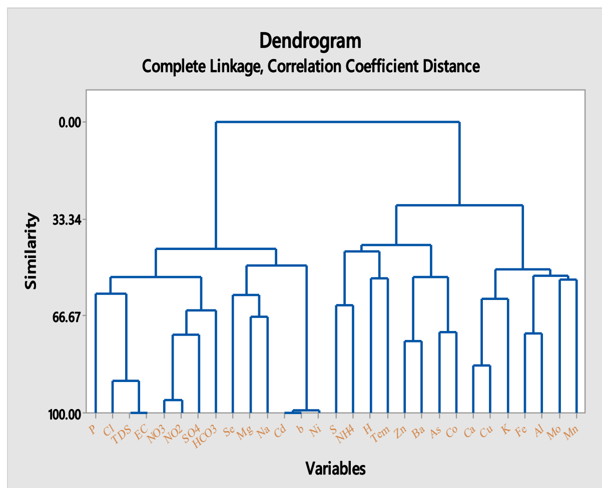

Figure 2: Dendogram of Water Quality Parameters from the study area

In Group 2; S, NH_4, P^H, Temperature, Zn, Ba, As, Co, Ca, Cu, K, Fe, Al, Mo and Mn are joined together. This group shows some major and trace elements such as Ca, K and Fe, Al, Mn respectively, as well as physical parameters, such as P^H and Temperature. In this group, Ca and Cu have highest similarity followed by Zn and Ba, while As and Co, Fe and Al have the equal similarity.

CONCLUSION

The application of multivariate analysis using principal component and cluster analyses in the study has proven to be valuable tools in groundwater evaluation in the study area. The findings of this research indicate that, anthropogenic process is the one affecting the groundwater quality in the area, through inorganic pollution usually from industrial effluents mostly from the upstream part of the study area and intensive application of agro-chemicals (pesticides, insecticides and fertilizers).

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