Hydro-Statistical Assessment of Anthropogenic Contamination of Groundwater in Nsukka Area, Enugu State Nigeria

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ABSTRACT

This research investigates the impact of sewage and domestic solid wastes on the shallow groundwater within Nsukka and its environs using hydrogeochemical and multivariate analysis. The parameters were analyzed using Spectrophotometer for some anions, all cations, and heavy metals, Hanna Meters for TDS, EC, pH, Titrimetric Methods for Cl and microbial Sensitivity Range Count for microbial analysis.

The highest cation, anion, and heavy metal parameters are Ca^{2+}, Cl^- and Zn^{2+}, respectively. The high pH and iron values in the samples could be anthropogenically induced. The Durov plot unraveled Ca^{2+}-Cl^- and Na^+ +K^- –Cl^- water types. From the multivariate analyses, nitrate shows a positive correlation with chloride, potassium, iron, and magnesium. Calcium correlates with manganese, zinc, bicarbonate, and sulfate. These agree with the first cluster and third factor variables which suggest that the parameter associations could be attributed to possible sewage contamination due to the presence of nitrate and chloride. Sulfate has positive correlation with lead, and in agreement with third cluster and first factor analyses scores which could be attributed to solid waste contamination. The result of the modified water quality index shows 10% indicates groundwater with no pollution impact.

(Keywords: perched aquifer, multivariate analysis, sewage contamination, Nsukka, hydrogeochemistry, contamination, heavy metals, environmental quality)

INTRODUCTION

Groundwater quality assessment is important to unravel its suitability for a particular use. Geostatistical evaluation of groundwater provides a better understanding on the possible changes in the quality of groundwater. (Fazelabdolabadi and Golestan, 2020).

The study area is a home to the prestigious University of Nigeria, located in the southeastern part of Nigeria. The presence of this school leads to large population of people at the area. Besides increased generation of waste attracted by this large population and possible soil and groundwater contamination, people of Nsukka are also faced with acute water scarcity because of high depth of water table at the area which ranges from 34m to over 220m (Ezeh, 2012). They trek long distances in search of water for domestic use.

Two aquifer systems in the area are shallow perched aquifer and deep unconfined and semi-confined aquifer (Ezigbo and Ozoko,1989, Mama, et al., 2020, Egboka and Uma, 1986). Perched aquifers are found in the unsaturated zone and it is formed when percolating groundwater normally trapped by a lens of less porous/permeable rock leads to accumulation of groundwater above the lens or to the flowing of the trapped water across the edge of the lens (Ozoko, 2015).

This area is underlain by local perched aquifer and is the main groundwater source in the area, this also contributed to the attractiveness of the area for human habitation resulting in unplanned system of sewage and domestic waste management. Increase in population will definitely lead to increase in human activities which both directly and indirectly influence water quality (Jiayu Wu, et al., 2015).

Humans directly and negatively affect water quality by additions of fertilizer and pesticides into land or by leakage of oil and other pollutants from motor vehicles. The aim of this research is to investigate the impact of the associated wastes on the shallow groundwater within Nsukka using hydrogeochemical and multivariate analyses.

Study Area Description

The Nsukka Town is bounded by Latitudes 6°49'N and 6°52'N and Longitudes 7°21'E and 7°24'E (Figure 1). Two precipitation seasons are experienced in the study area, the wet season which lasts from April to November and the dry season which lasts from December to March. Cloud seasonal variation also exist in the study area, the clearest sky is normally between November to March. The hottest period within the study area is around February with temperature range of 34-36.2^{O} C while the coldest time is around December when the temperature drops to 18^{0}C (Mama, et al., 2021).

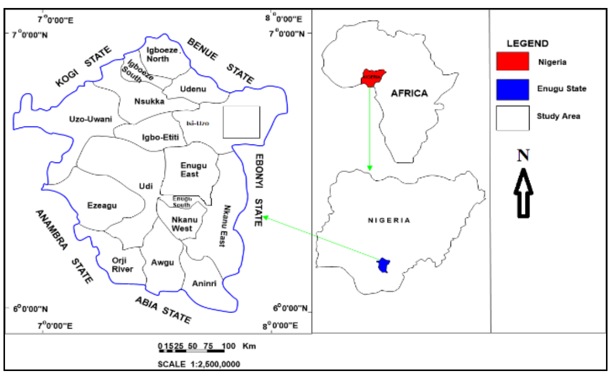

Figure 1: Location Map of the Study Area. (Modified after Onwuka, et al., 2018).

The study area is undulating and ranges from 567m at high peak areas to 341m (Figure 2). The North-eastern part of the study area is on high relief, undulating at the central part and descending into a lower elevation at the western and north-western parts. Nsukka Town is underlain by two main formations which are within the Anambra basin, Ajali and Nsukka Formations (Figure 3) while medium to coarse grained, cross bedded sandstones with thin clay intercalations make up the Ajali Formation, Nsukka Formation, which is the formation of interest in this research, consists of intercalation of sandy-shale, shale and sandstone.

The permeable intercalation lens or horizon is sealed by a basal impermeable layer, resulting in perched aquifers which are normally within the depth of 5 to 30m.

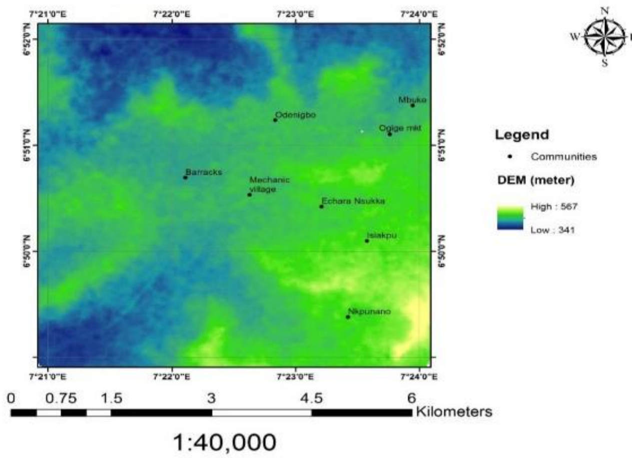

Figure 2: Topographic Map of the Study Area. (Modified after Mama, et al., 2020).

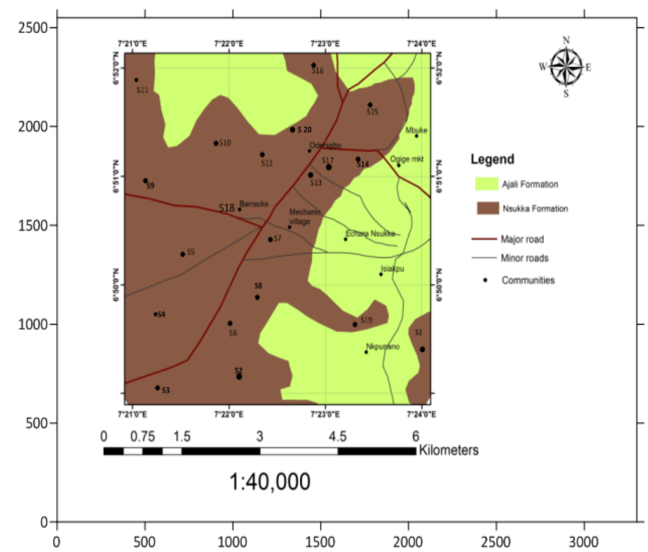

Figure 3: Local Geologic Map of the Study Area with Sample Points (Modified after Mama, et al., 2021)

MATERIALS AND METHODS

The study adopted three approaches in this survey, namely field observation, sample collection, and laboratory analysis. The first approach, reconnaissance and field survey to the study area was done from 29th August 2019 to 2nd September 2019 aimed at unravelling the geology, depth to water, possible sources of contamination, and getting permission from relevant authorities and personnel for sample collections.

Twenty perched aquifer water samples were collected from hand dug wells using 75cl plastic containers on 30th August 2019. The physical parameters such as pH and EC were measured *in situ* due to its rapid chemical changes with time while other parameters were analyzed in the laboratory using recent and standardized methods for major anions, cations, and heavy metals.

Hanna pH test meters were used to test for EC, TDS, and pH. The samples were preserved in an iced container to avoid chemical changes and sent to the laboratory on the same day. The number of samples were determined based on the availability of hand dug wells in close proximity to sewage storage tanks and open waste disposal.

The precautionary measure of rinsing the containers with source water prior to collection was done. Twenty (20) groundwater (hand dug well) samples were collected within the suspected areas of contamination (areas with perceived high population), whereas one (1) spring water from proven non-contamination sample was also collected to serve as a control experimental sample. All the analyzed parameters were compared with World Health Organization (2017) standards for drinking water quality.

Fourteen (14) different parameters were analyzed from these two set of samples (Main experiment and Control experiment). Pb, Fe, Cu, and Zn were analyzed using Atomic Absorption spectrophotometer while Cr, Cd, Hg, and Mn were analyzed colourimetrically using a UV-Visible spectrophotometer with sensitivity of 0.5nm and detection limit of 0.00-900nm. Chlorine, NO_3, HCO_3, and SO_4 were detected by Titrimetric Method. Turbidity was read directly with Turbidity test meter. The following software were used in this study, Rockworks was used to produce the Durov plot which unravel the water type and controlling factors of the analyzed physicochemical parameters. Multivariate analyses were done using Stat Graphics software, hydrochemical plots were made using Rockworks 16, and maps were produced with ArcGIS 10.2 and Surfer10.

Modified Water Quality Index (MWQI) Equation

The modified water quality index is a hydro-geochemical technique for assessing drinking water suitability by comparing the measured values of polluted and unpolluted parameters with relevant standards. Several authors (Oygard, et al., 2004, Mor, et al., 2006, Oman and Junestedt, 2008, Vasanthavigar, et al., 2010, Cumar and Nagaraja, 2011) have used extensive modified water quality index to unravel the extent and percentage of pollution. The inputs of the background values (control experiment values) make the MWQI unique from other water quality indexes. The first stage in this assessment was to assign a weight index (WI) to the parameters with minimum and maximum weight index range of 1 to 5 based on their health significances and role in groundwater while the relative weight (WI) was calculated using the following formula.

$$Wi = wi / \sum_{i=1}^{n}(wi) \quad \textbf{(1)}$$

Where n is the total number of parameters, Wi is relative weight and wi is weight of parameter. The modified water quality index (MWQI) was calculated with the following equation:

$$MWQI = \frac{\sum_{i=1}^{n}(wi * si)}{\sum_{i=1}^{n}(wi)} \quad \textbf{(2)}$$

where MWQI is the quality index for groundwater pollution, wi is the weight of the i-th pollutant variable, and n is the number of groundwater pollutants. Si, which is the values of sub-index of analyzed parameters which denotes the upper and lower classes of the values is calculated using the following equation:

$$Si = Cp / Cb \quad \textbf{(3)}$$

Where Cp is the concentration of the i-th parameter in each of the polluted groundwater samples, and the Cb is the concentration of the i-th parameter in the control (background) sample.

RESULTS AND DISCUSSIONS

The analyzed parameters are in the following order of abundance $Ca^{2+}>Mg^{2+}>K^{+}>Na^{2+}$; $Cl^{-}>NO_3^{-}>HCO_3^{-}>SO_4^{2-}$ and $Zn^{2+}>Mn^{2+}>Fe^{2+}>Pb^{2+}$ (Table 1). According to Ezenwaji and Ezenweani (2018), the mean is not a true representative of the sample from which it was computed, thus they used standard deviation above the mean, from our standard deviation computations, 90% are below the mean, and 10% are slightly above the mean indicating general true mean. pH of the groundwater samples has average of 6.32 (Table 1) indicating acidic concentrations throughout the study area which is against the recommended range of WHO (2017).

The control (Background at location 20) samples are within the permissible limit of the recommended standards which suggests that the acidic pH in the main samples could be anthropogenically induced. The total dissolved solids (TDS) ranges from 5.93 to 193.70 mg/L (Table 1) with an average of 91.7mg/L which is below the permissible limits for drinking water. The TDS values of some samples are high in some locations, and this suggests that there are dissolved solid infiltrations in the recharge water in the respective locations (Sako, 2018, Anchal, et al., 2020). Groundwater at all sites are fresh water according to the classification based on TDS (fresh: <1000 mg/L, slightly saline: 1000–3000 mg/L, moderately saline: 3000–10,000 mg/L, highly saline: 10,000–35,000 mg/L) as suggested by the US Geological Survey.

The EC of the groundwater ranges from 0.18 to 6.22 μS/cm and is still within the permissible limits. Iron ranges from 0.51 to 0.59 (μS/cm) with average of 0.56μS/cm. Iron concentration of the groundwater ranges from 0.51 to 0.59μS/cm. Maximum recommended concentration of Fe used for drinking water is 0.30mg/L (WHO 2017). The high value could be from anthropogenic source. High content of iron in the samples could be due to the lateritic nature of outlier of Nsukka Formation in the area (Uzoije, et al., 2014).

Manganese ranges from 0.76 to 2.42 mg/L with an average of 0.95 mg/L which are above the recommended standards of 0.40mg/L. However, the control spring sample at location 20 has 0.38mg/L and is below WHO, 2017 standard. This is an indication that the increased concentration of manganese in the study area is anthropogenically induced.

The lead concentration in the groundwater of the study area, ranges from 0.14 to 0.22 mg/L with average value of 0.09 and standard deviation of 0.02 mg. In all the samples, lead concentrations are above the permissible limits (WHO 2017) indicating lead contamination which could be geogenic or anthropogenic influence. Increased lead concentration in groundwater could be attributed to the influence of open waste dumps or automobile waste disposal, which contain high lead component accessories.
The Zinc concentration in the groundwater ranges from 1.42 to 1.46mg/L with average and standard deviation of 1.14 and 0.01mg/L respectively. All the zinc samples are within the recommended standards of 4.00mg/L (Table 2). High zinc concentration in groundwater is always anthropogenically and can be attributed to waste dump contamination.

The groundwater unravels sodium concentration of 0.63 to 1.11mg/L with average and standard deviation of 0.78 and 0.12mg/L, respectively which is below the permissible limits. The potassium concentration from the groundwater of the study area ranges from 2.69 to 10.41mg/L with average and standard deviation of 4.997 and 2.79mg/L, respectively. Samples are within the recommended standards mentioned above.

Anomalies in potassium concentrations is usually attributed to agricultural waste (Houria, et al. 2020). Calcium concentration ranges from 5.5 to 200.5 mg/L with average and standard deviation of 43.14 and 62.5mg/L, respectively. The magnesium concentration of groundwater in the study area ranges from 1.7 to 38.3 mg/L with an average and standard deviation of 14.8 and 14.3 mg/L, respectively. All the sample are within the WHO, 2017 recommended standard.

Bicarbonate concentration ranges from 0.34 mg/L to 1.44 mg/L with average value of 0.37 and standard deviation of 0.38mg/L. The chloride concentration ranges from 40.5 to 244.4mg/L with an average value of 152.36 mg/L and standard deviation of 62.0mg/L. All the samples are within the recommended standard (250mg/L). The nitrate concentration ranges from 9.3 to 78.5 mg/L with average of 22.70 mg/L which is above the recommended standard and could be attributed to sewage contamination. The concentration of sulfate ranges from 0.18 to 0.34mg/L with an average and standard deviation of 0.22 and 0.06 mg/L, respectively. The samples are within the recommended standards.

Geochemical Water Type and Controlling Factor

The Durov plot unraveled Ca-Cl and Na + K –Cl water types with ion exchange and simple dissolution or mixing as the dominant factors controlling the groundwater chemistry of the area. This geochemical process suggests that host rock dissolution, which is geogenic has less significance than ion exchange mechanism (Figure 4).

Table 1: Analyzed Physicochemical Parameters.

Sample No	EC μS/cm	TDS mg/L	pH	Na(mg/L)	K+ mg/L	Ca^{2+}(mg/L)	Mg^{2+} mg/L	Cl^- mg/L	HCO_3^- mg/L	SO_4^{2-} mg/L	NO_3^- mg/L
S1	0.24	60.70	6.30	0.64	2.77	15.5	3.35	194.10	0.34	0.18	20.40
S2	1.1	11.50	6.30	0.83	10.41	7.15	35.48	236.70	0.34	0.19	21.00
S3	0.49	193.70	6.30	0.75	10.41	39.2	1.7	59.20	0.34	0.19	20.90
S4	0.98	173.70	6.50	1.11	9.03	5.5	1.7	59.20	0.48	0.186	20.60
S5	0.26	66.7	6.13	0.9	4.10	5.5	1.7	151.50	0.42	0.19	20.90
S6	0.49	176.70	6.10	0.84	5.39	5.5	1.7	179.90	0.36	0.18	20.60
S7	0.35	108.70	6.40	0.73	2.85	5.5	38.8	165.70	0.58	0.18	78.50
S8	0.26	64.70	6.20	0.81	4.38	28.00	1.70	172.80	0.36	0.19	20.30
S9	0.38	115.70	6.10	0.91	2.82	5.50	29.20	208.3	0.42	0.18	20.20
S10	0.31	98.70	5.90	0.76	5.04	33.0	26.70	244.40	0.46	0.18	20.00
S11	0.27	72.70	5.90	0.67	2.82	30.50	26.70	144.2	0.4	0.18	20.00
S12	0.25	6.12	5.80	0.82	2.83	30.50	14.20	101.80	0.36	0.18	20.00
S13	0.18	5.93	5.70	0.64	2.74	18.0	1.70	165.70	0.38	0.301	19.90
S14	1.97	154.70	5.70	0.78	8.71	5.50	33.84	236.70	1.32	0.31	19.80
S15	2.25	101.70	6.30	0.66	6.65	200.5	30.13	236.70	1.26	0.31	19.80
S16	2.05	108.70	6.30	0.78	7.73	178.00	30.13	179.90	1.44	0.18	20.70
S17	0.35	111.70		0.67	3.01	178.00	7.06	144.40	0.46	0.18	20.90
S18	6.22	45.70	6.10	0.75	2.69	38.00	3.35	52.10	0.48	0.34	20.20
S19	0.31	86.70	6.00	0.63	2.74	15.5	4.36	73.40	0.4	0.34	20.10
S20	0.27	70.70	7.40	0.89	2.81	18.00	4.17	40.50	0.42	0.34	9.30
WHO	1000	500	6.5-8.5	200.0	12.00	75	50.0	250	250	250	10.00
Mean	0.65	282.00	6.31	0.78	4.99	43.14	14.88	152.3	0.37	0.22	22.70
SD	0.66	397.00	0.26	0.12	2.79	62.5	14.30	67.20	0.38	0.06	13.30

Table 2: Analyzed Heavy Metals.

Sample No	Fe^{2+}(μg/L)	Mn^{2+}(μg/L)	Pb^{2+}(μg/L)	Zn^{2+}(μg/L)
S1	0.56	1.60	0.15	1.45
S2	0.58	0.82	0.14	1.46
S3	0.58	0.81	0.16	1.46
S4	0.56	0.86	0.17	1.46
S5	0.56	0.80	0.16	1.43
S6	0.53	0.89	0.14	1.45
S7	0.55	0.82	0.16	1.43
S8	0.55	2.42	0.15	1.45
S9	0.59	0.77	0.14	1.43
S10	0.56	0.88	0.16	1.43
S11	0.59	0.76	0.17	1.42
S12	0.54	0.79	0.19	1.42
S13	0.51	0.79	0.20	1.43
S14	0.54	0.86	0.20	1.44
S15	0.55	0.91	0.22	1.44
S16	0.56	0.84	0.17	1.43
S17	0.54	0.77	0.20	1.43
S18	0.61	0.85	0.20	1.44
S19	0.55	0.85	0.20	1.43
S20	0.23	0.35	0.00	1.44
WHO	0.30	0.400	0.01	4.0
Mean	0.56	0.95	0.17	1.44
SD	0.02	0.38	0.02	0.01

Correlation Coefficient Values and Correlation Scores

Correlation coefficient is used to establish the relationships between the parameters (Danijela 2015). It is used to unravel parameters and predicts the other. The correlation scores for TDS, major ions and heavy metals are presented and significance of the parameters were fixed at values equal to or greater than 0.5 (Onwuka and Ezugwu, 2019).

Nitrate shows a positive correlation of 0.9125, 0.5077, -0.9416, and -0.7311 with chloride, potassium, iron, and magnesium, respectively (Appendix). This is also in conformity with the first cluster (Figures 5 and 6) and third factor analyses (Figure 7 and Table 4) variables which suggests that the parameter associations are from the same source and could be attributed to possible sewage contamination due to the presence of nitrate and chloride (Busico, et al., 2018).

Calcium also shows positive correlations -0.8320, 0.5839, 0.5300, and 0.5215 with manganese, zinc, bicarbonate, and sulfate, respectively. This is also in agreement with the second cluster and factor analyses variables which suggests that the parameter associations are from the similar source and could be attributed to geogenic contamination as suggested by the Durov plot in Figure 4 (Busico, et al., 2019). Sulfate has positive correlation with lead (0.7805) and is also in agreement with third cluster and first factor analyses scores (Papazotos, et al., 2019).

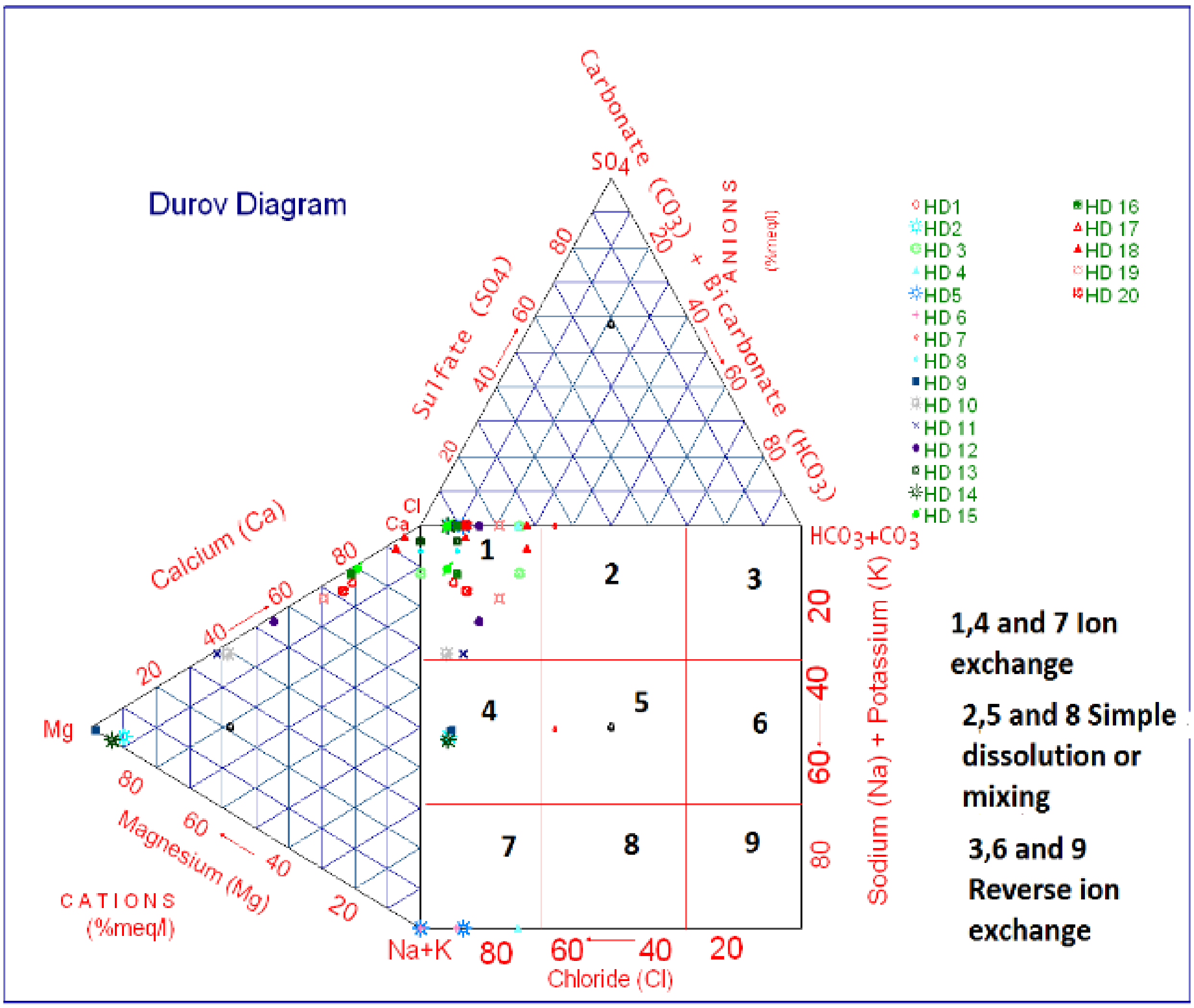

Figure 4: Durov Plot Showing Dominant Geogenic Groundwater Processes.

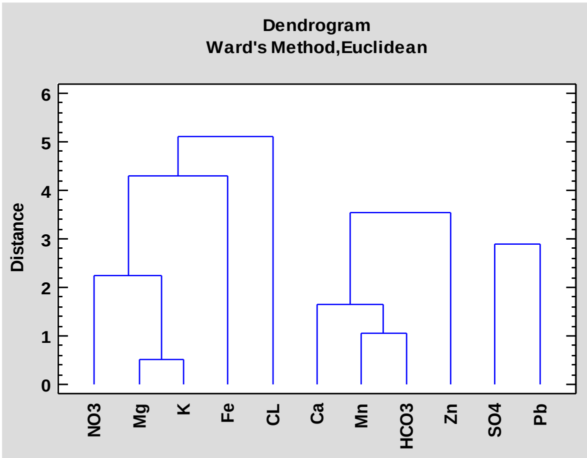

Figure 5: Dendogram Showing the Observed Clusters.

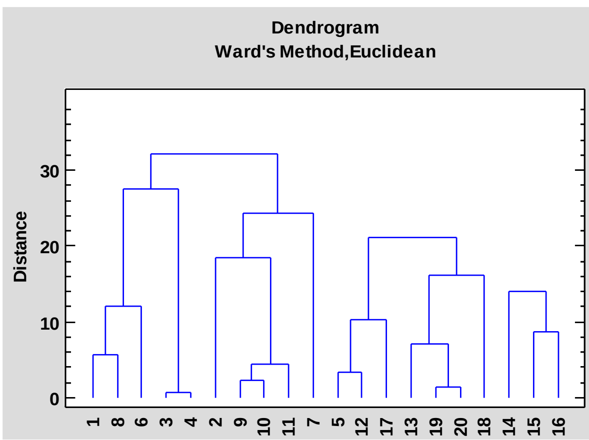

Figure 6: Dendogram Showing the Variation of the Clusters with Respect to their Locations.

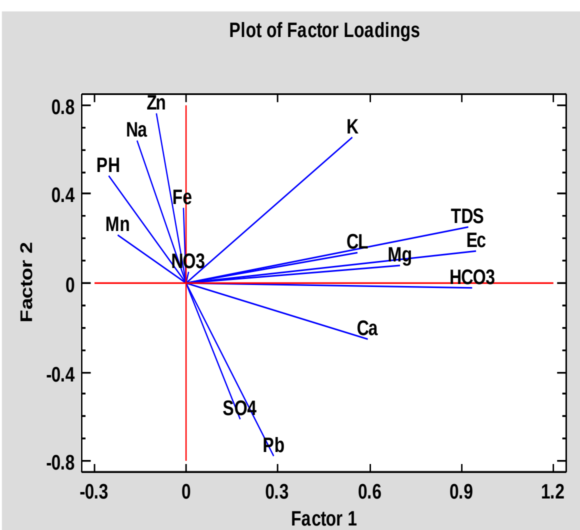

Figure 7: Showing Plots of the Factor Loading of the Analyzed Parameters.

Table 3: Showing Factor Scores of the Analyzed Parameters.

Analyte	Factor 1	Factor 2	Factor 3
NO_3	0.006	0.053	-0.594
pH	-0.255	0.481	0.401
Cl	0.560	0.1339	-0.593
Ca	0.592	-0.253	0.155
Mg	0.698	0.083	-0.559
Mn	-0.225	0.513	-0.099
Fe	-0.009	0.538	-0.149
Zn	-0.099	0.761	0.421
K	0.544	0.656	0.316
HCO_3	0.936	-0.023	0.119
SO_4	0.176	-0.612	0.510
Pb	0.285	-0.781	0.492
Ec	0.947	0.141	0.200
TDS	0.924	0.252	0.109
Na	-0.164	0.642	0.298

Cluster Scores

From the cluster analysis, the controlling factor scores were used to determine the spatial variation with respect to their location (Vasileiou, et al., 2019), (Figure 8).The first cluster (cluster 1) is high for groundwater samples at locations 1, 8, 6, 3, 4, 2, 9, 10, 11, and 7.The second cluster has high cluster for groundwater samples at locations 5, 12, 13, 17, 19, 20, and 18, The third shows high score for groundwater samples at locations 14, 15, and 16. The first cluster variables suggests that the parameter associations are from the same source and could be attributed to possible sewage contamination due to the presence of nitrate and chloride (Busico, et al., 2018) while the second cluster suggests that the parameter associations could be attributed to geogenic contamination. The third cluster was attributed to sewage waste contamination based on the sulphate and lead parameter associations

Factor Analysis

The factor analysis results shows that chloride, calcium, magnesium, EC and TDS fell within factor 1, which suggests that the parameter associations are from the same source and could be attributed to possible sewage contamination (Erdogan, et al. 2020), the factor 2 has high factor for manganese, iron, zinc, potassium, sulphate and lead and could be attributed to possible agricultural waste contamination (Voutsis, et al., 2015, Rana, 2018) The factor 3 was attributed to possible solid waste contamination due to high scores for nitrate, sulphate and manganese (Rakotondrabe, et al., 2018) (Table 4).

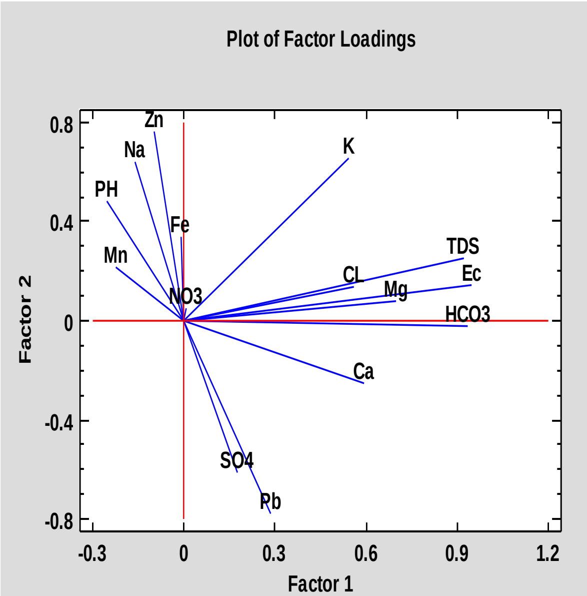

Figure 8: Showing Plots of the Factor Loading of the Analyzed Parameters.

Modified Water Quality Index

From the result of the modified water quality index, 10% indicates groundwater under no pollution impact, 25% shows moderately polluted groundwater, and 55% indicates poor groundwater with appreciable pollution while 10% are within the strongly polluted groundwater (Tables 4 and 5 and Figure 8). The moderate pollution was attributed to onsite sanitary sewage and solid waste contamination (Onwuka, et al., 2018, Paul, et al., 2019, Vasistha, et al., 2020). Samples from all the locations indicate different ranges of pollution as shown in the Table 6 with exception of the control samples at location 20

Table 4: Weight for parameters used in MWQI.

Parameters	Weight (wi)	Relative Weight (Wi) Wi-wi/∑wi
pH	4	0.1
Fe^{2+}	3	0.075
Mn^{2+}	3	0.075
Pb^{2+}	4	0.1
Zn^{2+}	2	0.05
Na^{+}	4	0.1
K^{+}	1	0.025
Ca^{2+}	2	0.05
Mg^{2+}	2	0.05
HCO_3^-	3	0.075
Cl^-	4	0.1
NO_3^-	4	0.1
SO_4^{2-}	4	0.1
Total	∑wi=40	∑Wi= 1.00

Table 5: Water Quality Classification based on MWQI Value.

MWQI Value	Interpretations	% of pollution
MWQI ≤1	Groundwater under no pollution impact	10
1<MWQI ≤2	Moderately polluted groundwater	25
2<MWQI ≤5	Poor groundwater with appreciable pollution	55
MWQI >5	Strongly polluted groundwater	10

Table 6: Modified Water Quality Index (MWQI) Classification for the Individual Water Sample.

Sample ID	MWQI Value	Degree of Pollution
S1	1.52	Moderate pollution
S2	1.96	Moderate pollution
S3	1.54	Moderate pollution
S4	0.32	No pollution
S5	3.77	Appreciable pollution
S6	1.17	Moderate pollution
S7	4.33	Appreciable pollution
S8	3.44	Appreciable pollution
S9	2.01	Appreciable pollution
S10	3.28	Appreciable pollution
S11	3.16	Appreciable pollution
S12	4.74	Appreciable pollution
S13	5.46	Strongly polluted
S14	2.13	Appreciable pollution
S15	4.35	Appreciable pollution
S16	3.69	Appreciable pollution
S17	6.84	Strongly polluted
S18	2.43	Appreciable pollution
S19	1.91	Moderate pollution
S20	0.72	No pollution

CONCLUSION

The following conclusions were drawn from the research:

The analyzed parameters when compared with WHO 2017 standard showed that most were above the permissible limits and was attributed to less geogenic and more anthropogenic impacts. The result of the modified water quality index indicates 10% groundwater under no pollution impact, 25% shows moderately polluted groundwater, and 55% poor groundwater with appreciable pollution while 10% are within the strongly polluted groundwater.

The moderate pollution was attributed to onsite sanitary sewage and agricultural waste contamination. This geochemical process suggests that host rock dissolution which is geogenic has less significance than ion exchange mechanism. Nitrate shows a positive correlation of **0.9125, 0.5077, -0.9416** and **-0.7311** with chloride, potassium, Iron and magnesium respectively. This is in conformity with the first cluster and third factor analyses variables which suggest that the parameter associations are from the same source and could be attributed to possible sewage contamination due to the presence of nitrate and chloride.

Calcium also shows positive correlations **-0.8320, 0.5839, 0.5300**, and **0.5215** with manganese, Zinc, bicarbonate and sulfate respectively. This also aligns with the second cluster and factor analyses variables which suggest that the parameter associations are from a similar source and could be attributed to geogenic contamination as suggested by the Durov plot. Sulfate has positive correlation with lead (0.7805) and is also in agreement with third cluster and first factor analyses scores.

Limitations

The limited access and availability of hand-dug wells within the study area reduced the number of samples collected. The absence of mature open waste dumps (over 50 years) with appreciable proximity to the hand dug wells also affected our choice of sampling.

REFERENCES

1. Amah, J.I., I.O. Elizabeth, and O.O. Solomon. 2016. “Statistical Modeling of the Hydrostratigraphy and Hydraulics of the Cretaceous Aquifers in Nsukka, North of the Anambra Basin, Southeast Nigeria”. *Advances in Applied Science Research*. 2016, 7:32-41.

2. Anchal, S., G. Rajiv, and K.G. Ashok. 2020. “Impact Assessment of Leachate Pollution Potential on Groundwater: An Indexing Method”. *J of Environ Engineering*. 146.

3. Aniebone, V.O. 2014. “Hydrogeochemistry and Quality Assessment of Some Ground Water Samples from Enugu and Environs, South-Eastern, Nigeria”. *Global of Journal of Geo. Science* 13(1):15.

4. Batabyal, A.K. and S. Chakraborty. 2015. “Hydrogeochemistry and Water Quality Index in the Assessment of Groundwater Quality for Drinking Uses”. *Water Environ Res*. 87: 607–617.

5. Busico, G., E. Cuoco, N. Kazakis, N. Colombani, M. Mastrocicco, D. Tedesco, and K. Voudouris. 2018. “Multivariate Statistical Analysis to Characterize/Discriminate between Anthropogenic and Geogenic Trace Elements Occurrence in the Campania Plain, Southern Italy”. *Environ Pollut.* 234: 260-269. Doi: 10.1016/j.envpol.2017.11.053.

6. Busico, G., N. Kazakis, E. Cuoco, N. Colombani, D. Tedesco, K. Voudouris, and M. Mastrocicco. 2019. “A Novel Hybrid Method of Specific Vulnerability to Anthropogenic Pollution using Multivariate Statistical and Regression Analyses”. *Water Research*. 171.

7. Cumar, S.K. and B. Nagaraja. 2011. “Environmental Impact of Leachate Characteristics on Water Quality”. *Environ Monitoring and Assess*. 178:499–505.

8. Egboka, B.C. and K.O. Uma. 1986. “Comparative Analysis of Transmissivity and Hydraulic Conductivity Value, from Ajali Aquifer System”. *Nigeria Journal of Hydrogeology*. 83: 185-196.

9. Erogan, I.G., E. Fosso-Kan, and S.K.O. Ntwampe. 2020. “Seasonal Variation of Hydrochemical Characteristics of Open-Pit Groundwater near a closed Matalliferious Mine in O’kiep Namaqualand Region, South Africa”. *Environ Earth Sci*. 79: 119. https://doi.org/10.1007/s12665-020-8863-2.

10. Eze, C.C. and G.Z. Ugwu. 2010. “Geoelectrical Sounding for Estimating Groundwater Potential in Nsukka L.G.A. Enugu State, Nigeria”. *International Journal of Physical Science.* 5: 415-420.

11. Ezeh, C.C. 2012. “Hydrogeophysical Studies for the Delineation of Potential Groundwater Zones in Enugu State Nigeria”. *International Research Journal of Geology and Mining (IRJGM)*. (2276-6618) 2: 103-11.

12. Ezeigbo, H.I. and D.C. Ozoko. 1989. “An Evaluation of the Water Resources of Nsukka and Environs, Anambra State Nigeria”. *Water Resources (NAH).* 1: 111-116.

13. Ezenwaji, E.E. and I.D. Ezenweani. 2018. “Spatial Analysis of Groundwater Quality in Warri Urban, Nigeria”. *Sustain Water Resour. Manag.* 1:2. https://doi.org/10.1007/s40899-018-0264-2.

14. Fazelabdolabadi, B. and M.H. Golestan. 2020. “Towards Bayesian Quantification of Permeability in Micro-scale Porous Structures–The Database of Micro Networks”. *High Tech and Innovation J*. 1: 148-160. DOI: 1028991/hij-2020-01-04-02.

15. Flyhammar, P.J. 1995. “Heavy Metals in the Environment”. *Journal of Environmental Quality*. 24: 612–621.

16. Ezigbo H.I. and D.C. Ozoko. 1989. “An Evaluation of the Water Resources of Nsukka and Environs, Anambra State, Nigeria”.
.

17. Gulgundi, M.S. and A. Shetty. 2018. “Groundwater Quality Assessment of Urban Bengaluru using Multivariate Statistical Techniques”. *Appl Water Sci* 8: 43. https://doi.org/10.1007//s13201-018-0684-z.

18. Houria, B., K. Mahdi, and T.F. Zohra. 2020. “Hydrochemical Characterisation of Groundwater Quality: Merdja Plain (Tebessa town, Algeria)”. *Civil Eng J*. 6(2): 318-325.

19. Jiayu, W., W.S. Timothy, R.T. Janette, K.K. Randall, and J.F. Kristie. 2015. “Watershed Features and Stream Water Quality: Gaining insight through Path Analysis in a Midwest Urban Landscape”. *U.S.A. Landscape and Urban Planning*. 143(5): 219-229.

20. Kazakis, N., C. Mattas, A. Pavlou, O. Patrikaki, and K. Voudouris. 2017. “Multivariate Statistical Analysis for the Assessment of Groundwater Quality under different Hydrogeological Regimes”. *Environ Earth Sci*. 6(349): 1-33.

21. Khan, A.U., H.U. Rahman, L. Ali, M.I. Khan, H.M. Khan, A,U, Khan, and I. Ahmad. 2021. “Complex Linkage between Watershed Attributes and Surface Water Quality: Gaining Insight via Path Analysis”. *Civil Eng. J.* 7(4): 701-712.

22. Mama, C.N., C.N. Chidozie, I. Ogbonnaya, H.O. Obinna, K.E. Chimankpam, and J.U. Ikechukwu. 2020. “Assessment of Heavy Metal Pollution in Soils: A Case Study of Nsukka Metropolis”. *Environmental Forensics*, DOI: 10.1080/15275922.2020.1850567.

23. Mama, C.N., O. Igwe, and C.K. Ezugwu. 2021. “Impact Assessment of Solid Waste Contamination on Soil: A Case Study of Nsukka and Environs”. *Arab J Geosci.* 14: 935. https://doi.org/10.1007/s12517-021-07315-9.

24. Mor, S., K. Ravindra, R.P. Dahiya, and A. Chandra. 2006. “Leachate Characterization and Assessment of Groundwater Pollution Near Municipal Solid Waste Landfill Site”. *Environmental Monitoring and Assessment*.118: 435–456.

25. Nigerian Standard for Drinking Water Quality (NSDWQ). 2015. Niger Ind Stand 554:13–14.

26. Oman, C.B. and C. Junestedt. 2008. “Chemical Characterization of Landfill Leachates—400 Parameters and Compounds”. *Waste Management*. 28: 1876–1891.

27. Onwuka, O.S., C.K. Ezugwu, and S.I. Ifediegwu. 2018. “Assessment of the Impact of Onsite Sanitary Sewage System and Agricultural Wastes on Groundwater Quality in Ikem and its Environs, South-Eastern Nigeria”. *Geol Ecol Landsc.* https://doi.org/10.1080/24749 508.2018.1493635.

28. Onwuka, S.O. and C.K. Ezugwu. 2019. “Multivariate Statistical Assessment and Spatial Distribution of Groundwater Contamination in Neke and its Environ South-Eastern Nigeria”. *Int J of Phy. Scien*. 14(8): 62-80.

29. Øygard, J.K., A. Måge, and E. Gjengedal. 2004. “Estimation of the Mass-Balance of Selected Metals in four Sanitary Landfills in Western Norway, with Emphasis on the Heavy Metal Content of the Deposited Waste and the Leachate”. *Water Research*. 38: 2851–2858.

30. Ozoko, D.C. 2015. “The Geology of Perched Aquifers and Hydrochemistry of Springs in Nsukka Area, South-Eastern Nigeria”. *J of Environ and Earth Scs*. 5:8

31. Ozoko, D.C. 1988. “The Hydrogeology of Nsukka Area and Environs, Anambra State, Nigeria”. Unpublished M.Sc. Thesis, University of Nigeria, Nsukka, Nigeria. 127pp.

32. Papazotos, P., E. Vasileiou, and M. Perraki. 2019. “The Synergistic Role of Agricultural Activities in Groundwater Quality in Ultramafic Environments: The Case of the Psachna Basin, Central Euboea, Greece”. *Environ Monit. Assess*. 191: 317. https://doi.org/10.1007/s10661-019-7430-3.

33. Paul, R., K. Brindha, G. Gowrisankar, M.L. Tan, and M.K. Singh. 2019. “Identification of Hydrogeochemical Processes Controlling Groundwater Quality in Tripura, Northeast India using Evaluation Indices, GIS, and Multivariate Statistical Methods”. *Environ Earth Sciences*. 78(15): 470.

34. Rakotondrabe, F., J.R.N. Ngoupayou, Z. Mfonka, E.H. Rasolomanana, A.J.N. Abolo, and A.A. Ako. 2018. “Water Quality Assessment in the Bétaré-Oya Gold Mining Area (East-Cameroon): Multivariate Statistical Analysis Approach”. *Scs of the Total Environment*”. 610: 831-844.

35. Rana, R., R. Ganguly, and A.K. Gupta. 2018. “Indexing Method for Assessment of Pollution Potential of Leachate from Non-Engineered Landfill Sites and its Effect on Ground Water Quality”. *Environ Monit Assess*. 190: 46. https://doi.org/10.1007/s10661-017-6417-1.

36. Saba, N. and R. Umar. 2016. “Hydrogeochemical Assessment of Moradabad City, An Important Industrial Town of Uttar Pradesh, India”. *Sustain Water Resour Manag*. 2:217–236.

37. Sako, A., J.M. Yaro, and O. Bamba. 2018. “Impacts of Hydrogeochemical Processes and Anthropogenic Activities on Groundwater Quality in the Upper Precambrian Sedimentary Aquifer of Northwestern Burkina Faso”. *Appl Water Scs*. 8:88.

38. Uma, K.O. 2003. “Hydrogeology of the Perched Aquifer Systems in the Hilly Terrains of Nsukka Town, Enugu State, S.E. Nigeria”. *Water Resour. J. Nig. Asso. of Hydrogeologists*. 14, 27.

39. Uma, K.O. 2003. Hydrogeology of the Perched Aquifer Systems in the Hilly Terrains of Nsukka Town, Enugu State, Nigeria”. *Water Resour. J. NAH*. 14: 85-92.

40. Uzoije, A.P., A.A. Onunkwo, S.I. Ibeneme, and E.Y. Obioha. 2014. “Hydrogeology of Nsukka Southeast – A Preliminary Approach to Water Resources Development”. *American J. of Engr. Research (AJER)*. 03: 150-162. www.ajer.org.

41. Vasanthavigar, M., K. Srinivasamoorthy, K. Vijayaragavan, G.R. Rajiv, S. Chidambaram, P. Anandhan, R. Manivannan, and S. Vasudevan. 2010. “Application of Water Quality Index for Groundwater Assessment: Thirumanimuttar Sub-basin, Tamilnadu, India”. *Environ Monitoring and Assess*, 17: 595–609.

42. Vasileious, E., P. Papazotos, and P. Dimitrakopoulos. 2019. “Expounding the Origin of Chromium in Groundwater of the Sarigliol Basin, Western Macedonia, Greece: A Cohesive Statistical Approach and Hydrochemical Study”. *Environ. Monit. Assess.* 191:509. https://doi.org/10.1007/s10661-019-7430-3

43. Vasistha, P. and R. Ganguly, R. 2020. “Assessment of Spatio-Temporal Variations in Lake Water Body using Indexing Method”. *Environ. Sci. Pollut. Res.* 27: 41856–41875. https://doi.org/10.1007/s11356-020-10109-3.

44. Voutsis, N., E. Kelepertzis, E. Tziritis, and A. Kelepertsis. 2015. “Assessing the Hydrogeochemistry of Groundwaters in Ophiolite Areas of Euboea Island, Greece, using Multivariate Statistical Methods”. *J. of Geochem. Explorn*. 159, 79-92.

45. WHO (2017). *Guidelines for drinking water quality, 3rd edn.* World Health Organization: Geneva, Switzerland.

Appendix: Correlation Table

	NO^{-}_{3}	pH	Cl-	Ca^{-}	Mg^{2+}	Mn^{2+}	Fe^{2+}	Zn^{2+}	K^{+}	HCO^{-}_{3}	SO^{2-}_{4}	Pb^{2+}
NO^{-}_{3}		-0.0353	**0.9125**	-0.1185	**0.5077**	-0.0640	**-0.9416**	-0.0956	**-0.7311**	0.0207	0.2395	-0.2417
		(20)	(20)	(20)	(20)	(20)	(20)	(20)	(20)	(20)	(20)	(20)
		0.8824	0.6367	0.6186	0.0744	0.7887	0.8617	0.6884	0.5818	0.9309	0.3091	0.3045
pH	-0.0353		-0.3658	-0.0138	-0.2682	-0.0673	0.0293	0.4543	0.1966	-0.1930	0.2197	-0.2425
	(20)		(20)	(20)	(20)	(20)	(20)	(20)	(20)	(20)	(20)	(20)
	0.8824		0.1127	0.9538	0.2529	0.7781	0.9024	0.0442	0.4060	0.4150	0.3520	0.3029
Cl^{-}	**0.9125**	-0.3658		0.1686	**0.6347**	0.1435	-0.0727	-0.1455	0.1770	0.3827	0.2510	-0.2778
	(20)	(20)		(20)	(20)	(20)	(20)	(20)	(20)	(20)	(20)	(20)
	0.6367	0.1127		0.4772	0.0026	0.5461	0.7606	0.5406	0.4554	0.0958	0.2858	0.2356
Ca^{2+}	-0.1185	-0.0138	0.1686		0.1910	**-0.8320**	-0.0512	**-0.6008**	0.1043	**0.5839**	**0.5300**	**0.5215**
	(20)	(20)	(20)		(20)	(20)	(20)	(20)	(20)	(20)	(20)	(20)
	0.6186	0.9538	0.4772		0.4198	0.7272	0.8302	0.3959	0.6615	0.0069	0.8242	0.0642
Mg^{2+}	0.4077	-0.2682	**0.6347**	0.1910		-0.2780	0.2261	-0.3052	0.2335	0.4618	0.1261	-0.0858
	(20)	(20)	(20)	(20)		(20)	(20)	(20)	(20)	(20)	(20)	(20)
	0.0744	0.2529	0.0026	0.4198		0.2354	0.3378	0.1907	0.3218	0.0099	0.5963	0.7192
Mn^{2+}	-0.3320	-0.0673	0.1435	**-0.8320**	-0.2780		-0.0850	**0.3537**	-0.0967	-0.1618	0.1359	-0.3409
	(20)	(20)	(20)	(20)	(20)		(20)	(20)	(20)	(20)	(20)	(20)
	0.7887	0.7781	0.5461	0.7272	0.2354		0.7215	0.1261	0.6850	0.4957	0.5679	0.1413
Fe^{2+}	0.9416	0.0293	-0.0727	-0.0512	0.2261	-0.0850		0.1611	0.1309	-0.0523	0.1838	-0.3306
	(20)	(20)	(20)	(20)	(20)	(20)		(20)	(20)	(20)	(20)	(20)
	0.8617	0.9024	0.7606	0.8302	0.3378	0.7215		0.4976	0.5823	0.8265	0.4379	0.1546
Zn^{2+}		0.4543	-0.1455	-0.2008	-0.3052	0.3537	0.1611		**0.5933**	-0.0820	0.1316	-0.4115
	(20)	(20)	(20)	(20)	(20)	(20)	(20)		(20)	(20)	(20)	(20)
	0.6884	0.0442	0.5406	0.3959	0.1907	0.1261	0.4976		0.0058	0.7310	0.5801	0.0715
K^{2+}	**-0.7311**	0.1966	0.1770	0.1043	0.2335	-0.0967	0.1309	0.5933		0.5003	0.1639	-0.1841
	(20)	(20)	(20)	(20)	(20)	(20)	(20)	(20)		(20)	(20)	(20)
	0.5818	0.4060	0.4554	0.6615	0.3218	0.6850	0.4823	0.0058		0.0247	0.4899	0.4371
$HC0^{-}_{3}$	0.0207	-0.1930	0.3827	0.5839	0.5618	-0.1618	-0.0523	-0.0820	0.5003		0.2371	0.3259
	(20)	(20)	(20)	(20)	(20)	(20)	(20)	(20)	(20)		(20)	(20)
	0.9309	0.4150	0.0958	0.0069	0.0099	0.4957	0.8265	0.7310	0.0247		0.3142	0.1609
SO^{2-}_{4}	0.3300	-0.2197	-0.2510	0.0530	-0.1261	-0.1359	-0.1838	-0.1316	-0.1639	0.2371		0.7805
	(20)	(20)	(20)	(20)	(20)	(20)	(20)	(20)	(20)	(20)		(20)
	0.3091	0.3520	0.2858	0.8242	0.5963	0.5679	0.4379	0.5801	0.4899	0.3142		0.0000
Pb^{2+}	**0.5215**	-0.2425	-0.2778	0.4215	-0.0858	-0.3409	-0.3306	-0.4115	-0.1841	0.3259	**0.7805**	
	(20)	(20)	(20)	(20)	(20)	(20)	(20)	(20)	(20)	(20)	(20)	
	0.3045	0.3029	0.2356	0.0642	0.7192	0.1413	0.1546	0.0715	0.4371	0.1609	0.0000	
EC	-0.0807	-0.1588	0.4223	**0.5403**	**0.5336**	-0.1382	-0.0559	0.1071	0.6469	0.9414	0.1787	0.2499
	(20)	(20)	(20)	(20)	(20)	(20)	(20)	(20)	(20)	(20)	(20)	(20)
	0.7353	0.5037	0.0636	0.0139	0.0154	0.5613	0.8149	0.6532	0.0021	0.0000	0.4509	0.2879
TDS	-0.0753	-0.0279	0.5246	0.4436	0.6206	-0.1360	0.0632	0.1629	0.6911	0.8287	0.1229	0.1107
	(20)	(20)	(20)	(20)	(20)	(20)	(20)	(20)	(20)	(20)	(20)	(20)
	0.7524	0.9071	0.0176	0.0501	0.0035	0.5674	0.7913	0.4926	0.0007	0.0000	0.6057	0.6422
Na^{+}	-0.8165	0.3893	-0.2181	-0.3408	-0.1042	-0.0572	0.0983	0.4700	0.3394	-0.0912	0.2712	-0.3399
	(20)	(20)	(20)	(20)	(20)	(20)	(20)	(20)	(20)	(20)	(20)	(20)
	0.6248	0.0898	0.3556	0.1415	0.6619	0.8108	0.6802	0.0365	0.1432	0.7020	0.2475	0.1426

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