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Statistical and Pollution Index Assessment of Water Quality Parameters in Ilorin metropolis, Nigeria

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Abstract:
Background: *The practice of determining water quality before usage and consumption of water resources globally can never be over-emphasized due to proliferating natural and anthropogenic issues that pollutes both surface and groundwater everywhere. It is therefore everyone's responsibility to be aware of the necessity to protect the water resources around us. This study utilized an integrated approach of descriptive statistics, multivariate statistics, geostatistics (kriging) and Pollution Index to measure the quality of water in Ilorin metropolis.*

Materials and Methods: *Water samples were collected from hand-dug wells across the metropolis and were analysed for physicochemical parameters such as T°, TBD, pH, EC, TDS, TH, Ca^{2+}, Mg^{2+}, Cl^-, F, NH_3, NO_3^-, and NO_2. Also, heavy metals constituents as Pb, Cd, Cu, Cr, Ni, Zn and Fe, which were compared to the NSDWQ standards. Descriptive statistical methods were used to generate a summary of range, minimum and maximum concentration, standard deviation and variance of all parameters. Pearson's correlation coefficient (r) value was used to identify the relationship between all parameters with its significance test of p-value $p<0.05$, $p<0.01$. Geostatistical (kriging) method was used to generate a spatial model from the standardized concentration of all parameters. Pollution Index (Pi) was used to characterize parameters with significant level of pollution*

Results: *The result revealed constituents such as TBD, TDS, Ca, Mg, Cl, NO_2, TH, Pb, Cd, Cr and Ni were higher than the NSDWQ permissible limits at some sampled locations. While, Pearson correlation revealed significant positive correlation and negative correlation between parameters. Geostatistical analysis showed zones with low, medium and high risk of poor water quality within the study area, then the pollution index (Pi) indicated Mg, NO_2, Pb, Cd, Cr and Ni were the significant pollutants according to the method used.*

Conclusion: *The outcome of this study showed that an integrated approach to the study of water quality will provide insights that can help in protection and management of water resources.*

Key Word*:Water Quality; Pearson Correlation; Multivariate Statistics;Geostatistics; Pollution Index*

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I. Introduction

With reference to previous studies on the groundwater contamination by possible leakages of underground storage tanks from filling stations aged above 15 years in Ilorin metropolis, various assessments involving physicochemical, heavy metals and volatile organic compounds were carried out[1,2]. These studies revealed that activities from the surrounding filling stations might be responsible for the identified anomalies in the quality of water taken from sampled hand dug wells at close proximity, which poses great health risk for potential users or consumers of the water resources.

In determining water quality, the practice of measuring the concentrations of parameters and comparing it to standards is generally acceptable but a further investigative procedure of applying statistical analysis such as correlation and regression coefficient, geostatistical method (kriging) and other simple descriptive statistical methods on large data will helps in revealing the interrelationship of the parameters assessed, with respect to the relative concentration of various pollutants in indicating the extent of water quality[3]. One unique advantage of the kriging approach is its application in spatial correlation and variations of the available water quality parameters in modelling, which can be used to predict the quality at un-sampled locations within a defined context[4].

Other approaches developed over time for the effective evaluation of water quality were the water quality indices (WQI). There are different types of WQI, examples are Heavy metal pollution index (HPI), heavy metal evaluation index (HEI), Water Quality Index, etc.[5]. These indices help in converting large water quality information into a single value that can now be scaled in determining the level of pollution[6] and has been applied by many public and environmental health scientists globally.

This study aimed at utilizing an integrated approach of descriptive statistics, multivariate statistics, geostatistical modelling and Pollution Index (Pi) to further interpret and represent the water quality in Ilorin metropolis.

II. Material and Methods

Experimental methods

All water samples were collected from hand dug wells at close proximities to the sampled filling stations within Ilorin metropolis. Physico-chemical parameters such as, temperature, turbidity, pH, electrical conductivity (EC), total dissolved solids (TDS), total hardness (TH), calcium (Ca2+), magnesium (Mg2+), chloride (Cl-), Fluoride (F-), Ammonia (NH3), Nitrate (NO3-), and Nitrite (NO2) were measured following described standard procedures[7]. Also, heavy metals such as Lead (Pb), Cadmium (Cd), Copper (Cu), Chromium (Cr), Nickel (Ni), Zinc (Zn) and Iron (Fe) were measured using the atomic absorption spectrophotometer as described by the Association of Official Analytical Chemist[8].

Statistical methods

The statistical analyses were done by using Statistical Packages for Social Science(SPSS version 23)[9], the parameters measures were analyzed using descriptive statistical methods which showed the range, minimum value, maximum value, variance and standard deviation, the result were presented in tables and compared to the Nigeria Standard for Drinking Water Quality[10]. The multivariate statistical analysis explored was the Pearson correlation (r), which indicates the association between two variables[11]. In order to calculate correlation coefficients, correlation matrix was constructed by calculating the coefficients of different pairs of parameters, a correlation coefficient near -1 or 1 means a strongest negative or positive relationship between them[12,13], the significance of correlation was further tested by applying p-value. The significance is considered at the level of 0.01 and 0.05 (2- tailed analysis). Geostatistical analysis (kriging) was used to reveal the spatial distribution of the parameters using Geographical Information System (GIS), the ordinary kriging was preferred due to its simplicity and prediction accuracy[4] with which a kriged map showing a spatial distribution of the measured parameters were generated using ESRI ArcGIS (10.4 version)[14].

Pollution Index (Pi)

Pollution index (Pi) is defined as the ratio of the concentration of individual parameter evaluated to that of recommended standard. It expresses the relative pollution contributed by each parameter. The threshold value is 1.0. Values less than 1.0 indicates no pollution has occurred whereas values greater than 1.0 shows significant level of pollution.

III. Result

Descriptive Statistical results

The descriptive statistical results of both physico-chemical parameters and heavy metals are summarized and presented on Table 1 and Table 2 respectively. Each table contained information such as range of concentration, minimum and maximum concentrations, mean, standard deviation, variance and the NSDWQ[10].

Table no 1: Descriptive Statistical Summary for Physico-chemical parameters

Parameters	Range	Minimum	Maximum	Mean	Std. Deviation	Variance	NSDQW
T (°C)	1.3	26.6	27.9	27.238	.3188	.102	Ambient
TBD. (NTU)	6.9	2.1	9.0	5.762	2.0533	4.216	5
pH	.5	7.0	7.5	7.219	.1234	.015	6.5-8.5
TDS (mg/l)	475.7	94.3	570.0	406.281	160.5346	25771.354	500
Ca (mg/l)	70.0	15.0	85.0	49.615	15.5334	241.286	75
Mg (mg/l)	107.0	12.0	119.0	42.885	24.1848	584.906	2.0
Cl- (mg/l)	253.0	12.0	265.0	172.423	102.1129	10427.054	250
F- (mg/l)	.33	.05	.38	.1615	.06757	.005	1.5
NH3 (mg/l)	.17	.10	.27	.1612	.05472	.003	-
NO3 (mg/l)	6.10	4.10	10.20	7.8308	2.03383	4.136	50
NO2 (mg/l)	.22	.10	.32	.1700	.07730	.006	0.2
CON. (µS/cm)	780	200	980	743.00	311.343	96934.640	1000
TH (mg/l)	254	130	384	242.23	100.206	10041.225	150

Table no 2: Descriptive Statistical Summary for Heavy metal concentration of Water Samples

Parameters	Range	Minimum	Maximum	Mean	Std. Deviation	Variance	NSDQW
Pb (mg/l)	0.04	0.01	0.05	.02	.013	.000	0.01
Cd (mg/l)	0	0.01	0.01	.01	.000	.000	0.003
Cu (mg/l)	0.07	0.01	0.08	.47	1.743	3.037	1.00
Cr (mg/l)	0.65	0.01	0.75	.03	.021	.000	0.05
Ni (mg/l)	0.035	0.01	0.045	.02	.013	.000	0.02
Zn (mg/l)	0	0.1	0.01	.01	.000	.000	3.00
Fe (mg/l)	0.16	0.01	0.17	.35	1.485	2.205	0.30

Multivariate Statistical results

The multivariate statistical method used was the Pearson correlation (r) which reveals the mutual relationship between two variables, which were later tested for significance by applying p-value. Correlation coefficient (r) ranges between +1 and -1, and a positive correlation means an increase in a parameter will cause a respective increase in the other parameter while a negative correlation means an increase in a parameter will respectively decrease the other parameter. The parameters are said to be correlated when the value of $r > 0.5$ but can be categorized as been strong when ranged between ±0.8 to ±1.0, moderate between ±0.5 to ±0.8 and weak between ±0.0 to ±0.5. The variations are significant if $p<0.05$, $p<0.01$, and non-significant if $p>0.05$.

Table no 3: Pearson Correlations among Physico-chemical parameters of Water Samples

Parameters	T (°C)	TBD. (NTU)	pH	CON. (µS/cm)	TDS (mg/l)	TH (mg/l)	Ca (mg/l)	Mg (mg/l)	Cl- (mg/l)	F- (mg/l)	NH3 (mg/l)	NO3 (mg/l)	NO2 (mg/l)
T (°C)	1												
TBD. (NTU)	.905**	1											
pH	.723**	.673**	1										
CON. (µS/cm)	-.607**	-.614**	-.712**	1									
TDS (mg/l)	-.612**	-.524**	-.555**	.604**	1								
TH (mg/l)	-.310	-.206	-.441*	.526**	.863**	1							
Ca (mg/l)	-.154	-.216	-.257	.507**	.195	.246	1						
Mg (mg/l)	-.089	.143	-.106	-.107	-.029	-.077	-.415*	1					
Cl- (mg/l)	-.501**	-.390*	-.413*	.325	.942**	.830**	.051	.008	1				
F- (mg/l)	-.582**	-.652**	-.292	.349*	.538**	.190	.191	-.126	.503**	1			
NH3 (mg/l)	.614**	.575**	.506**	-.676**	-.514**	-.417*	-.311	.078	-.330	-.330*	1		
NO3 (mg/l)	.820**	.964**	.513**	-.406*	-.383*	-.046	-.122	.204	-.302	-.672**	.458**	1	
NO2 (mg/l)	.839**	.872**	.797**	-.904**	-.623**	-.440*	-.440*	.152	-.399*	-.533**	.748**	.728**	1

**Correlation is significant at the 0.01 level (2-tailed)

*Correlation is significant at the 0.05 level (2-tailed

Table no 4: Pearson Correlations among Heavy metal concentration of Water Samples

	Pb (mg/l)	Cd (mg/l)	Cu (mg/l)	Cr (mg/l)	Ni (mg/l)	Zn (mg/l)	Fe (mg/l)
Pb (mg/l)	1						
Cd (mg/l)	.						
Cu (mg/l)	-.314	.	1				
Cr (mg/l)	.732*	.	.410	1			
Ni (mg/l)	-.174	.	-.284	-.191	1		
Zn (mg/l)	.	.	.	.	.	.	
Fe (mg/l)	-.035	.	.095	.110	.794*	.	1

*Correlation is significant at the 0.05 level (2-tailed

Geostatistical Modelling (Kriging)

The physicochemical and heavy metals parameters across all samples were modelled using the ArcGIS 10.4 software by the geostatistical approach called Kriging.

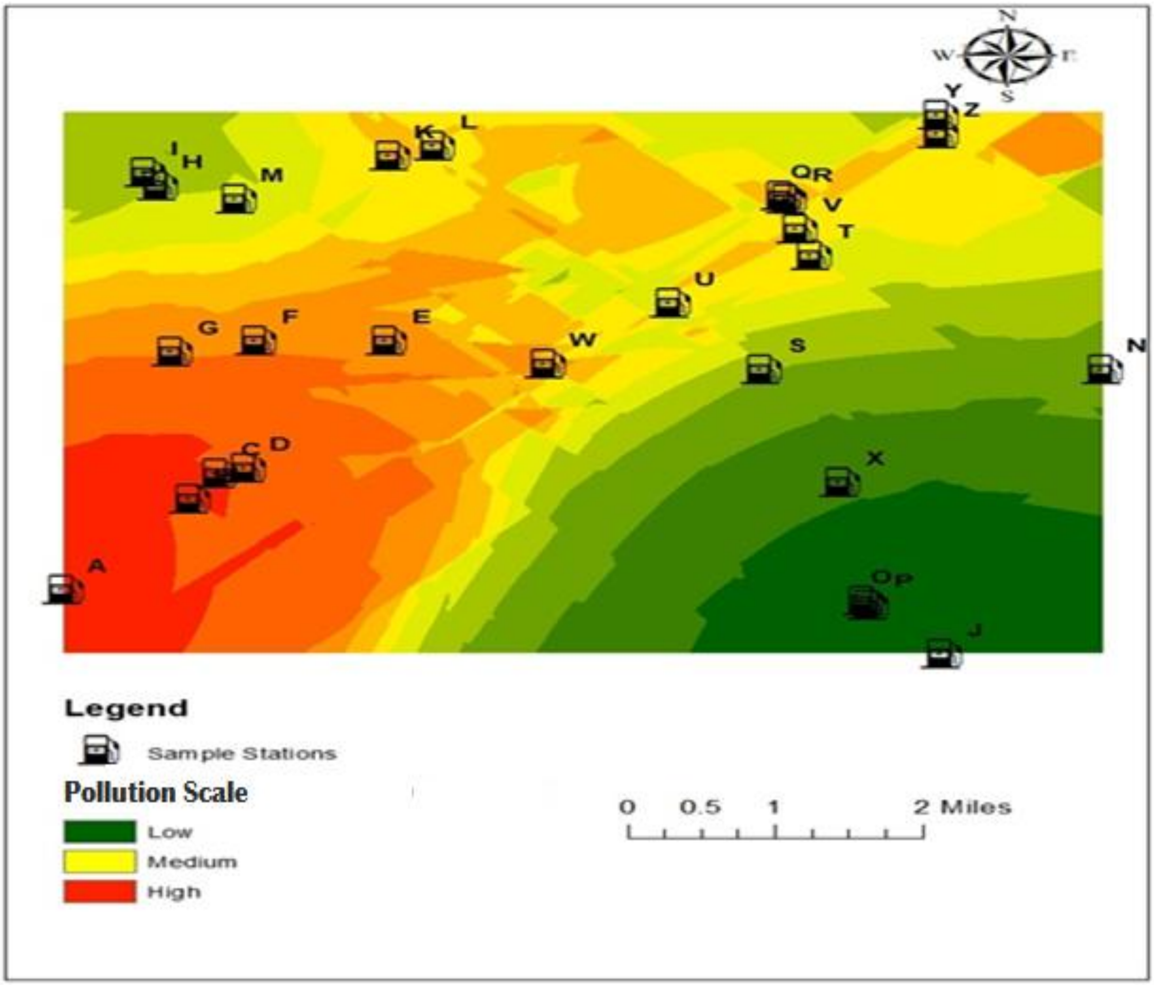

Figure 1: Kriged map based on Physico-chemical and heavy metal parameters in the samples

Pollution Index (Pi)

This tool was used in the testing of multivariable water data against numeric water-quality guidelines according to the NSDWQ[10] standard to produce a single unit less number that represents the overall water quality.

Table no 5: Pollution Index (PI) for all Sample Parameters

Parameters	Pollution Index (PI)	Concentration	NSDQW Standards	Remark
Temperature	Ambient	-	-	
TBD	1.15	5.76	5	significant level of pollution
pH	0.96	7.22	6.5 – 8.5	
CON	0.74	7.43	1000	
TDS	0.81	406.28	500	
TH	1.61	242.23	150	significant level of pollution
Ca	0.66	49.62	75	
Mg	21.44	42,885	2.0	significant level of pollution
Cl	0.69	172.42	250	
F	0.11	0.162	1.5	
NH3	-	0.161	-	
NO3	0.16	7.831	50	
NO2	0.85	0.17	0.2	
Pb	2.06	0.020625	0.01	significant level of pollution
Cd	3.33	0.01	0.003	significant level of pollution
Cu	0.05	0.0495	1	
Cr	0.63	0.0314	0.05	
Ni	0.89	0.0177	0.02	
Zn	0.003	0.01	3	
Fe	0.13	0.1295	0.3	

IV. Discussion

For the physico-chemical constituents, the turbidity (TBD), total dissolved solids (TDS), calcium (Ca), magnesium (Mg), chloride(Cl^-), nitrate (NO_2) and total hardness (TH) all have their maximum limits higher than the NSDWQ permissible limits as shown in Table 1. The maximum limits of heavy metal concentrations as shown on Table 2 revealed that lead (Pb), cadmium (Cd), chromium (Cr) and nickel (Ni) were higher than the NSDWQ permissible limits. There are limited reports of health effects for the aforementioned physico-chemical parameters as they basically render water resources aesthetically unappealing[1, 10] but, the heavy metals even at low concentrations has been reported to pose greater health risks and has been linked to cause brain tumour and damage, nervous system breakdown, kidney defects etc.[1,15,16].

In Table 3 showing the correlation coefficient "r" value of the physico-chemical parameters, there were strong positively correlation between T° and TBD, NO_3, NO_2 also TBD showed a strong positive correlation with NO_3, NO_2. TH, TDS and Cl were found to be strongly positive correlated at significant level of $p<0.01$, which means an increase in any of the parameters will subsequently yield an increase in the other parameter. CON and NO_3 has a strong negative correlation which means an increase in one parameter is a decrease in the other parameter. Moderately positive correlation exists between T° and pH; TBD bears with pH and NH_3; pH bears with NH_3, NO_3, NO_2; CON bears with TDS, TH, and Ca while moderate negative correlation exists between T° and CON, TDS, Cl, F. TBD also bears negative correlation with CON, TDS, F, NH_3 etc. For the heavy metals correlation at significant level of $p<0.05$, Pb bears a significantly positive correlation with Cr. Also, Ni bears a significantly positive correlation with Fe.

The Kriging method was used to produce the spatial patterns of water quality over the study area where geostatistical analysis method uses the standardization (Z-score) generation sequence to synthesize all the physicochemical parameter measured at all stations including heavy metals, and a contour differentiating these areas into categories that of low, medium and high concentrations of pollutants which are represented by green, yellow and red colours respectively. A noticeable trend of medium to high risk zone towards the NE-SW direction is significant as all stations within this zone revealed high concentration of the measured physicochemical parameters.

Of the 20 heavy metal ions considered in the present study, (Mg, NO_2, Pb, Cd, Cr and Ni) were the significant ones. Pollution index was used to evaluate the extent of pollution of groundwater samples. The pollution index values for Mg, NO_2, Pb, Cd, Cr and Ni were above the unity implying that the water samples are polluted and not safe for drinking.

V. Conclusion

This study utilized an integrated approach to assess water quality in Ilorin metropolis, where physicochemical and heavy metal constituents such as turbidity (TBD), total dissolved solids (TDS), calcium (Ca), magnesium (Mg), chloride(Cl^-), nitrate (NO_2), total hardness (TH), lead (Pb), cadmium (Cd), chromium (Cr) and nickel (Ni) were higher than the NSDWQ permissible limits at some sampled locations indicating possible pollution. While Pearson correlation revealed significant positive correlation between T°, TBD, pH, NH_3, NO_3, NO_2 and negative correlation for TBD, TDS, F, Cl. Geostatistical analysis (Ordinary Kriging) showed that water quality within the study area is not generally polluted except in some high risk areas, then the pollution index (Pi) indicated Mg, NO_2, Pb, Cd, Cr and Ni were the significant pollutants according to the method used. Hence, that the application of statistics in water quality assessment yields a more reliable result that reveals the extent of impact of possible pollution which in turns can help respective water resource planners in policy making and taking the required control measures for protecting water resources against public health risks.

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