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An Application of Multivariate Statistical Techniques to Evaluate Water Quality Across Dumpsites along Otamiri-Ochie River, Etche

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Abstract

The status of water quality in rural areas is attracting a great deal of attention on how suitable it is for public consumption, recreation and other purposes. There is however a lack of studies on water quality using multivariate statistical techniques to predict the sources of pollutant along Otamiri-Ochie River. Multivariate statistical approaches, including principal component analysis (PCA) and cluster analysis (CA) were employed to evaluate the water quality of the river. In this study, eight physico-chemical parameters were analysed in each water sample collected from four sampling sites surrounded by dumpsites along the river. Exploratory analysis of the dataset involved use of PCA, CA and water quality index (WQI) in attempt to identify the sources of variation measured in the samples. PCA was used to reduce the dataset to three components with predominantly dissolved oxygen (DO), total dissolved solids (TDS) and total suspended solids (TSS) contributing to over 55% of the total variance. CA classified the sites into two distinct groups identified as the upstream and downstream of the river. Chokocho (CHR) axis of the river was identified as being closer to the pollutant source and hence it is the most heavily polluted portion of the river. WQI value suggests that the water is unsuitable for drinking and may likely not be fit for domestic uses. The results prove multivariate statistics to be a powerful tool in identifying pollutant sources, which can be applied to both urban and rural water bodies.

Keywords*: River, Water quality, Multivariate statistics, Physico-chemical parameters.*

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Background to the Study

The availability of good quality water is a major concern to life since it is directly linked to human health and the environment. The most important sources of water are unfortunately under severe threat due to human activities. Human activities such as commercial, agricultural practices and recreation have generated various waste materials (both domestic and industrial wastes) that are released into surface water bodies (Sadiq et al., 2010; Grupta et al., 2003; Sincock et al., Al-Mutairi et al., 2014). These materials have potential negative impact on aquatic ecosystems, which may result to poor water quality and an overall decrease in quality of life for the residents.

Although, standard quality of water suitable for domestic and agricultural purposes is well known, investigations into water bodies within the rural areas are necessary (Zhao et al., 2012; Dhhou et al., 2016; Kumar and Alappat, 2009). Otamiri-Ochie River connects different communities where this water body serves as means of irrigation**.** Whilst the presence of pollutants in surface water poses a great risk to human health and the ecosystem, identifying its source has always been a challenge in previous studies (Miller and Hutchins, 2017). However, a study by Howladar et al. (2017), has investigated the influence of mining activities on water quality around mining industrial areas using multivariate statistical techniques.

Since water is essential to life, less attention has been paid to assessing the status of water quality within certain geographical areas. In contrast, it is not clear whether pollutant sources of water bodies can be easily identified by applying statistical analyses. Therefore, additional studies on water bodies are needed in order to provide better understanding on water quality with respect to the sources of contamination. The overall aim of this study is to evaluate the water quality along Otamiri-Ochie River using multivariate statistical approaches, which include principal component analysis and cluster analysis. With these techniques, it is hoped that the outcomes will be used as an evaluation of water bodies in rural and urban environments with specific reference to its suitability.

Materials and Methods

Study Area

Otamiri-Ochie River is situated within Etche Local Government Area in North-East of Rivers State (between $05^{0}08^{''}$ and $04^{0}45'$North latitude and between $06^{0}05^{''}$and $07^{0}14'$ East Longitude). The area is rich in agricultural produce where the small river body serves as source of water. For this present study, four sampling sites were chosen along the Otamiri-Ochie river as shown in Figure 1.

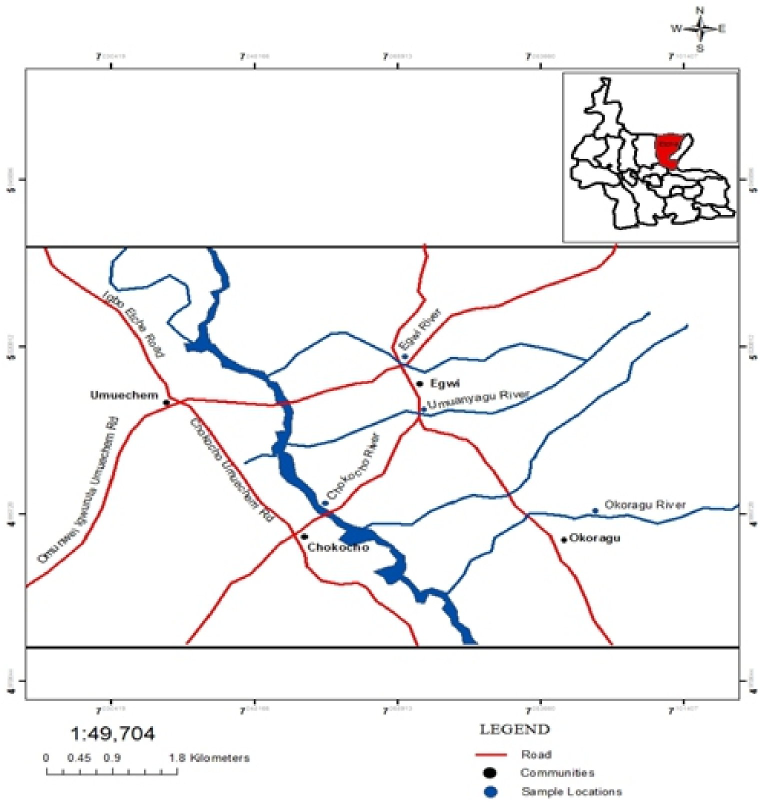

Figure 1: Location map of sampling sites across Otamiri-Ochie river

This water body practically receives domestic wastes and drainage water from residential areas throughout the year.

Sample Analyses

Water samples from four locations were collected from the surface (<30 cm) and analysed for eight physicochemical parameters using an established procedure. Samples were collected between August and September, 2017 and transferred into different amber bottles from the sampling locations. The laboratory analysis was carried out in Anal Concept Limited Laboratory according to standard procedures of APHA methods (1995). The APHA methods were adopted to determine the following parameters: pH, total dissolved solids (TDS), electrical conductivity (EC), total alkalinity (TA), total hardness (TH), total suspended solids, dissolved oxygen (DO) and biological oxygen demand (BOD) per sample. The occurrence of seasonal variation was not considered because of the cost implication.

Water Quality Index (WQI)

The water quality index (WQI) analysis provides a clear picture of the quality of the surface and ground water used for domestic purposes. Its summaries multiple water quality parameters to single numerical value (Yogendra and Puttaiah, 2008). In this study, eight (8) most important parameters were determined for the calculation of water quality index (WQI).

The WQI was calculated by using standards for drinking water recommended by World Health Organisation (WHO), India Council for Medical Research (ICMR) and Bureau of India Standards (BSI).

Multivariate Statistical analysis

Multivariate statistical analysis is a tool employed to assess the water quality where a lot of variables are contributing to influence the water quality. The most common approach used to identify the dominating component and sources that account for the variations responsible for the environmental impact on water quality are the hierarchical cluster analysis, principal component analysis and correlation matrix analysis. Cluster analysis involves multivariate methods of grouping samples into clusters based on their similarity. Principal component analysis is a powerful technique for pattern recognition in which the variance of a large set of data is reduced into a smaller set of uncorrelated variables. The multivariate statistical analysis was performed using Minitab statistical package (16.2 Version).

Results and Discussion

Analysis of water parameters

Table 1 shows the results of physicochemical parameters of water obtained from four (4) locations along the Otamiri-Ochie River in Etche. A total of eight parameters were determined including the pH, electrical conductivity (EC), total dissolved solids (TDS), dissolved oxygen (DO), biological oxygen demand (BOD), total suspended solids (TSS), total alkalinity (TA) and total hardness (TH) in each of the water samples. Except pH measurement, all other parameters are measured in mg/L, while the EC is expressed in μS/cm.

Table 1: Physicochemical parameters of water obtained from different locations

Sampling location	pH	EC (μS/cm)	TDS (mg/l)	TA (mg/l)	TH (mV)	TSS (mg/l)	DO (mg/l)	BOD (mg/l)
CHR	6.36	428.5	20.3	8.36	68.4	160.2	20.3	28.3
UMR	6.85	760.4	18.8	14.6	35.6	118.1	18.8	11.4
OKR	6.38	574.3	16.3	12.4	24.4	256.3	15.6	64.3
EGR	6.77	114.2	34.8	18.7	35.3	412.2	35.7	38.2

Note: Chokocho River (CHR), Umuanyagu River (UMR), Okomoko River (OKR) and Egwi River (EGR).

pH ranges from 6.36 to 6.77 and is thus slightly acidic. TDS, TA and TH vary from 16.3 – 34.8, 8.36 – 18.7, 118.1 – 412.2 mg/L, respectively. DO and BOD in the samples indicated a wide range of values from15.6 – 35.7 and 11.4 – 64.3 mg/L, respectively. While, EC ranges between 114.2 and 760.4 μS/cm. Data obtained are similar to investigations performed on water parameters from river basins previously reported by many researchers (Zhao et al., 2012; Al-mutairi et al., 2014; Diamantini et al., 2017). Similarities amongst the data appeared as a results of the high DO obtained in all the water samples. The agricultural land use and population of the sampling locations may contribute to the variations in the data set. The highest pH, EC and TH is observed in one of sampling locations (UMR) likely caused by several human activities that occurred within this area. This area based on the available data may have poor water quality because of the population density and other anthropogenic activities in the environment. Due to agricultural land use and population, the water quality is of major concern to the residents within the area.

Water quality index (WQI)

The quality of Water bodies can be grouped based on the following classification presented in Table 2. The water samples obtained across the studied areas is considered to be unsuitable for drinking based on the WQI calculation**.**

Table 2: Water Quality Index (WQI) and status of water quality (Chatterji and Raziuddin, 2002)

Water Quality Index level	Water quality status
0 – 25	Excellent water quality
26 -50	Good water quality
51 -75	Poor water quality
76 – 100	Very poor water quality
>100	Unsuitable for drinking

Following the analysis of water by using the eight physiochemical parameters, four sampling locations were combined together to obtain the WQI for the area. Although, the parameters showed wide variability with respect to the acceptable standard range, results from the studied area suggest the presence of pollutants. Yogendra and Puttaiah (2008) observed that changes in WQI values could be due to weather conditions being reported for rainy, winter and summer seasons. The water quality at the studied areas was not considered according to the seasonal variations over a period of time.

Although, the sampling locations are close to a dump site, the flow of the river along the area has influenced the WQI value. Application of WQI value to each location across the sampling sites may not be relevant because the river is flowing in a particular direction which could generally affect quality of the water from time to time. These results suggest that further investigations are necessary in order to determine the effect of seasonal changes on the water quality.

Principal component analysis (PCA)

The results of the PCA analysis based on the correlation matrix of various parameters are presented in Table 3. Three components of PCA showed 100% of variance in the data in which the eigenvector classified the 8 parameters into four groups. The first components include the most significant variables which explain 55.1% of the total variance dominated by TDS and DO having the highest contribution. Second and third components contribute 24.2 and 20.8% of total variance in the data set, respectively.

Table 3: Summary of PCA loading for water parameters

Variables	PCA 1	PCA 2	PCA 3
pH	0.251	-0.242	0.208
EC	-0.388	-0.295	-0.319
TDS	0.457	-0.028	0.217
TA	0.409	-0.225	-0.314
TH	-0.140	0.003	0.741
TSS	0.427	0.309	-0.090
DO	0.455	-0.043	0.227
BOD	0.042	-0.043	0.227
Eigenvalue	4.407	1.932	1.661
Proportion (%)	55.1	24.2	20.8
Cumulative (%)	55.1	79.2	100

These results are consistent with those reported previously for water quality around granite mining area in Bangladesh (Howladar et al. 2017). In the second component of the PCA, TSS and BOD indicated positive and moderate correlation. Positive and moderate correlation of TDS and TSS observed in PCA 1 is an indication that the water contained a wide variety of materials such as industrial wastes, decayed plant and wastes as well as sewage (Null et al., 2017, Sincock et al., 2003). In this study, PCA helps to provide a better understanding of the major parameters that influence the quality of water across the investigated areas.

Cluster Analysis (CA)

A dendrogram of sampling locations obtained by Ward Method is shown in Figure 2**.** Four sampling locations were investigated and subjected to a cluster analysis so that the sites with similar results are divided into two groups. Cluster 1 consists of two sites (CHR and OKR) that are similar, located to the downstream of the river. Cluster 2 contains a site located at EGR, which represents the upstream of the river. The results are consistent with previously reported study that uses a cluster analysis to group sampling sites with respect to physical and chemical variables (Zhao et al. 2012). The two groups identified by the cluster analysis reveal that these sites vary according to natural background features.

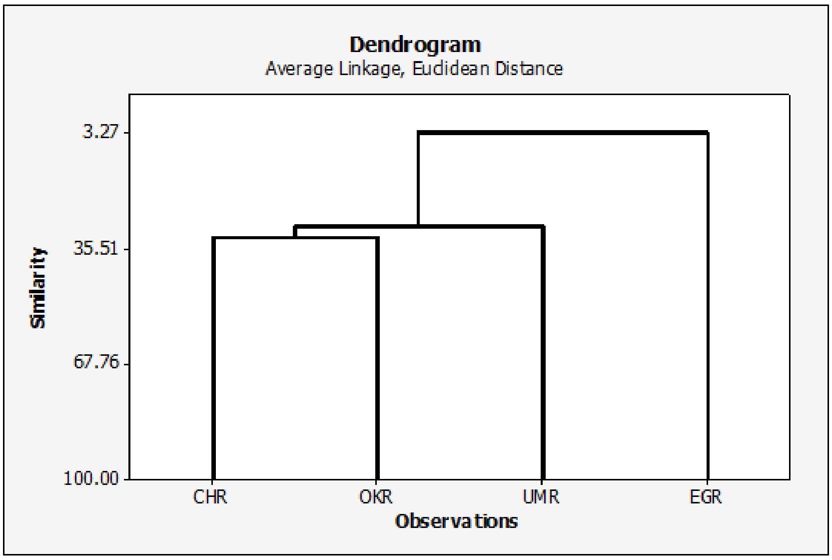

Figure 2: Dendrogram based on average linkage clustering of sampling sites

The dump site being the major source of pollutants is located at CHR and is closer to OKR, these areas are likely most heavily polluted sampling sites. Water quality from UMR and EGR may have been influenced by non-point source of the pollutants from the River. This suggests that EGR site can be described as the least polluted area of all the sampling sites as at the time of the study (Figure 2).

Conclusion

The use of multivariate statistical techniques gives a clear insight into identification of pollutant sources along the Otamiri-Ochie River. From cluster analysis, two locations were identified to be severely polluted due to dumping of waste materials generated from various human activities. The results from principal component analysis (PCA) showed that over 55.1% of the total variance tends to greatly influence the overall water quality. In addition to information on the status of the water quality, the study also illustrates how water quality index (WQI) was applied to determine the suitability of the water. The WQI value suggests that the water is unsuitable for drinking and would most likely be unfit for domestic purposes. This was further explained by the presence of potential contaminants dispersed across the water way.

This study provides a better understanding to quantitative measure of the water quality around the Otamiri-Ochie River, which suggests that there is need for remediation actions to mitigate the pollutant sources in order to keep the water safe and clean for present and future use. Furthermore, this work will be helpful to monitor and manage the water quality to prevent pollution in surrounding areas.

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