

## Evaluation of Water Quality of the Savannah River Networks

Maccido, A. I.<sup>1\*</sup>, Aliyu, G. A<sup>1</sup>, and Bambale, S. U<sup>1</sup>

<sup>1</sup>Department of Geography, Faculty of Sciences, Federal University of Education, Azare, Bauchi State. Nigeria

\*Corresponding Author: [gadaf.loveu@gmail.com](mailto:gadaf.loveu@gmail.com)

### ABSTRACT

Using fifteen sampling stations, study was conducted to assessed the water quality parameters of samples collected from River Galma, Zaria, Northwestern Nigeria, in wet and dry seasons. This was achieved using analysis of water quality index calculation, Hierarchical Cluster Analysis (HCA) and Principal Component Analysis (PCA) techniques. The Analysis of water quality index shows that sampling point number 15 located downstream of the river has the largest number of water quality index of 105.77 and 126.34, while sampling points 1 located upstream of the river has 62.71 and 78.09 in both wet and dry seasons respectively. This indicates that all the monitoring sites were polluted and the water could be utilized for industrial and irrigation specified due to the purposes only. HCA identified 4 and 3 different groups in wet season (WS) and dry seasons (DS) from 18 water quality parameters, indicates that the variation in water quality are due to natural and anthropogenic processes. Two components resulted from PCA analysis from both WS and DS. PCA explained 79.33% of the total variance in the variables which are included in the component in WS, and 80.09% of the total variance in the variables which are included in the component in DS, in which the major sources of pollution are related to agriculture and other human activities. From this study it shows that application of environmetric multivariate techniques are significant to environmental management, and the result will help stakeholders in decision making towards sustainable management support of the river system.

**Keywords:** Hierarchical cluster analysis (HCA), River Galma, Principal Component Analysis (PCA), Savanna River monitoring, Statistical Analysis, Water quality index (WQI).

### 1. INTRODUCTION

As a result of precipitation, weathering processes and human-caused activities such as agriculture, urbanization, industrial exercises, surface waters are helpless against pollution (Carpenter et al 1998, Jarvie et al 1998 and Shahrizim, 2018). Recently, more attention partakes to water quality monitoring because of its strong relationships with human riches (Filik et al 2008, Zhang et al 2009 and Ekeleme & Agunwamba, 2018). River water as a source of inland waters and asset for domestic, agriculture and industrial purposes, control measures are important to the rivers Simeonova et al (2003) so as to have a well-developed data bank on water quality for fruitful management.

Rivers serve as significant water sources for domestic, industrial, and agricultural uses (Jain, 2009). River Galma water serves as a source for

irrigation, fishing and other agricultural activities as well as the main source of raw water to Zaria water works for domestic supply. Physico-chemical properties of river water entails its quality level and suitability for both human's consumption and survival of the living organisms.

In Developing countries, scarcity and water pollution constitute a primary challenge for sustainable water resources management. Despite the World Health Organization's guidelines (WHO 2016) for water quality data sets, water pollution from various sources has been continuously increasing in most countries (Tredoux and Talma, 2006; Eruola et al 2011 and Mkoma and Mihayo, 2012). Thus, ensuring water quality must be an issue of scientific and public concern. Scientists and researchers have identified several factors that pose serious threats to water quality. These include, but not limited to, agricultural activities, habitat

destruction, invasive species, pollution and human overpopulation (Defersha et al 2012, and Dessu et al 2014). Several studies also shown that many fresh water bodies are continually being disturbed and polluted which influence changes in the hydrologic regime, water quality and biodiversity of water bodies (Sundaray et al 2006, Dessu et al 2014, Garabaa and Zielinski, 2015 and Tint et al. 2018) Contaminated water affects the health of ecosystem and organisms (man, animals and plants) living in or using that particular water.

Water quality refers to the standard chemical, physical, and biological characteristics of water, which measure the condition of water relative to the requirements of one or more biotic species and or to any human need (Patil et al 2012). To assess the water quality, water quality index calculation,

and evaluation. Therefore, the main objective of this research is to make detailed studies to evaluate water quality of the river by utilizing various techniques such as water quality index calculation, Hierarchical Cluster Analysis (HCA) and Principal Component Analysis (PCA) of River Galma in Zaria, Kaduna State, Nigeria in the year 2025.

## 2. MATERIALS AND METHODS

### 2.1 Study Area

The study was conducted in Zaria city domestic water source, Galma River located southeastern part of the city in the year 2018. As the main drainage channel of other tributaries forming the rivers system it is located on lat. 11.30 N and long. 7.40 E (Nnaji et al 2010) and 128 km and 64 km Southeast of Kano and Northeast of Kaduna respectively (Figure: 1). The area falls within the Guinea

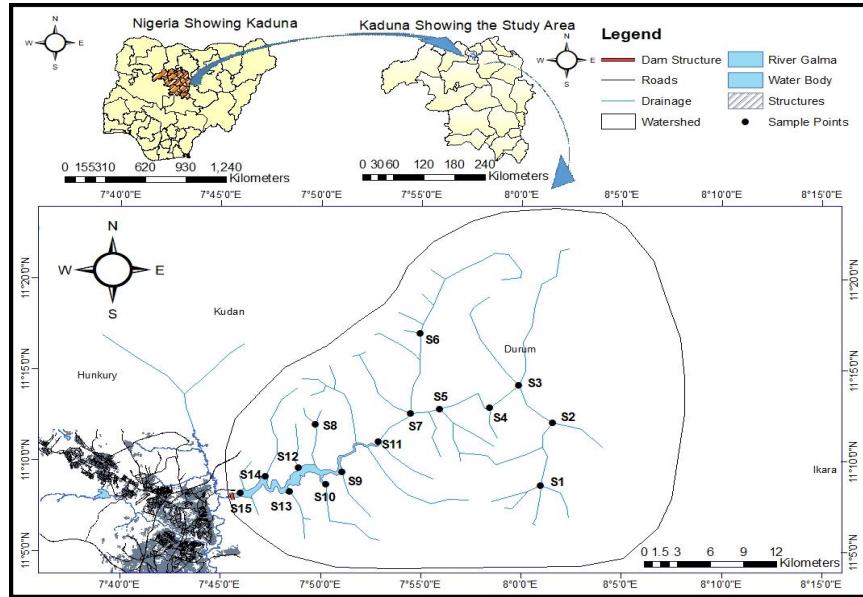


Figure 1: Geographic location of the study area along with the sampling stations in Galma River, Nigeria.

Hierarchical Cluster Analysis (HCA) and Principal Component Analysis (PCA) are suitable for such studies and used to reveal and interpret useful information from the data set obtained from the samples of interest (Einax et al 1997 and Shahrizim, 2018). Lately, the use of environmetric multivariate techniques to complex datasets has been of great scientific interest (Einax et al 1997), with many related studies carried out using these multivariate techniques to assess surface water quality (Shrestha and Kazama, 2007; Zhang et al 2009; Zhao and Cui, 2009 and Juahir et al 2010).

Due to rising water pollution in unmanaged rivers and streams either purposely or accidentally, this study conducted to assess water quality of River Galma utilizing environ-metric multivariate statistical approaches, The river receives various pollutant loads from agricultural, sand quarrying, mechanical villages, bathing and domestic activities. These necessitate the need for periodic water monitoring networks for water quality assessment

Savanna climate, with two different distinct seasons (Udo, 1978). The dam was constructed on the Galma river channel in 1975 in Zaria of Kaduna State to support farming, animal and other human activities which has been happening even before the advent of the Dam construction era along the river banks.

### 2.2 Data collection

Two separate set of water sampling of in-situ (in the original site) and ex-situ (away from its original location) were considered for collection and measurements in the months of July and January of the year 2025 wet and dry seasons respectively. For water sampling, the sites were identified and stratified random sampling scheme was used with objective of arriving at representative water samples in the study area. Fifteen (15) selected stations were chosen and sampled along the river channel (Fig. 1) using both in-situ and the ex-situ methods. The in-situ involves measuring some parameters onsite using hand held Multiparameter (YSI Professional

Plus) probe. Whereas in the ex-situ fifteen samples with three replicas having a total of 45 samples were collected for each seasons using clean polyethylene bottles that are pre-treated with deionized water and then brought to the laboratory for analysis. Public Health Laboratory of the Department of Water Resources and Environmental Engineering of Ahmadu Bello University, Zaria, Nigeria was used for these analyses.

### 2.3 Research Methodology

Standardized methods as described by the American Public Health Association (APHA 2022) were used for physicochemical parameters determination and analysis. Parameters of pH, Temperature (°C), Turbidity (NTU), Electrical Conductivity (s/m), Total Dissolve Solid (mg/L), Dissolve Oxygen (mg/l) and Salinity (ppt or PSU) were considered for the in-situ measurement while Nitrate,  $\text{NO}_3^-$  (mg/L), Nitrite,  $\text{NO}_2^-$  (mg/L), Sulphate,  $\text{SO}_4^{2-}$  (mg/L), Phosphate,  $\text{PO}_4^{3-}$  (mgL<sup>-1</sup>), Magnesium,  $\text{Mg}^{+2}$  (mgL<sup>-1</sup>), Calcium,  $\text{Ca}^{+2}$  (mgL<sup>-1</sup>), Chloride,  $\text{Cl}^-$ (mgL<sup>-1</sup>), Sediments, TSS (mgL<sup>-1</sup>), Total solids, TS (mgL<sup>-1</sup>), Biochemical oxygen demand,  $\text{BOD}_5$  (mgL<sup>-1</sup>) and Chemical Oxygen Demand, COD (mgL<sup>-1</sup>) for ex-situ laboratory analysis. The data were subjected to descriptive statistics using Microsoft Excel, water quality index calculation, Principal Component Analysis (PCA) using statistical Package for Social Science (SPSS statistic 23) and Hierarchical Cluster Analysis (HCA) using Past3 respectively (Fig. 2).

measures the amplitude, scope and frequency of water quality which produces a value to indicate the type of the water. The WQI summarized the water quality data for easy reporting of the status of water quality to the public for comparison purposes. The smaller WQI value represents better quality for domestic uses. WQI is calculated by utilizing the standardized parameters provided by the Nigerian Standard alongside WHO Standard and their unit weight parameters, which is also obtained using the standardized parameters. Table 1 is a further use in this study to assist in determining the status of the samples.

Table 1: WQI and corresponding water quality status

WQI	Status	Possible Usages
0-25	Excellent	Drinking and Industrial
26-50	Good	Domestic and Industrial
51-75	Fair	Irrigation and Industrial
76-100	Poor	Irrigation
101-150	Very Poor	Restricted for Irrigation
Above 150	Unfit for Drinking	Proper treatment required before use.

(Horton, 1965; Stambuk- Giljanovic, 1999; Mohebbi et al., 2013)

#### Calculation of WQI

Calculation of WQI was carried out using Horton's method as in Eqs. 1 and 2 (Stambuk- Giljanovic, 1999; Mohebbi et al., 2013).

$$WQI = \frac{WQE}{\sum w_i} \quad (1)$$

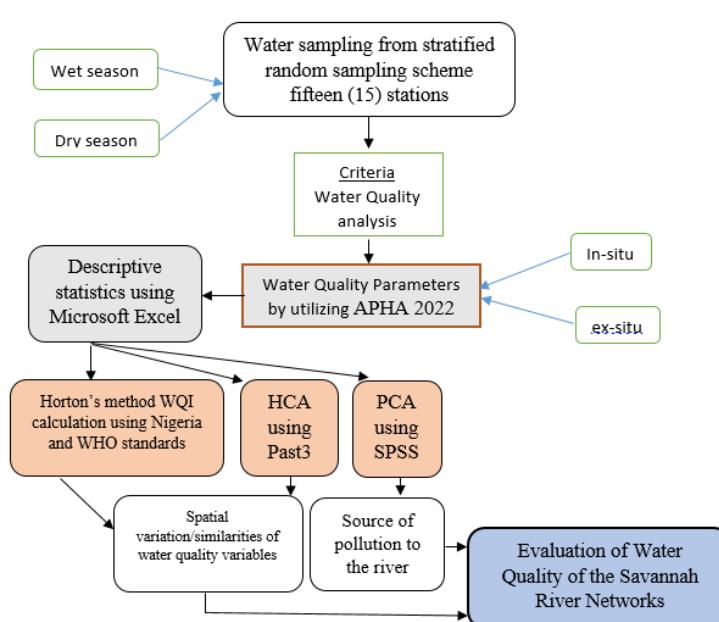


Figure 2: Flow chart diagram of the research methodology

#### 2.4 Water quality index

WQI is a tool for measuring water quality (Al-Janali et al., 2012), which is found helpful for the selection of appropriate treatment technique to meet the concerned issues. (Tyagi et al., 2013) state that WQI

$$WQE = \sum q_i w_i \quad (2)$$

Where,  $q_i$  is the quality rating of  $i^{th}$  parameter  $W_i$  is the unit weight of  $i^{th}$  parameter *Quality rating*

The quality rating ( $q_i$ ) is shown in Eq. 3 and (Table 5).

$$q_i = \frac{(V_i - V_{id})}{(s_i - V_{id})} \times 100 \quad (3)$$

Where,  $V_i$  is the value of  $i^{th}$  water quality parameter of the sample  $V_{id}$  is the ideal value of  $i^{th}$  parameter in pure water. (Note that  $V_{id}$  for pH is 7 and 0 for other parameters)  $s_i$  is the standardized parameter by Nigerian standard

#### Unit weight of parameter

The important steps in calculating the unit weight,  $W_i$  is to identify the standard maximum allowable concentration,  $s_i$  and the constant proportionality,  $k$ . The value of  $k$  depends on the  $s_i$  Value of  $k$  varies on the amount of parameters involve in the study.

The unit weight of parameter,  $W_i$  is shown in Eq. 4.

$$W_i = \frac{k}{s_i} \quad (4)$$

Where,  $s_i$  is the standardized parameter by local permissible limit and were is not stated, WHO standard is been applied.  $k$  is constant of proportionality.

The constant proportionality is shown in Eq. 5 by utilizing the  $s_i$ . Hence, the calculation is further shown in (Table 4)

$$k = \frac{1}{\sum s_i} \quad (5)$$

### 3. RESULTS AND DISCUSSIONS

Table 2 show the descriptive statistic of wet and dry season water quality parameters in Galma River

with the minimum, maximum, tested means and standard deviation of the river water quality parameters and (Table 3) shows the water quality standards used in the research.

**Table 3: Water quality standards used in the current study**

Parameter	Unit	Maximum allowable concentration (WHO)	Local permissible limit Nigerian standard (NG)	Desirable limit ( $S_i$ )
Sal.	(mg/L)	0.5	Not Stated	WHO
BOD5	(mg/L)	5	5	NG
DO	(mg/L)	5	5	NG
NO <sub>2</sub> <sup>-</sup>	(mg/L)	3	Not Stated	WHO
pH	-	7.0 – 8.0	7.0 – 8.0	NG
SO <sub>4</sub> <sup>2-</sup>	(mg/L)	250	Not Stated	WHO
PO <sub>4</sub> <sup>3-</sup>	(mg/L)	5	Not Stated	WHO
T	(°C)	20 - 32	40	NG
NO <sub>3</sub> <sup>-</sup>	(mg/L)	5	Not Stated	WHO
EC	(s/m)	1500	1500	NG
TSS	(mg/L)	500	Not Stated	WHO
COD	(mg/L)	80	Not Stated	WHO
TDS	(mg/L)	1000	1000	NG
Turb.	(NTU)	5.0	500	NG
TS	(mg/L)	1000	Not Stated	WHO
Mg <sup>+2</sup>	(mg/L)	30	30	NG
Ca <sup>+2</sup>	(mg/L)	75	75	NG
CL <sup>-</sup>	(mg/L)	250	250	NG

#### WQI Calculation

The first step is to calculate the denominator of Eq. 5. The constant proportional,  $k$  and the weight,  $W_i$  for all the parameters were calculated as in Eq. 6.

$$\sum \frac{1}{s_i} = 3.0338 \quad (6)$$

$$\text{Then, } k = \frac{1}{3.0338} = 0.3296$$

After the  $k$  value had been identified, proceed with Eq. 4 and find the Weight,  $W_i$ .

Table 4: Calculation of numerator and denominator of unit weight

**Table 2: Descriptive statistic of wet and dry season water quality parameters**

Parameter	Unit	Sampled stations (N)	Wet season (WS)			Dry season (DS)		
			Min.	Max.	Tested mean $\pm$ SD	Min.	Max.	Tested mean $\pm$ SD
Sal	(mg/L)	15	0.09	0.10	0.10 $\pm$ 0.01	0.09	0.10	0.09 $\pm$ 0.00
BOD5	(mg/L)	15	4.00	5.70	5.00 $\pm$ 0.60	4.50	5.80	5.35 $\pm$ 0.40
DO	(mg/L)	15	6.70	6.80	5.44 $\pm$ 0.61	5.10	6.60	5.81 $\pm$ 0.40
NO <sub>2</sub> <sup>-</sup>	(mg/L)	15	2.90	10.50	5.99 $\pm$ 2.27	4.00	10.80	7.69 $\pm$ 2.11
pH	-	15	6.10	6.50	6.25 $\pm$ 0.12	6.90	7.90	7.39 $\pm$ 0.26
Mg <sup>+2</sup>	(mg/L)	15	8.20	71.30	35.15 $\pm$ 21.53	20.70	77.30	51.78 $\pm$ 20.32
SO <sub>4</sub> <sup>2-</sup>	(mg/L)	15	9.21	19.45	12.99 $\pm$ 3.92	14.51	23.53	19.05 $\pm$ 2.87
PO <sub>4</sub> <sup>3-</sup>	(mg/L)	15	11.68	27.81	15.96 $\pm$ 5.08	11.68	27.81	19.92 $\pm$ 6.20
Ca <sup>+2</sup>	(mg/L)	15	18.00	58.50	26.08 $\pm$ 11.99	17.50	59.50	38.76 $\pm$ 15.39
NO <sub>3</sub> <sup>-</sup>	(mg/L)	15	20.28	48.07	31.79 $\pm$ 6.77	29.01	49.00	36.59 $\pm$ 6.86
T	(°C)	15	28.03	28.37	28.17 $\pm$ 0.12	29.44	32.00	30.81 $\pm$ 0.74
CL <sup>-</sup>	(mg/L)	15	47.00	250.00	175.73 $\pm$ 60.74	112.00	260.00	202.13 $\pm$ 42.92
TSS	(mg/L)	15	30.00	145.67	77.04 $\pm$ 32.43	33.00	156.00	82.20 $\pm$ 35.68
EC	(s/m)	15	23.00	80.67	56.44 $\pm$ 18.69	32.00	96.00	72.00 $\pm$ 17.89
COD	(mg/L)	15	90.00	320.00	171.07 $\pm$ 70.25	120.00	292.00	192.53 $\pm$ 50.38
TDS	(mg/L)	15	260.00	652.33	425.56 $\pm$ 110.99	350.00	877.00	586.80 $\pm$ 187.47
Turb.	(NTU)	15	398.67	926.33	546.29 $\pm$ 140.81	545.00	926.00	704.27 $\pm$ 131.07
TS	(mg/L)	15	355.67	867.33	576.87 $\pm$ 147.86	386.00	897.58	640.97 $\pm$ 167.62

Now,  $WQE = \sum q_i w_i$

Where,  $WQE = 59.67$  for wet season and  $WQE = 74.33$  for dry season

**Table 4: Calculation of numerator and denominator of unit weight**

Parameter	$S_i$	$s_i - V_{id}$	Weight, $\mathcal{W}_i$
T	40 °C	40	0.00980
pH	8.0	1.0	0.03922
EC	1500 s/m	1500	0.00021
DO	5 mg/L	5	0.06275
Turb	5NTU	500	0.06275
Sal	0.5 mg/L	0.5	0.62747
TDS	1000 mg/L	1000	0.00031
$NO_2^-$	3 mg/L	100	0.00314
$NO_3^-$	5 mg/L	5	0.06275
$PO_4^{3-}$	5 mg/L	5	0.06275
$SO_4^{2-}$	250 mg/L	250	0.00125
COD	80 mg/L	80	0.00392
BOD5	5 mg/L	5	0.06275
TSS	500 mg/L	500	0.00063
TS	1000 mg/L	1000	0.00031
$Mg^{+2}$	30 mg/L	30	0.01046
$Ca^{+2}$	75 mg/L	75	0.00418
$CL^-$	250 mg/L	250	0.00125
			0.95182

river watershed (Fig. 1) and these tributaries were influenced by lot of agriculture and domestic activities, which were finally connected to the sampling point 15 (Sp15), in the downstream section of the river. This is why Sp15 has the largest value of WQI in both WS and DS, 105.77 and 126.34 respectively, which is much higher than Sp1 located upstream of the river with WQI of 62.71 in WS and 78.09 in DS. This indicate that Sp15 is the most polluted and problematic sampling point, a mirror image of strong impact of agricultural and domestic activities within the downstream section of the river. This may be resulting from non-point source pollution such as domestic disposal, agricultural activities and runoff that dissolve pollutants in the river water. This is in line with the work of Obozige *et al.* (2017), on evaluation of the Water Quality of River Kaduna, Nigeria Using Water Quality Index. More so, Table 6 shows the samplings in DS to be more polluted than those in WS through all the sampling points. At sampling points (Sp1, Sp2 and Sp3) in the WS, WQI exhibit fair (51-75) water quality status (WQS), in the upstream part of the river, however within the same sampling point it

**Table 5: Calculation of numerator and denominator of quality rating**

Parameter	Wet season (WS)			Dry season (DS)		
	Value ( $\mathcal{V}_i$ )	$\mathcal{V}_i - V_{id}$	Value $q_i$	Value ( $\mathcal{V}_i$ )	$\mathcal{V}_i - V_{id}$	Value $q_i$
T	28.36	28.36	70.900	30.02	30.02	75.05
pH	6.50	0.50	50.000	7.50	0.50	50.00
EC	73.67	73.67	4.667	87.00	87.00	5.80
DO	4.70	4.70	94.000	5.60	5.60	112.00
Turb	420.33	420.33	84.000	572.00	572.00	114.40
Sal	0.1	0.1	19.000	0.10	0.10	19.00
TDS	470.67	470.67	47.100	397.00	397.00	39.70
$NO_2^-$	3.40	3.40	3.400	7.30	7.30	7.30
$NO_3^-$	20.28	20.28	405.600	30.74	30.74	614.80
$PO_4^{3-}$	12.80	12.80	256.000	13.80	13.80	276.00
$SO_4^{2-}$	9.72	9.72	3.884	14.51	14.51	5.80
COD	90.00	90.00	112.500	140.00	140.00	175.00
BOD5	4.50	4.50	90.000	5.20	5.20	104.00
TSS	51.33	51.33	10.200	53.00	53.00	10.60
TS	652.33	652.33	65.200	667.00	667.00	66.70
$Mg^{+2}$	8.20	8.20	27.333	20.70	20.70	69.00
$Ca^{+2}$	18.00	18.00	24.000	17.50	17.50	23.33
$CL^-$	47.00	47.00	18.800	112.00	112.00	44.80

Then,  $WQI$  is calculated by utilizing Eq. 1. The summation of weight,  $\mathcal{W}_i$  is 0.95182. Sample point 1 (Sp1) of wet season (WS) has  $WQI = 62.70$  and Sample point 1 (Sp1) of the dry season (DS) has  $WQI = 78.09$  the same calculation was performed to find the WQI for the rest of the sampling points that are presented in Table 6.

From Table 6 above, spatial variation of the water quality in both wet season (WS) and dry season (DS), shows that, the water quality index is increasing from the upstream of the river to the downstream of the river. Galma River has a large number of tributaries toward the southern part of the

changed to poor status in the dry season (76-100) WQS. This indicates that the concentration of the water quality parameters tends to increase due to absence of rainfall and excessive water evaporation during DS. Similarly, wet season WQI exhibit poor (76-100) WQS in the middle of the river to very poor (101-150) WQS at the downstream of the river, yet looking at the dry season, it shows a very poor (101-150) WQS from the middle up to the downstream of the river. In general, the results of WQI showed that the monitoring sites were significantly polluted and could be used for Industrial and Irrigation purpose (Table 1). This is in accordance with the findings of Bhangaonkar and Patel, (2017) on water quality

zoning of Vishwamitri River to access environmental flow needs through aggregation of water quality index. A better knowledge of the river's recent water quality situation will be possible thanks to the water quality index results.

based on their spatial similarities were employed in this study. The water quality parameters were analyzed using HCA technique to identify seasonal pollution sources. Hierarchical cluster analysis yielded a dendrogram (Fig. 3WS) with the eighteen

**Table 6: WQI for all the 15 sampling stations**

Sampling points	Wet Season (WS)			Dry Season (DS)		
	WQI	Status	Possible Usages	WQI	Status	Possible Usages
Sp1	62.70	Fair	Irrigation and Industrial	78.09	Poor	Irrigation
Sp2	67.46	Fair	Irrigation and Industrial	81.85	Poor	Irrigation
Sp3	69.82	Fair	Irrigation and Industrial	76.67	Poor	Irrigation
Sp4	78.85	Poor	Irrigation	73.89	Poor	Irrigation
Sp5	88.11	Poor	Irrigation	89.48	Poor	Irrigation
Sp6	77.11	Poor	Irrigation	76.74	Poor	Irrigation
Sp7	82.99	Poor	Irrigation	91.77	Poor	Irrigation
Sp8	76.85	Poor	Irrigation	83.09	Poor	Irrigation
Sp9	81.94	Poor	Irrigation	110.77	Very Poor	Restricted for Irrigation
Sp10	74.80	Poor	Irrigation	89.90	Poor	Irrigation
Sp11	92.15	Poor	Irrigation	105.18	Very Poor	Restricted for Irrigation
Sp12	92.84	Poor	Irrigation	108.52	Very Poor	Restricted for Irrigation
Sp13	144.76	Very Poor	Restricted for Irrigation	124.52	Very Poor	Restricted for Irrigation
Sp14	94.82	Poor	Irrigation	121.54	Very Poor	Restricted for Irrigation
Sp15	105.77	Very Poor	Restricted for Irrigation	126.34	Very Poor	Restricted for Irrigation

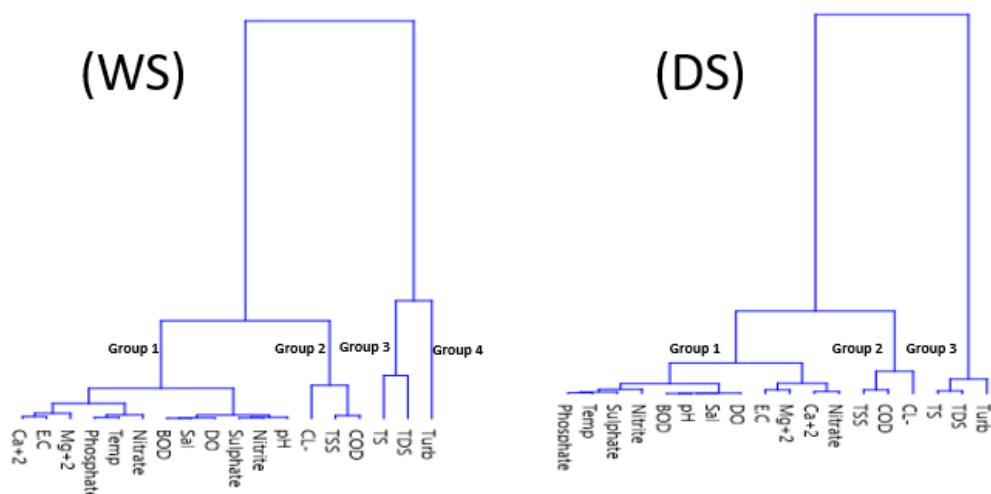
#### **Water pollution source identification using HCA and PCA**

HCA and PCA applied in this research to monitor and identify the sources of pollution into the river was considered to be appropriate and useful to provide significant reduction in data dimensionality. To obtain reliable information about the relationships among the environmental variables, HCA and PCA was applied to the datasets to explore the water quality parameters similarities/grouping and the water pollution source identification.

#### **Multivariate analysis of hierarchical cluster analysis (HCA)**

Multivariate analysis of hierarchical cluster analysis (HCA) using ward method classification of variables

water quality parameters (WQP) in wet season (WS) classified into four major groups, (Willet, 1987) suggested it to be preferred method as it accurately classifies the groups. As shown in dendrogram (Fig. 3WS), group 1 consists of twelve WQP: pH, Nitrite, Sulphate, DO, Salinity, BOD, Nitrate, Temp, Phosphate, Mg<sup>2+</sup>, EC and Ca<sup>2+</sup>. WQP in group 1 in WS could be relate to human activities during the WS. Group 2 consisting of three WQP: COD, TSS and Cl<sup>-</sup> which is more related to agricultural activities. While Group 3 comprises of two WQP: TDS and TS corresponding to sand mining and land clearing for farming. Lastly, group 4 consist of one WQP, Turbidity that is related to agricultural runoff



**Figure 3: Dendrogram (using Ward Method) showing classification of variables based on their spatial similarities produced by cluster analysis**

and atmospheric deposition (Mohamed et al. 2015 and Khan et al. 2015)

The cluster analysis of the data collected during the dry season (DS) is shown in Fig. 3DS. As indicated in the dendrogram, eighteen WQP were classified into three groups. Group 1 corresponding to Nitrate,  $\text{Ca}^{+2}$ ,  $\text{Mg}^{+2}$ , EC, DO, Sal, pH, BOD, Nitrite, Sulphate, Temp and Phosphate. This group signifies farming activities and other anthropogenic activities. Group 2 consisting of three WQP, COD, TSS and  $\text{Cl}^-$  is related to agricultural activities, and lastly, group 3 consists of three WQP, Turbidity, TDS and TS corresponding to Sand querying, agricultural runoff, land clearing and domestic waste.

The HCA technique reveals its capability in offering a acceptable grouping of surface-water physicochemical parameters in the study area. As a tool, will provides objective interpretations of physicochemical properties of surface-water as well as identify pollution sources, that will help to apportion efforts toward sustainable management of a river basin Venkatramanan et al (2014) as well these clustering results are supportive of the results of the study conducted by (Othman et al 2018).

#### **Principal component analysis (Pollution Source Identification)**

Principal component analysis (PCA) is a data reduction method which transforms a number of possibly correlated variables into a smaller number of uncorrelated variables called principal

components or factors by analyzing the correlation between variables. In this study PCA is used for Pollution Source Identification, were applied to the 18 WQP. Component loading above 0.50 is considered to be significant (Liu et al 2003). PCA requires that the Kaiser-Kaiser-Meyer-Olkin Measure of Sampling Adequacy (KMO-MSA) be greater than 0.50 for each individual variable as well as the set of variables (Shahrizim, 2018). From anti-image correlation matrices (AICM) column of WSA in Table 7, Temp, EC, TDS, Sulphate, COD and BOD has KMO-MSA of less than 0.50. As it do not fulfil the requirement of PCA, the variables were then removed and the PCA was run again. Also, column WSB in WS of Table 6 revealed that DO, pH and salinity exhibit KMO-MSA value of less than 0.50 still not satisfy PCA requirement, were also removed and PCA was rerun. Going by column WSC, all the variables are greater than 0.50 KMO-MSA, hence fulfilling the PCA requirement. Again, considering the overall KMO-MSA in the raw column section of WS in Table 6, it can be seen that the overall KMO-MSA is increasing from 0.567 to 0.742 and finally to 0.809 which exceeds the minimum requirement of 0.50 for overall KMO-MSA values which satisfied PCA requirement (Shahrizim, 2018).

From AICM column of DSA of dry season in Table 7, Temp, EC, Nitrate, COD, TSS, TS,  $\text{Ca}^{+2}$  and  $\text{Cl}^-$  have KMO-MSA value less than 0.50 therefore,

**Table 7: Anti-image matrices, Kaiser-Meyer-Olkin Measure of Sampling Adequacy (KMO-MSA) and Total variance explain**

Parameters	Wet Season Anti-image Correlation			Parameters	Dry season Anti-image Correlation		
	WSA	WSB	WSC		DSA	DSB	DSC
<b>Turbidity</b>	0.867 <sup>a</sup>		0.848 <sup>a</sup>	pH		0.841 <sup>a</sup>	0.856 <sup>a</sup>
<b>Nitrite</b>	0.682 <sup>a</sup>		0.770 <sup>a</sup>	DO		0.809 <sup>a</sup>	0.822 <sup>a</sup>
<b>Nitrate</b>	0.762 <sup>a</sup>		0.801 <sup>a</sup>	Turbidity		0.785 <sup>a</sup>	0.786 <sup>a</sup>
<b>Phosphate</b>	0.899 <sup>a</sup>		0.883 <sup>a</sup>	TDS		0.657 <sup>a</sup>	0.663 <sup>a</sup>
<b>TSS</b>	0.601 <sup>a</sup>		0.767 <sup>a</sup>	Nitrite		0.820 <sup>a</sup>	0.817 <sup>a</sup>
<b>TS</b>	0.578 <sup>a</sup>		0.703 <sup>a</sup>	Phosphate		0.774 <sup>a</sup>	0.790 <sup>a</sup>
<b>Mg+2</b>	0.920 <sup>a</sup>		0.833 <sup>a</sup>	Sulphate		0.720 <sup>a</sup>	0.720 <sup>a</sup>
<b>Ca+2</b>	0.801 <sup>a</sup>		0.784 <sup>a</sup>	BOD		0.797 <sup>a</sup>	0.801 <sup>a</sup>
<b>Cl<sup>-</sup></b>	0.698 <sup>a</sup>		0.790 <sup>a</sup>	Mg+2		0.793 <sup>a</sup>	0.787 <sup>a</sup>
<b>DO</b>	0.236 <sup>a</sup>			Salinity		0.465 <sup>a</sup>	
<b>pH</b>	0.481 <sup>a</sup>			Temp	0.344 <sup>a</sup>		
<b>Salinity</b>	0.498 <sup>a</sup>			EC	0.079 <sup>a</sup>		
<b>Temp</b>	0.313 <sup>a</sup>			Nitrate	0.474 <sup>a</sup>		
<b>EC</b>	0.385 <sup>a</sup>			COD	0.075 <sup>a</sup>		
<b>TDS</b>	0.282 <sup>a</sup>			TSS	0.294 <sup>a</sup>		
<b>Sulphate</b>	0.461 <sup>a</sup>			TS	0.460 <sup>a</sup>		
<b>COD</b>	0.163 <sup>a</sup>			Ca+2	0.450 <sup>a</sup>		
<b>BOD</b>	0.264 <sup>a</sup>			Cl <sup>-</sup>	0.492 <sup>a</sup>		
<b>Overall KMO-MSA</b>	0.567	0.742	0.809		0.503	0.765	0.771

were removed and PCA is run again. Salinity from column DSB also exhibit a value less than 0.05 also was removed and PCA was run again. Lastly column DSC reveals that all the variable satisfied PCA requirement as overall KMO-MSA is 0.771 which exceeds the minimum requirement of 0.50.

The water quality parameters analyzed using PCA to identify seasonal pollution source as in (Fig. 4WS) and the WS data in Table 7 produced a loading plot in which the eighteen WQP in WS were reduced to nine WQP and two components were extracted. The first component in WS (WS1) explained that 68.16 % of the total variance has a strong positive loading on Turbidity, Nitrite, Nitrate, Phosphate, TS, Mg<sup>+2</sup> and Cl<sup>-</sup>. This component signify agricultural and other human activities involvement along the river watershed (Mohamed et al. 2015 and Khan et al. 2015, Kumar et al. 2018, Rakotondrabe et al. 2018, Aliyu et al. 2019 and Shil et al. 2019). Nitrite, Nitrate, Phosphate, Mg<sup>+2</sup> and Cl<sup>-</sup> may be attributed to originate from fertilizer and pesticides application in the farms that have found their way into the water.

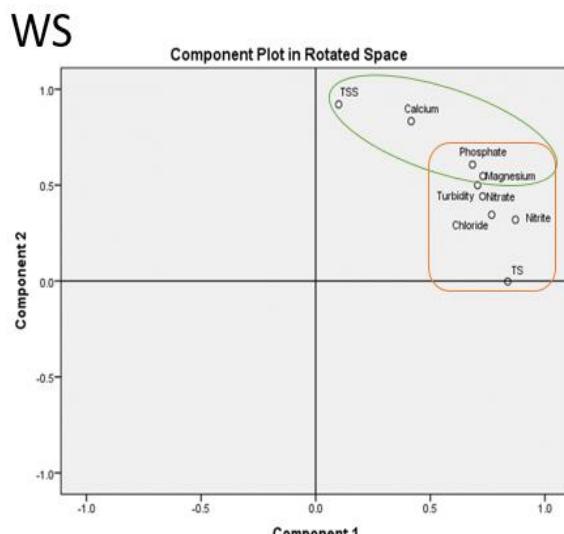


Figure 4: Loading plot produced by principal component analysis

While Turbidity and TS were contributed from atmospheric deposition, agricultural runoff, leaching from solid waste disposal sites and sand quarrying along the river bank (Ibrahim et al 2015, Kumar et al. 2018, Rakotondrabe et al. 2018 and Shil et al. 2019). More so, from Table 8 the second component loading in WS (WS2) designated 11.17 % of the total variance with strong positive loading on Phosphate, TSS, Mg<sup>+2</sup> and Cl<sup>-2</sup> (Fig. 4WS). This component explained the effects of agricultural and residential runoff, leaching from solid waste disposal sites and point source water pollution discharging from nearby residential and sand quarrying areas along the river bank (Tamer et al 2018 and Shil et al. 2019).

Table 8: Factor loadings after Varimax rotation

Variables	Wet Season (WS) Component		Dry Season (DS) Component		
	WS1	WS2	DS1	DS2	
Turbidity	<b>0.706</b>	0.499	pH	<b>0.777</b>	0.026
Nitrite	<b>0.871</b>	0.319	DO	0.062	<b>0.903</b>
Nitrate	<b>0.728</b>	0.441	Turbidity	<b>0.838</b>	0.476
Phosphate	<b>0.684</b>	<b>0.607</b>	TDS	<b>0.869</b>	0.268
TSS	0.100	<b>0.921</b>	Nitrite	0.429	<b>0.757</b>
TS	<b>0.838</b>	-0.002	Phosphate	<b>0.626</b>	<b>0.694</b>
Mg <sup>+2</sup>	<b>0.729</b>	<b>0.547</b>	Sulphate	<b>0.752</b>	<b>0.543</b>
Ca <sup>+2</sup>	0.416	<b>0.833</b>	BOD	0.315	<b>0.823</b>
Cl <sup>-</sup>	<b>0.768</b>	0.345	Mg <sup>+2</sup>	<b>0.749</b>	0.444
Eigenvalue	6.134	1.005		6.087	1.121
Variability %	68.159	11.166		67.633	12.455
Cumulative%	68.159	<b>79.325</b>		67.633	<b>80.088</b>

Fig. 4DS also shows the Principal Component Analysis of the DS data in table 7 and loading plot (Figure: 4DS), having eighteen WQP reduced to nine WQP and two extracted components. The first Component of DS1 explained 67.633% of the total variance with strong positive loading on pH, Turbidity, TDS, Phosphate and Sulphate. This component is sturdily related to farming activities

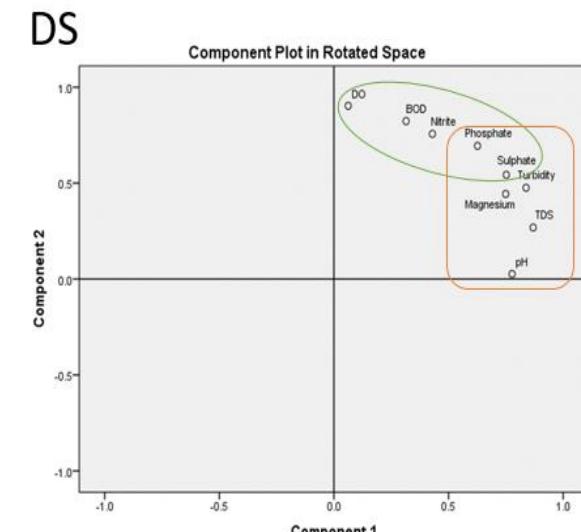


Figure 4: Loading plot produced by principal component analysis

and conductive ions coming from dissolved salts and inorganic materials. This may be as a result of salts and other chemicals from non-point sources such as domestic disposal and agricultural runoff that dissolve in water and break down into positively and negatively charged ions (Tamer et al 2018 and Shil et al. 2019).

Component of DS2 showed 12.455% of the total variance with strong positive loading on DO, Phosphate, Sulphate and BOD. These elements clarify agriculture activities and organic loading as pollutant in the river, indeed all these contaminants are of relevance in relation to the point source pollution (How can I use BOD5 as pollution indicator in water quality? 2019). These components

loading difference indicate that in DS the pollution is more noticeable due to absence of rainfall as was indicated by Independent Samples Test above (Table 5). These results by principal component analysis are supportive of the results (Ibrahim et al 2015). Besides, these PCA results are in line with the findings using multivariate statistical techniques (Tamer et al 2018). The study is also consistent with the findings (Venkatramanan et al 2014).

#### 4. CONCLUSION

Eighteen water quality parameters for fifteen sampling points were studied for River Galma Zaria, by applying water quality index (WQI) calculation, Hierarchical Cluster Analysis (HCA) and Principal Component Analysis (PCA). WQI result shows that the monitoring sites were polluted and could be specified for the purpose of Industrial and Irrigation usage. Analysis of the Hierarchical Cluster Analysis (HCA) revealed 4 groups in WS and 3 groups in DS and for the both seasons, anthropogenic (human induced) and natural processes as a major pollution sources. PCA explained 79.33 % of the total variance in the variables which are included in the component in WS and 80.09 % of the total variance in the variables which are included in the component in DS with agriculture and other human activities as major pollution sources which was also identified by HCA above. Considering the loading plots, 9 out of the 18 variables were represented by 2 components in both wet and dry seasons. Thus, application of environ-metric multivariate statistical techniques to sustainable environmental management are important tools for studies of this kind. This investigation study, suggested that precautions could be taken to prevent future surface water pollution which may be dangerous to human health and aquatic life living in the river. It is hoped the information will provide necessary steps if taken into account by both the local communities and concerned authority will significantly improve management of the river ecosystem and reduces pollution risks within the watershed. Further research study should look into heavy metals and other trace elements in the water body of the River Galma.

#### ACKNOWLEDGMENT

We would like to express our very great appreciation to TETfund to see this research was a success.

#### CONFLICT OF INTEREST

The authors declares that there is no conflict of interests regarding the publication of this manuscript. In addition, ethical issues, such as plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission and redundancy have been observed by the authors.

#### REFERENCES

Aliyu, G.A.; Jamil, N.R.B.; Adam, M.B.; Zulkeflee, Z., (2019). Assessment of Guinea Savanna River system to evaluate water quality and water monitoring networks. *Global J. Environ. Sci. Manage.*, 5(3).

Al-Janali, Z. Z.; Al-Kubaisi, A., Al-Obaidy, A., (2012). Assessment of water quality of Tigris River by using water Quality Index (CCME WQI). *J. Al-Nahrain University*, 15(1): 119-126 (8 pages).

Al-Mutairi, N.; AbaHussain, A., El-Battay, A., (2015). Spatial assessment of monitoring network in coastal waters: a case study of Kuwait Bay. *Environ. Monit. Assess.* 187: 621 (11 pages).

Animesh, A.; Saxena, M., (2011). Assessment of pollution by physicochemical water parameters using regression analysis: A case study of Gagan River at Moradabad India. *Adv. Appl. Sci. Res.*, 2(2): 185-189 (5 pages).

APHA, (2022). Standard methods for examination water and wastewater. *American Public Health Association*. 23rd Edn. APHA, AWWA, WPCF, Washington D.C, USA.

Arzu, A.U.; Tamer, A., (2017). Assessment of water quality of Yağlıdere Stream (Turkey), using multivariate statistical techniques. *Polish J. Environ. Stud.*, 26(4): 1715-1723 (9 pages).

Balan, I.; Shivakumar, M.; Kumar, P.M., (2012). An assessment of groundwater quality using water quality index in Chennai, Tamil Nadu, India. *Chron. Young Sci.*, 3(2): 146-150 (5 pages).

Bhandarkar, P.D.; Patel, J.S., (2017). Water quality zoning of Vishwamitri River to access environmental flow requirements through the aggregation of water quality index. *Int. J. Hum. Capital Urban Manage.* 2(4): 281-292 (12 pages).

Bhangaonkar, P., D. and Patel J., S. (2017). Water quality zoning of Vishwamitri river to access environmental flow requirements through aggregation of water quality index. *Int. J. Hum. Capital urban manage.* 2(4): 281-292.

Bloesch, J., Sandu, C., Janning, J., (2012). *Integrative water protection and river basin management policy: The Danube case*. *River Syst.* 20: 129-144 (16 pages).

Bora, M.; Goswami, D.C., (2017). Water quality assessment in terms of water quality index (WQI): Case study of the Kolong River, Assam, India. *Appl. Water Sci.*, 7(6): 3125-3135 (11 pages).

Carpenter, S.R., Caraco, N.F., Correll, D.L., Howarth, R.W., Sharpley, A.N. & Smith, V. H. (1998). Nonpoint pollution of surface waters with phosphorus and nitrogen. *Ecology Application*, 8: 559–568.

CCME, (2015). Guidance manual for optimizing water quality monitoring program design. Canadian Council of Ministers of the Environment.

Chowdhury, M.S.; Faridah, O., Wan Zurina, N.C.M.; Wan Jaafar, M.I. (2018). Assessment of pollution and improvement measure of water quality parameters using scenarios modeling for Sungai Selangor basin. *Sains Malay*. 47: 457–469 (13 pages).

D.A.Umar, M.F.Ramli, A.Z.Aris, Jamil, N.R.B., and Aderemi, A., A. (2019). Evidence of climate variability from rainfall and temperature fluctuations in semi-arid region of the tropics. *Atmospheric Research*. Volume 224, 1 August 2019, Pages 52-64.

Defersha, B.M., Melesse, M.A., and McClain, E.M. (2012). Watershed scale application of WEPP and EROSION 3D models for assessment of potential sediment source areas and runoff flux in the Mara River Basin, Kenya *Catena*. 95:63–72.

Dessu, B.S., Melesse, M.A., Bhat, G.M., and McClain, E.M (2014) Assessment of water resources availability and demand in the Mara River basin. *Catena*. 115: 104–114.

Dominick D.; Juahir H., Latif M.T., Zain S.M., Aris A.Z., (2012). Spatial assessment of air quality patterns in Malaysia using multivariate analysis. *Atmos. Environ.*, 60: 172–181 (10 pages).

Einax JW, Zwanziger HW, Geis S. (1997). Chemometrics in environmental analysis. Wiley, Weinheim.

Ekeleme, A. C., and Agunwamba, J. C. (2018). Experimental determination of dispersion coefficient in soil. Emerging Science Journal. Vol. 2, No. 4, August, 2018. 213-218 (6 pages)

Eruola A.O., Ufoegbune G.C., Eruola A.O., Awomeso J.A. and Abhulimen S.A. (2011). Assessment of cadmium, lead and iron in hand dug wells of Ilaro and Aiyetoro, Ogun State, SouthWestern Nigeria, Res. J. Chem. Sci. 1(9): 1-5.

Filik I. C., Emiroglu, O., Ilhan, S., Arslan, N., Yilmaz, V. and Ahiska, S. (2008). Application of multivariate statistical techniques in the assessment of surface water quality in Ulubat Lake. Turkey. Environmental Monitoring and Assessment, 144: 269-276.

Garabaa, S.P., and Zielinski, O. (2015). An assessment of water quality monitoring tools in an estuarine system. *Remote Sensing Applications: Society and Environment*. 2: 110. doi: 10.1016/j.rsase.2015.09.001.

Gor, A.; Shah, A., (2014). Water Quality Index of Mahi River, Vadodara, Gujarat. *J. Engg. Devel. Res.*, 2(3): 3214-3219 (6 pages)

Haritash, A.K.; Gaur, S.; Garg, S., (2016). Assessment of water quality and suitability analysis of River Ganga in Rishikesh, India. *Appl. Water Sci.*, 6(4): 383-392 (10 pages).

Horton, R.K., (1965). *An index number system for rating water quality*. *J. Water Pollut. Control Fed.*, 37(3): 300–305 (6 pages).

How can I use BOD5 as pollution indicator in water quality? (2019). Research Gates, Retrieve from, [https://www.researchgate.net/post/How\\_can\\_I\\_use\\_BOD5\\_as\\_pollution\\_indicator\\_in\\_water\\_quality](https://www.researchgate.net/post/How_can_I_use_BOD5_as_pollution_indicator_in_water_quality)

Ibrahim, A. et al. (2015). Assessment of surface water quality using multivariate statistical techniques in the Terengganu river basin. *Malaysian Journal of Analytical Sciences*, 19 (2): 338 – 348.

Jain, A. K. (2009). River pollution. 1st Ed. New Delhi: APH Publishing. ISBN: 8131304639, pp: 330.

Jarvie, H. P., Whitton, B. A., and Neal, C. (1998). Nitrogen and phosphorus in east coast British rivers: speciation, sources and biological significance. *Science of the Total Environment*, 211: 79–109.

Juahir, H., Zain, M.S., Yosoff, M.K., Ismail, T.T.H., Samah, A.M.A., Toriman, M.E. and Moktar, M. (2010). Spatial assessment of Langtan river basin (Malaysia) using environmental techniques. *Environment Monitoring Assessment*, 173: 625-641.

Kannel P.R.; Lee S., Kanel S.R., Khan S.P., (2007). Chemometric application in classification and assessment of monitoring locations of an urban river system. *Anal. Chim. Acta*; 582(2):390-399 (10 pages).

Khan, M.Y.A., Gani, K.M. and Chakrapani, G.J. (2015) Assessment of surface water quality and its spatial variation. A case study of Ramganga River, Ganga Basin, India. *Arab J Geosci*.

Kumar, B., Singh, U.K. and Ojha, S.N. (2018) Evaluation of geochemical data of Yamuna River using WQI and multivariate statistical analyses: a case study. *Int J River Basin Manag.*

Liu, C.W., Lin, K.H. and Kuo, Y.M. (2003). Application of factor analysis in the assessment of groundwater in a Blackfoot disease area in Taiwan. *Science of the Total Environment*, **313**(1-13): 77-89.

Marimuthu, T.; Rajendran, S., (2017). An analysis of water quality parameters of Vennaimalai in Karur District, Tamilnadu, India. *Int. J. Chem. Tech. Res.*, **10**(6): 745-748 (4 pages).

Mkoma S.L.; Mihayo I.Z., (2012). Chemical water quality of bottled drinking water brands marketed in Mwanza City, Tanzania. *Res. J. Chem. Sci.*, **2**(7): 21-26 (6 pages).

Mohamed, I., Othman F., Ibrahim, A.I.N., Alaa-Eldin M.E. and Yunus R.M. (2015) Assessment of water quality parameters using multivariate analysis for Klang River basin, Malaysia. *Environ Monit Assess* **187**:4182.

Mohebbi, M.; Reza, S., Montazeri., (2013). Assessment of water quality in groundwater resource of Iran using a modified drinking water quality index. *Eco. Indic.*, **30**(1): 28-34 (7 pages).

Nnaji C. J., Uzairu A., Harrison G.F.S. and Balarabe M. L. (2010). Effect of pollution on the physico chemical parameters of water and sediments of Galma River, Zaria, Nigeria. *Libyan Agric. Res. Cen. J. Int.*, **1** (2): 115-122 (8 pages).

Ogbozige, F. J.; Adie, D. B., Igboro, S. B., Giwa, A., (2017). Evaluation of the Water Quality of River Kaduna, Nigeria Using Water Quality Index. *J. Appl. Sci. Environ. Manage.*, **21**(6): 1119-1126 (8 pages).

Osei J.; Nyame F., Armah T., Osae S., Dampare S., Fianko J., Adomako D., Bentil N., (2010). Application of Multivariate Analysis for Identification of Pollution Sources in the Densu Delta Wetland in the Vicinity of a Landfill Site in Ghana. *J. Water Res. Protect.*, **2**(12): 1020-1029 (10 pages).

Othman, F.; Chowdhury, M.S., Wan Jaafar, W.Z., Faresh, E.M.M., Shirazi, S.M., (2018). Assessing Risk and Sources of Heavy Metals in a Tropical River Basin: A Case Study of the Selangor River, Malaysia. *Polish J. Environ. Stud.*, **27**: 1659-1671 (13 pages).

Parsa, N., Khajouei, G., Masigol, M., Hasheminejad, H., and Moheb, A. (2018). Application of electrodialysis process for reduction of electrical conductivity and COD of water contaminated by composting leachate. *Civil Engineering Journal*. Vol. 4, No. 5, May, 2018. 1034-1045 (12 pages)

Patil, P.N., Sawant, D.V., and Deshmukh, R.N. (2012) Physico-chemical parameters for testing of water – A review. *International Journal of Environmental Sciences*. **3**(3): 1194-1207.

Rajankar, P.N.; Wate, S.R.; Tambekar, D.H.; Gulhane, S.R., (2013). Assessment of groundwater quality using water quality Index (WQI) in Wardha district. *J. Environ. Sci. Sustain.*, **1**(2): 49 – 54 (6 pages).

Rakotondrabe, F., Ngoupayou, J.R.N, Mfonka, Z., Rasolomanana, E.H., Abolo, A.J.N. and Ako, A.A. (2018). Water quality assessment in the Bétaré-Oya gold mining area (East Cameroon): multivariate statistical analysis approach. *Sci Total Environ* **610-611**:831-844.

Samantray, P.; Mishra, B.K.; Panda, C.R.; Rout, S.P., (2009). Assessment of water quality index in Mahanadi and Atharabanki Rivers and Taldanda Canal in Paradip area, India. *J. Hum. Ecol.*, **26**(3): 153-161 (9 pages).

Santhi, V.A., Mustafa, A.M., 2013. Assessment of organochlorine pesticides and plasticizers in the Selangor River basin and possible pollution sources. *Environ. Monit. Assess.*, **185**: 1541-1554 (14 pages).

Shahrizim, Z. (2018). Work shop on statistical analysis for ecological data [supplementary materials]. December 13, 2018 from:

Sharma, D.; Kansal, A., (2011). Water quality analysis of River Yamuna using water quality index in the national capital territory, India (2000–2009). *Appl. Water Sci.*, **1**(3-4): 147-157 (11 pages).

Shil, S., Singh, U. K., and Mehta, P. (2019). Water quality assessment of a tropical river using water quality index (WQI), multivariate statistical techniques and GIS. *Applied Water Science*. **9**:168.

Shrestha, S. and Kazama, F. (2007). Assessment of surface water quality using multivariate statistical technique as: Fuji river basin Japan. *Environmental Modeling and Software*, **22**(4): 464-475.

Simeonova, P., Simeonova, V. and Andreev, G. (2003). Environmetric analysis of the Struma River water quality. *Central European journal of Chemistry*, 2: 121-126.

SON, (2007). Standard Organization of Nigeria. *Nigerian Standard for Water Quality*. 15-17 (3pages).

Stambuk G., (1999). Water quality evaluation by index in Dalmatia. *Water Res.*, 33 (16): 34233440 (18 pages).

Sundaray, S.K., Panda, U.C., Nayak B. B. and Bhatta D. (2006). Multivariate statistical techniques for the evaluation of spatial and temporal variations in water quality of the Mahanadi river estuarine system (India) a case study. *Environmental Geochemistry and Health*, 28(4): 317 – 330.

Tamer A., Okan Y., Ramazan Y., and Mahmut Y. (2018). Assessment of irrigation water quality of Turkey using multivariate statistical techniques and water quality index: Siddikli Dam Lake. *Journal of Desalination and Water Treatment*. 115 (2018) 261–270.

Tint, Z. L., Kyaw, N. M., and Kyaw, K. (2018). Development of soil distribution and liquefaction potential maps for downtown area in Yangon, Myanmar. *Civil Engineering Journal*. Vol. 4, No. 3, March, 2018. 689-701 (13 pages)

Tredoux G. and Talma A.S. (2006) Nitrate pollution of groundwater in Southern Africa. In *Groundwater Pollution in Africa*, Xu Y, Usher B (eds), *Taylor and Francis/Balkema*: Leiden, The Netherlands. 15-36.

Triola, M.F., (1999). *Introdução á Estatística*. 7 Ed. Rio de Janeiro: Editora LTC. (410 pages).

Tyagi, S.; Sharma, B.; Singh, P.; Dobhal, R., (2013). Water quality assessment in terms of water quality index. *Am. J. Water Resour.*, 1(3): 34-38 (5 pages)

Venkatramanan, S., Chung, S. Y., Lee, S. Y and Park, N. (2014). Assessment of river water quality via environmetric multivariate statistical tools and water quality index: a case study of Nakdong river basin, Korea. *Carpathian Journal of Earth and Environmental Sciences*, May 2014, 9 (2): 125 – 132.

Wang, Y.B.; Liu, C.W., Liao, P.Y., Lee, J.J., (2014). Spatial pattern assessment of river water quality: implications of reducing the number of monitoring stations and chemical parameters. *J. Environ. Monit. Assess.*, 191: 100 (12 pages).

WHO, (1993). *Guidelines for Drinking-Water Quality*, 2nd Edit., Vol. 1: Recommendations. Geneva: World Health Organization. (5 pages).

WHO, (2016). Total dissolved solids in drinking water background document for development of WHO Guidelines for Drinking-water Quality, 2nd ed. Vol. 2, Health criteria and other supporting information, Geneva. *World Health Organization*. (564 pages).

Willet, P., (1987). *Similarity and clustering in chemical information systems*. New York: Wiley. 51-60.

Zhang, Y., Guo, F., Meng, W. and Wang, X. (2009). Water quality assessment and source identification of Daliao river basin using multivariate statistical methods. *Environmental Monitoring and Assessment*, 152: 105-121.

Zhao, Z. and Cui, F. (2009). Multivariate statistical analysis for the surface water quality of the Luan River, China. *Journal of Zhejiang University Science A*, 10(1):