Original Research Article

IDENTIFICATION OF CRITICAL INFLUENTIAL PARAMETERS RESPONSIBLE FOR INCONSISTENCY OF RIVER WATER QUALITY

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ARTICLE INFORMATION

ABSTRACT

The water quality in the middle stretch of River Kaduna, Nigeria was monitored for a period of 12 months in 15 sampling sites. Thirteen (13) water quality parameters were analyzed which include; temperature, turbidity, Total Dissolved Solids (TDS), pH, chloride (Cl^-), and Electrical Conductivity (EC). Others are Dissolved Oxygen (DO), 5-day Biochemical Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), Total Nitrogen (TN), Total Phosphorus (TP), Iron (Fe) and Manganese (Mn). Results were subjected to Factor Analysis (FA) and Principal Component Analysis (PCA) via SPSS version 20. FA/PCA extracted 3 Principal Components (PCs) which explain 83.84% of the variation in the water quality. Turbidity, TDS, Cl^- EC, DO, COD, TN and TP were identified to be the parameters strongly influencing the variability of the river water quality as their absolute factor loading were greater than 0.75.

1. INTRODUCTION

River Kaduna is an important river in North-Western Nigeria as the water is used for both agricultural and domestic purposes. However, the middle stretch of the river which is approximately 32.7 km within Kaduna metropolis receives a lot of pollutants from municipal and industrial discharges as well agricultural runoff (Mohamed *et al.,* 2015). The Shiroro Dam which is located at the lower stretch of the river (i.e downstream of Kaduna metropolis) also get its water from River Kaduna after flowing across Kaduna metropolis. Hence, it is important to know the water quality of the river as it will suggest the level of treatment to be given to the water when the need for using the water for a particular purpose arises. However, an extensive monitoring of the river has not been done despite been part of the responsibilities of the Kaduna State Environmental Protection Authority (KEPA).

Jinliang *et al.* (2011) revealed that one the challenged faced in monitoring water quality is the large data of water quality parameters, which are difficult to analyze and interpret because of latent interrelationships among parameters. Hence, it is crucial to tackle this challenge since river monitoring is a continuous process as the quality of water in a river changes from time to time. One possible way of doing this is to reduce the number of parameters usually analyzed. However, reducing the number of parameters to be analyzed could lead to the loss of vital information concerning the quality status of the monitored river. Hence, reduction of water quality parameters must be done in such a way that parameters that seriously contribute to the fluctuations in quality of the water are not excluded.

Ayobahan *et al.* (2014), Adebola *et al.* (2013) and Adie (2008) reported that multivariate statistical techniques such as Factor Analysis (FA) and Principal Component Analysis (PCA) are good tools in extracting key parameters responsible for water quality variability without much loss of information. In order words, the application of multivariate techniques such as FA/PCA in monitoring the water quality of River Kaduna will help in extracting the parameters responsible for the main variability in the water quality. This will help subsequent monitoring of River Kaduna to be limited to these critical parameters or reducing the sampling frequency of the insignificant parameters. Thus, reducing the cost to be incurred in successive monitoring of the said study area (River Kaduna). Hence, this research aimed to identify the critical physicochemical parameters responsible for the variability of the water in middle stretch of River Kaduna.

2. METHODOLOGY

2.1. Sampling Locations

The sampling locations comprised of 8 sites along River Kaduna and 7 sites (at about 30m away from the confluence points) along the major tributaries, making a total of 15 sampling sites (Figure 1). These sites corresponded to flow routes and inflow from discharge point. The justification for selecting these locations as sampling points is that, they represented the best point for gaining access to the rivers and also suitable for easy sampling of the current water quality status and have a more progressive pollution load (Adie, 2008). A hand held Global Position System (GPS) was used in recording the geographical coordinate of all the sampling locations and are presented in Table 1.
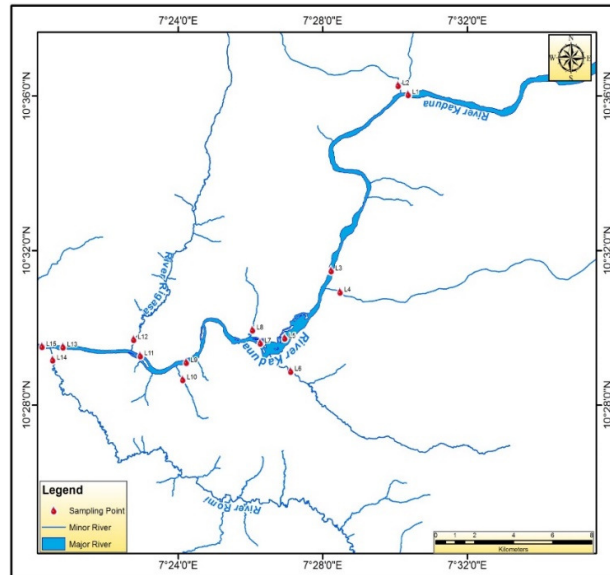
Figure 1: Sampling location map

Table 1: Sampling location coordinates

Location Code	Location Name	Geographical Coordinate
L1	Malali	10°36'3.09"N, 7°30'21.91"E
L2	Kwarau	10°36'16.96"N, 7°30'5.43"E
L3	NNPC	10°31'29.23"N, 7°28'14.04"E
L4	Kuyi	10°30'56.02"N, 7°28'28.84"E
L5	Barnawa	10°29'44.46"N, 7°26'56.86"E
L6	Kutimbi	10°28'53.12"N, 7°27'6.71"E
L7	Living Faith	10°29'36.82"N, 7°26'16.25"E
L8	Kigo	10°29'57.44"N, 7°26'3.32"E
L9	Down Quarters	10°29'6.80"N, 7°24'13.53"E
L10	Breweries	10°28'40.07"N, 7°24'7.42"E
L11	Ungwa Mu'Azu	10°29'17.15"N, 7°22'56.89"E
L12	Rigasa	10°29'42.63"N, 7°22'45.92"E
L13	Maigiginya	10°29'30.84"N, 7°20'48.66"E
L14	Romi	10°29'10.65"N, 7°20'31.50"E
L15	Railway Bridge	10°29'31.67"N, 7°20'13.77"E

2.2. Sampling Procedures and Laboratory Analyses

The sampling was done monthly for a period of one year between June 2016 and May 2017 thus, covering two metrological seasons. This sampling frequency and duration was done in line with that reported by Adebayo (2014) and Esengul *et al.* (2014). The grab sampling technique was employed in each sampling location. This was done by dipping high density polyethylene (HDPE) plastic bottles below the water surface at the center of the stream and ensuring that the mouth of the bottle faces the water current. Prior to sampling, the sample bottles were disinfected with methylated spirit and then thoroughly rinsed with the sample water before sample collection as recommended by APHA, (2005). The collected samples were stored in a cooler containing ice and delivered on the same day to the laboratory where they were refrigerated until analysis. However, DO, pH, TDS and EC were determined on-site. The materials and methods employed in analyzing the water quality parameters are shown in Table 2.

Table 2: Laboratory procedures for analyzing physicochemical parameters of water

Parameter	Method	Reference
Turbidity	Turbidimeter (HACH 2100N Turbidimeter made by HANNA, LTD, England)	U.S EPA, (2001)
TDS	Electrometric (TDS & EC hold, ±2% made by Griffin Company, USA).	U.S EPA, (2001)
pH	Electrometric (Pocket-sized pH meter, pHep®,±0.1, made by HANNA LTD, England)	U.S EPA, (2001)
Chloride (Cl⁻)	Titrimetric (Mohr's method: Silver nitrate as titrant)	U.S EPA, (2001)
EC	Electrometric (TDS & EC hold, ±2%) made by Griffin Company, USA)	U.S EPA, (2001)
DO	Electrometric (Portable DO meter, DO STARTER300D ±1%, made by OHAUS Corp., USA	U.S EPA, (2001)
BOD_5	Incubation technique with DO determination by DO meter	U.S EPA, (2001)
COD	Reflux distillation, followed by titrimetric	U.S EPA, (2001)
Total Nitrogen	Digestion, followed by distillation and titrimetric (Kjeltec 8200™ made by FOSS, Sweden).	U.S EPA, (2001)
Total Phosphorous	Digestion, followed by colorimetric (Colorimeter 257 made by Sherwood, USA).	U.S EPA, (2001)
Iron (Fe)	Atomic Absorption Spectrophotometric (280FS AA made by Agilent Technology, USA).	U.S EPA, (2001)
Manganese (Mn)	Atomic Absorption Spectrophotometric (280FS AA made by Agilent Technology, USA).	U.S EPA, (2001)

EPA = Environmental Protection Agency

2.3. Multivariate Analysis

Factor Analysis (FA) and Principal Component Analysis (PCA) were applied on the data in order to reduce the water quality parameters so as to identify the critical water quality indicators that are behind the changes in the water quality across the catchment area. This provides information on the most meaningful parameters which comes as principal components (PCs). The mathematical expression employed for the determination of principal components (PCs) is shown in Equation (1) (Liu *et al.,* 2016).

$$Z_{ij} = a_{i1}x_{1j} + a_{i2}x_{2j} + a_{i3}x_{3j} + \cdots + a_{im}x_{mj} \qquad (1)$$

Z is the omponent score, a is component loading, x is measured value of a variable (water quality concentration), i is component number, j is sample number, and m is the otal number of variables.

An eigenvalue gives a measure of the significance of the factor and factors with the highest eigenvalues are the most significant. Eigenvalues of 1.0 or greater are considered significant (Shrestha and Kazama, 2015). Classification of principal components is thus strong, moderate and weak, corresponding to absolute loading values of >0.75, 0.75 – 0.50 and 0.50 – 0.30, respectively (Liu *et al.,* 2016). PCs were defined according to the criterion that only factors that account for variance greater than 1 (eigenvalue one criterion) was included. The rationale for this is that any component should account for more variance than any single variable in the standardized test score space (Li and Zhang, 2013). Hence, PCA was applied using varimax rotation with Kaiser Normalization. By extracting the eigenvalues from the correlation matrix, the number of significant factors and the percentage of variance explained by each of them were calculated.

3. RESULTS AND DISCUSSION

Due to the largeness of the sample size (13 parameters × 15 sampling sites × 12 months), the results are given in the appendix. Nevertheless, the laboratory results subjected to the FA/PCA via SPSS version 20

yield the scree plot shown in Figure 2 which indicates that principal components (PCs) 1 – 3 had eigenvalues greater than 1.0 (i.e 6.045, 3.806 and 1.04 respectively as shown in Table 3). The rest PCs were less than 1.0 which indicated that they were not significant hence; their contribution to water quality variation was therefore negligible (Adie, 2008; Adebayo, 2014). In the reports of Onojake and Abrakasa (2012), Zhaoa *et al.* (2012) and Liu *et al.* (2016), factor loading were classified as strong, moderate and weak corresponding to absolute loading values of >0.75, 0.75 – 0.50 and 0.50 – 0.30 respectively. Hence, this research considered factor loading >0.75 as being significant without considering moderate and weak factors.
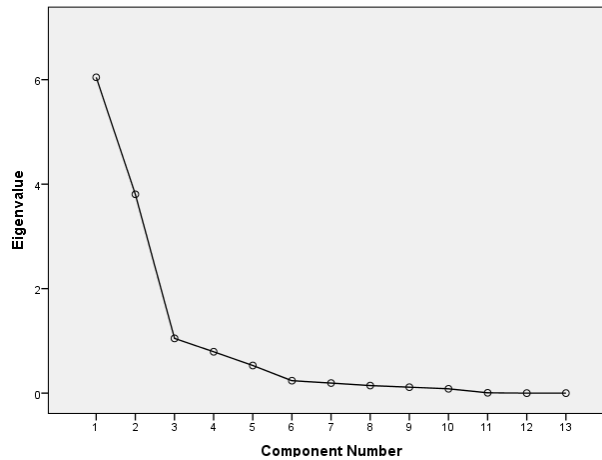

Figure 2: Scree plot

Despite the fact that the scree plot (Figure 2) showed that PC3 had eigenvalue greater than 1.0, it was not included as principal component (Table 3). This is because the absolute factor loading values were less than the target value (>0.75) as could be seen in Table 3.

Table 3: Absolute factor loading of parameters in principal components of water quality

Parameter	PC1	PC2	PC3
Temperature	−0.722	0.483	0.096
Turbidity	**−0.757**	0.613	0.052
Total Dissolved Solids	0.374	**0.889**	0.218
pH	0.440	−0.185	0.336
Chloride (Cl⁻)	0.375	**0.888**	0.219
Electrical Conductivity	0.374	**0.889**	0.219
Dissolved Oxygen	**−0.877**	−0.149	−0.175
BOD$_5$	0.642	0.481	−0.520
COD	**0.836**	0.292	−0.325
Total Nitrogen	**0.891**	−0.442	0.363
Total Phosphorus	**0.908**	−0.475	0.377
Iron (Fe)	0.736	−0.118	−0.185
Manganese (Mn)	0.542	−0.143	−0.256
Eigenvalue	6.045	3.806	1.048
Proportion of Variance (%)	46.501	29.276	8.064
Cumulative Proportion (%)	46.501	75.776	83.840

Extraction Method: Principal Component Analysis; Rotation Method: Varimax with Kaiser Normalization; Communalities (34 – 98%); Kaiser– Meyer–Olkin (KMO) measure of sampling adequacy = 0.812; Bartlett's Test of Sphericity (Chi-square = 6648.897; P<0.001). Bold figures indicate absolute values >0.75 of parameters with strong loading factor.

The three principal components (PC1, PC2 and PC3) accounted for 83.840% of the observed variations in the water quality. However, the first two principal components (i.e PC1 and PC2) which were extracted based on a strong factor loading of >0.75 accounted for 75.776%. PC1 represented 46.501% of variability which indicates a strong negative loading factor on turbidity and dissolved oxygen as well as a strong positive loading factor on COD, total nitrogen and total phosphorus. PC2 with 29.276% of variance designates a strong positive loading factor on total dissolved solids, chloride and electrical conductivity. The extracted critical parameters are shown in Table 4.

Table 4: Extracted principal components and critical parameters

	PC1	PC2
	Turbidity	Total Dissolved Solids
	Dissolved Oxygen	Chloride
	COD	Electrical Conductivity
	Total Nitrogen	
	Total Phosphorus	
Eigenvalue	6.045	3.806
Proportion of Variance (%)	46.501	29.276
Cumulative Proportion (%)	46.501	75.776

It could be inferred from Table 4 that among the 13 water quality parameters monitored along the middle stretch of River Kaduna, 8 strongly influenced the water quality changes. These 8 critical water quality parameters are turbidity, dissolved oxygen, COD, total nitrogen, total phosphorus, total dissolved solids, chloride and electrical conductivity.

4. CONCLUSION

Based on the results obtained and the analysis carried out, the most important outcome of this research are summarized as follows:

i.   Turbidity, TDS, Cl⁻ EC, DO, COD, total nitrogen and total phosphorous are the physicochemical parameters strongly influencing the variability of the water quality of River Kaduna (middle stretch).

ii.   Three principal components (PCs) out of thirteen accounts for 83.84% of the variation in water quality in middle stretch of River Kaduna.

5. ACKNOWLEDGEMENT

6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

SUPPLEMENTARY INFORMATION

Tables S1 to S13: Physicochemical parameters of water samples. This material is available free of charge via the Internet at http://rjees.com.

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