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RESEARCH PAPER

EVALUATION OF SURFACE WATER QUALITY CHARACTERISTICS IN OGUN WATERSHED OF SOUTH WESTERN NIGERIA USING PRINCIPAL COMPONENT ANALYSIS

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ABSTRACT
Utilization of water resources across watersheds in Nigeria has been without commensurate attention to protection from degradation at the basin level. One of the strategies in river basin management is effective monitoring and assessment of pollution levels, patterns and identification of major variables driving such degradation most importantly at the watershed scale. Therefore, it is important to evaluate how critical a quality indicator is in its contribution as well as its spatial extent within and across the entire water basin. Twenty six water quality indicators were assessed in Ogun watershed, Nigeria. The nitrogen forms; TN, NO_3^- and NH_4-N were significantly low in the watershed while TP and PO_4^{3-} were higher ($p<0.05$). The BOD_5 and COD were significantly high which explains the low DO observed in the watershed. High levels of Fe, Cd, Pb, Mn as well as E-coli and Fecal Coliform were recorded. Using Principal Component Analysis (PCA), 77% (20 out of 26) of the water quality indicators examined were found to be critical. These explained more than 90% of the observed water quality variation across the watershed. The variable inclusion level showed that these parameters were critical in 70% of the locations across the watershed. The selection of 77% of the parameters investigated by PCA over 70% of the locations revealed high levels of diffused pollution that calls for urgent attention.

Keywords: *Principal Component Analysis, Ogun watershed, Water Quality, Pollution, Nigeria*

INTRODUCTION
Diffused pollution in watersheds in Nigeria has been reported to be critical (Adedokun *et al*., 2008). Ajibade(2004)observed that the Asa River in Ilorin, north central Nigeria was polluted while Jaji *et al.*(2007) in their study of Ogun river in the south west of the country came up with similar conclusions. To achieve a shift from the current practices of location targeted assessment, holistic water quality assessment at the watershed level is recommended (Emmanuel *et al*., 2010). Whereas, the Ogun-River has been inconsistently monitored at different reaches in an uncoordinated manner (Martins and Awokola, 1996; Jaji *et al.,* 2007), River Ofiki, the second major river in Ogun

watershed which serves as the major source for the dry season agricultural activities and domestic water supply for the agrarian community of Oke-Ogun South Western Nigeria has not been adequately assessed and reported.

An assessment of river water quality using multivariate analysis will enhance the understanding of the pattern of water quality across watersheds (Shreshta and Kazama, 2007). The advantages of multivariate statistics include its capacity to consider complex data arrays and identify patterns otherwise difficult to understand by simple relationships (Cansu *et al*., 2009).

Principal Component Analysis (PCA) has been used in water resources research to identify major elements responsible for observed variation in surface and groundwater as well as sediment quality in watersheds (Karim and Taha, 2003; Ouyang *et al*., 2006; Harley *et al*., 2009). This tool enables the assessment of the relevance of water quality indicator to an environment and justifies its inclusion in the monitoring and assessment scheme to avoid under estimation of levels of water quality impairment.
This study assesses the level of quality impairment using PCA to identify critical water quality indicators with utmost concern in the river systems within Ogun watershed Southern, Nigeria.

METHODOLOGY

The Ogun Watershed

The Ogun watershed covers approximately 23,0447km^{2}and is drained principally by Rivers Ogun and Ofiki (Fig. 1). The rivers have several tributaries including Oyan, Ona and Opeki (OORBDA, 1996). Rivers Ogun and Ofiki were assessed using longitudinal profile technique (Meybeck *et al.,* 1996) across10 locations, which correspond to the established gauging stations in the watershed. The 10 sampling points met the requirement of thorough mixing, representativeness and accessibility (Fig. 1). The locations are: OG1, OG2, OG3, OG4, OG5 and OG6 on Ogun River; and OF1, OF2, OF3, and OF4 on Ofiki River.

Laboratory analysis

Grab sampling method (Meybeck *et al*., 1992) was employed in river water sample collection. Samples were stored in high-density polyethylene plastic bottles. The bottles were pre-rinsed with 1+HNO_3(APHA, 1998) before rinsing with river water at the sampling point. Twenty-six water quality parameters were examined. These include: Temperature, Electrical Conductivity (EC), pH, Dissolved Oxygen (DO), 5 days Biochemical Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), Total Acidity, Turbidity, Total Suspended Solid (TSS), Ammonium–Nitrogen, Nitrate-Nitrogen, Nitrite -Nitrogen, Total Nitrogen (TN), Total Phosphorous (TP), Phosphate(PO_4^{3-}), Iron (Fe), Cadmium (Cd), Zinc (Zn), Mercury (Hg), Copper (Cu), Manganese (Mn), Lead (Pb), Chromium (Cr), Total Viable Bacteria Count (TVC), *Euchearia* coliform (E-Coli) and Fecal Coliform (Fcol).

Samples were taken monthly for 12 months covering a hydrological season and were kept at <4^{o}C using ice parks in mobile cooler. Standard methods (APHA, 1998) were used in laboratory analyses, which include Atomic Absorption Spectrophotometry, Kjeldhal and Colorimetric methods (digestion, washing and addition of reagents for color development). Analyses were accomplished within 48hours after sampling. However, Temperature, EC, pH and DO were taken in situ using Hanna HI98130 meter.

Statistical analysis

Annual average value of each variable was computed while comparisons were made of the water quality variables with the Nigerian Industrial Standard (NIS, 2007), and World Health Organization (WHO, 2011) drinking water guidelines using the more stringent guide in each case. Drinking water guide was employed because river water for domestic abstraction is still a major demand in the watershed. The student's t-test was used for the mean comparison

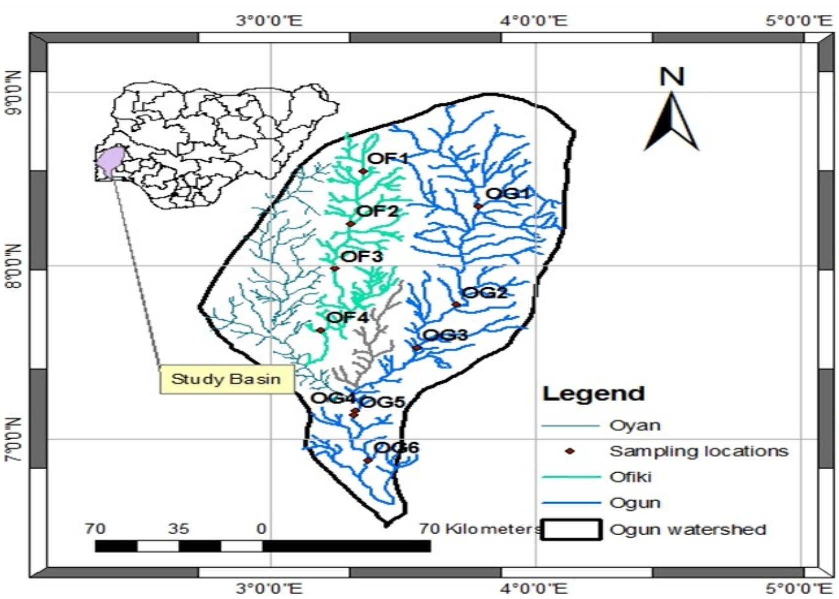

Fig. 1: Location map of Ogun watershed

given matrix (Ouyang *et al*., 2006; Cansu *et al*., 2009).

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

where:

a = component loading
z = component score
x= measured value of a variable (water quality concentration)
i= component number
j=sample number
m= total number of variables

The data matrix for each location was 12 months by 26 water quality variables. The PCA relies upon an eigenvector decomposition of the covariance or correlation matrix (Ouyang *et al*., 2006)In this study, only factors exhibiting an eigenvalue greater than unity were retained (Shresta and Kazama, 2007). Scree plots of the made to determine the principal components (PC) that meet the eigen value criterion. Also, a varimax rotation was performed to address the problem of variables loading moderately or equally on one or more of the axes. A secured increased PCs significance is the consequence of this rotation on the interpretation of the results (Karim and Taha, 2003; Ouyang *et al*., 2006). Using the component loading factor, a variable with factor loading more than 0.70 was considered to be significant (Shreshta and Kazama, 2007).The percentage of locations where a variable was listed as significant in PCs was noted as its Variable Inclusion Level (VIL) in the watershed (Equation 2). Variables with 70% VIL and above were taken as parameter of major concern in monitoring water quality variation in the watershed.

$$\text{Variable inclusion level} = \frac{\text{No of locations where a variable is included in the PCs}}{\text{Total no of locations studied in the watershed}} \times 100\% \quad (2)$$

RESULTS AND DISCUSSION

Water quality characteristics

The annual mean water quality indicators are shown in Table 1. The EC and pH across the locations ranged from 1.15 - 1.25dS/m and 6.9 – 7.1, respectively. Conductivity and pH were not significantly higher than the expected maximum of 10dS/m and 6.5 – 11.0 respectively. This shows that water quality in terms of acidity is adequate for agricultural purposes. The minimum and maximum water temperatures across the watershed ranged from 21 – 23^oC and 26 – 30^oC, respectively. Higher temperature was observed during the period of low rainfall. This may be due to increasing anaerobic digestion of deposited bio-degradable materials in the river system according to Ruth and Mathew (2003).

The DO was quite low across the basin (1.98 – 2.64mg/l). Relatively higher values were recorded during the wet seasons. The low level of DO is related to high level of organic wastes in the river systems (Gilbert, 1996). This was evidenced in high BOD_5 and COD which were significantly higher ($p<0.01$) than the limits set by WHO. The recorded mean value of BOD_5 in Ogun watershed ranged between 31.1mg/l in OG1 and 41.2mg/l in OG4, which are within agricultural and urban land-use respectively. A similar trend was observed in the values of COD. High levels of biodegradable organic materials adversely affects DO since available oxygen is used up in the oxidation process (Gilbert, 1996).

Turbidity (Turb) and TSS across the watersheds generally exceeded the acceptable limits of 5.0mg/l and 25mg/l respectively (Table 2). Across all locations in Ogun and Ofiki rivers, there were high levels of turbidity occasioned consequence is a decrease in light penetration to the river systems. These give the river poor aesthetic value with potential to increase sedimentation in reservoirs within the watershed. Emmanuel *et al*., (2010) had observed negative impact of discharged effluent from a wastewater treatment plant on a receiving watershed in South Africa.

The Nitrogen forms were generally lower than the limits set in NIS and WHO guides (Table 2). This suggest that Nitrogen based nutrient pollution may not be a major challenge in the watershed. However, the level of phosphate (11.9 – 14.1.9 mg/l) was significantly ($P<0.01$) higher than the limits of 0.02mg/l. Similarly, TP was higher than the expected 5.0mg/l across all the locations. Phosphate levels in the watershed could be linked to discharge of wastewater and runoff from farmlands using phosphate-based fertilizers in addition to the natural occurrence of phosphorous in the watershed. Impacts of nutrient pollution in the surface water of sub-Saharan Africa have generally been identified (Nyenje *et al*., 2010) with the impact of phosphorous being more pronounced in Ogun watershed.

With the exception of Zn, Cu and Cr, it was observed that the annual mean concentration of other metals across the watershed was significantly ($P<0.01$) higher than the limits set for each of the variables (Table 2). This elevated metal concentration should be of major concern for human health (GEMS, 2007). Farmers depend on the river water for irrigation and crops are prone to elevated metal uptake from irrigated soil with attended risk for consumers (Oluwatosin *et al*., 2009; Fiona *et al*., 2010).

The bacteria loads were significantly ($P<0.01$) higher than the 10cfu/100ml limit. Specific

Table 1: Descriptive statistics of the water quality data

Water Quality Indicators (units)[a]	NIS	WHO	Water Quality Sampled over 12 months									
			OG1	OG2	OG3	OG4	OG5	OG6	OF1	OF2	OF3	OF4
Temp (°C)			24.5±1.2	24.2±1.3	24.9±1.3	24.6±1.1	24.6±1.5	24.8±0.6	24.0±0.8	23.6±0.3	23.9±0.5	24.2±0.7
EC (dS/m)	10.0		1.15±0.04	1.15±0.03	1.19±0.04	1.23±0.10	1.25±0.11	1.23±0.14	1.23±0.11	1.20±0.12	1.22±0.07	1.20±0.07
pH	6.5-8.5	11.0	6.9±0.35	6.9±0.50	7.1±0.56	7.1±0.6	7.1±0.5	7.0±0.4	7.0±0.5	6.9±0.6	6.9±0.4	6.9±0.4
DO		2.0	2.02±1.02	1.98±1.0	2.15±1.04	2.29±1.16	2.40±1.14	2.19±1.23	2.56±31	2.60±1.23	2.61±1.23	2.64±1.21
BOD_5		3.0	31.1±14.9	33.5±17.0	39.0±20.9	40.6±21.0	40.8±20.9	37.5±19.2	33.3±19.1	34.6±17.5	38.3±20.1	41.2±20.1
COD		20	45.3±15.1	42.8±17.0	49.0±20.9	49.3±24.0	49.9±24.7	51.2±24.9	45.0±23.8	44.2±22.4	43.0±21.9	45.3±22.6
Turb(NTU)		5	12.5±2.3	11.8±2.5	12.0±1.9	13.1±4.6	14.1±4.7	13.4±4.5	13.2±2.6	13.1±2.5	14.9±5.7	15.1±5.0
Tacd (g/100g)		-	0.21±0.4	0.32±0.7	0.21±0.3	0.20±0.3	0.40±0.94	0.20±0.36	0.23±0.31	0.23±0.30	0.28±0.36	0.27±0.39
TSS		25.0	23.7±6.0	22.9±7.5	23.4±7.0	23.1±7.3	22.8±7.8	24.3±8.4	25.9±9.7	25.7±6.8	26.4±6.8	28.8±6.4
NH_4-N		0.2	0.12±0.04	0.13±0.02	0.13±0.04	0.12±0.06	0.12±0.05	0.11±0.06	0.11±0.06	0.12±0.06	0.12±0.06	0.11±0.06
NO_3-N	50.0	50.0	0.03±0.03	0.03±0.03	0.04±0.03	0.04±0.03	0.04±0.04	0.04±0.04	0.03±0.03	0.04±0.04	0.04±0.04	0.03±0.04
NO_2	0.2	3.0	0.03±0.03	0.03±0.04	0.03±0.03	0.04±0.04	0.04±0.05	0.03±0.04	0.03±0.04	0.03±0.04	0.03±0.04	0.03±0.05
TN(%100ml)		1.0	0.17±0.05	0.18±0.05	0.16±0.05	0.17±0.05	0.17±0.06	0.17±0.05	0.18±0.07	0.18±0.08	0.19±0.08	0.20±0.09
TP(%100ml)		5.0	11.2±2.2	10.7±2.7	10.9±2.6	11.2±3.1	10.9±2.7	11.4±2.2	11.7±1.7	12.5±1.6	12.6±1.39	13.5±1.12
PO_4		0.02	12.4±3.8	11.9±2.9	12.6±2.7	13.4±2.5	12.5±2.9	13.1±2.1	12.9±1.8	13.9±1.9	13.4±2.05	14.1±2.03
Fe	0.3	0.3	0.68±0.42	0.74±0.40	0.63±0.51	0.72±0.58	0.70±0.61	0.67±0.65	0.84±0.93	0.81±0.88	0.71±0.78	0.63±0.63
Cd	0.003	0.003	0.03±0.01	0.03±0.01	0.03±0.02	0.03±0.02	0.03±0.01	0.03±0.02	0.03±0.02	0.04±0.03	0.04±0.02	0.04±0.02
Zn	3.0	3.0	0.99±0.54	1.09±0.62	1.00±0.47	0.95±0.66	0.97±0.70	0.96±0.67	1.16±0.95	1.06±0.80	1.04±0.69	1.19±0.64
Hg	0.001	0.001	0.002±0.001	0.00±0.003	0.003±0.003	0.003±0.004	0.003±0.003	0.003±0.003	0.003±0.003	0.003±0.003	0.003±0.003	0.003±0.003
Cu	1.0	2.0	0.07±0.09	0.07±0.09	0.07±0.08	0.06±0.08	0.07±0.07	0.07±0.08	0.07±0.09	0.08±0.08	0.07±0.08	0.08±0.08
Mn	0.2	0.5	0.50±0.43	0.50±0.45	0.55±0.50	0.56±0.46	0.70±0.55	0.64±0.48	0.64±0.047	0.64±0.45	0.63±0.47	0.65±0.49
Pb	0.01	0.01	0.04±0.04	0.04±0.05	0.05±0.05	0.05±0.04	0.04±0.04	0.04±0.04	0.05±0.05	0.05±0.05	0.04±0.04	0.04±0.04
Cr	0.05	0.05	0.01±0.004	0.01±0.005	0.01±0.01	0.01±0.06	0.01±0.01	0.02±0.01	0.02±0.02	0.02±0.02	0.02±0.02	0.02±0.02
TVC (x 10^6 CFU/100ml)	10.0	10.0	22.3±2.9	23.3±2.0	23.6±4.5	21.4±4.0	19.2±5.2	20.3±3.9	20.9±4.0	19.0±4.7	18.7±5.1	18.1±4.8
E-*coli* (x 10^6 CFU/100ml)	0	0	1.3±0.41	1.5±0.33	1.3±0.45	1.2±0.45	1.3±0.51	1.4±0.4	1.6±0.41	1.7±0.32	1.6±0.48	1.7±0.38
Fcol (x 10^6CFU/100ml)	0	0	1.5±0.42	1.8±0.33	1.6±0.53	1.5±0.46	1.4±0.28	1.5±0.15	1.7±1.2	1.7±0.24	1.5±0.20	1.7±0.18

[a]All parameters are in mg/l except where stated; NIS = Nigerian Industrial Standard; WHO = World Health Organization;

Table 2 : Comparison of data average with guide values of maximum allowable limits

Variables (units [e])	Test guide value	sig ↑ [a]	ns↑ [b]	sig ↓ [c]	ns ↓ [d]
Temp (^oC)	-				
EC (dS/m)	3.0			*	
pH	6.5		*		
DO	2.0		*		
BOD_5	3.0	*			
COD	3.0	*			
Turb (NTU)	5.0	*			
Tacd (g/100g)	-				
TSS	25	*			
NH_4-N	0.2			*	
NO_3-N	50.0			*	
NO_2	0.2			*	
TN(%100ml)	1.0			*	
TP(%100ml)	5.0	*			
PO_4	0.02	*			
Fe	0.3	*			
Cd	0.003	*			
Zn	3.0			*	
Hg	0.001	*			
Cu	1.0			*	
Mn	0.2	*			
Pb	0.01	*			
Cr	0.05			*	
TVC (x 10^6 CFU/100ml)	10.0	*			
E-*coli* (x 10^6 CFU/100ml)	0	*			
Fcol (x 10^6CFU/100ml)	0	*			

*[a] significantly higher (p<0.01); [b] not significantly higher (p<0.01); [c] significantly lower (p<0.01) [d] not significantly lower (p<0.01); [e] All parameters in **mg/l** except where stated*

assay of E-*coli* and fecal coliform across the watershed also revealed a significantly high level of pathogenic load. The rural communities bordering the Ogun and Ofiki watershed still meet their water need mainly from rivers and streams without any form of treatment. This poses a high risk of water borne and water related diseases to the communities within the watershed. The high pathogenic loads across the watershed may be linked to unregulated cattle grazing and wash off of cattle dung, indiscriminate poultry and other solid wastes into the river systems.

Principal components analysis across the locations

The scree plots of eigen values generated in the analysis were used in determining the appropriate principal components (PCs) to be considered. Fig. 2 and Fig. 3 show the scree plots obtained from the eigen values for OG1 and OG2data respectively. Considering eigen values >1.0as proposed by Shresta and Kazama (2007), component numbers 1 – 4 (Fig. 2) met the criteria.The4PCs selected for the analysesi.e.PC1 – PC4, accounted for 58, 19, 8 and 7% thus totaling 93% of the total variance of information contained in the original dataset for the location. Similarly, the scree plot for location 2 (OG2) on the Ogun river (Fig. 3) show five PCs with eigen values >1.0 (PC1 –PC5), and therefore selected for further analysis at this location. The PC1–PC5 explained 54, 23, 8, 6 and 5% totaling 96% of the total variance of information contained in the original dataset for the location.

With PC extractions, the selected indicators were able to give substantial explanation of the observed variation without losing or distorting the complete picture of the data set. In OG1, the parameters in the PCs explained 93% of the variation observed, thus, the remaining 7% variation was explained by excluded indicators. The excluded indicators are not significant enough to affect the observed variation in the location. Karim and Taha (2003) have also used the strength of PCA to identify the drivers of variation and listing them as PCs.

The indicators constituting the PCs for location 1 (OG1) are presented in Table 3. PC1, which explains 58% of the variation observed at this location had heavy metals, conductivity and total viable counts as the major water quality indicators. The PC2 had Temperature, COD, Phosphate, heavy metals (Zn and Hg) and Fecal coliform as responsible for the observed 19% of the variation within the location. Organic constituent (BOD_5), which has direct influence on dissolved oxygen depletion in the water body and E-*coli* level in the river, explains 8.5% while turbidity accounted for 7% of the observed variation in the location. The contribution of PC1 shows that heavy metal pollution is a major consideration within OG1 in Ogun

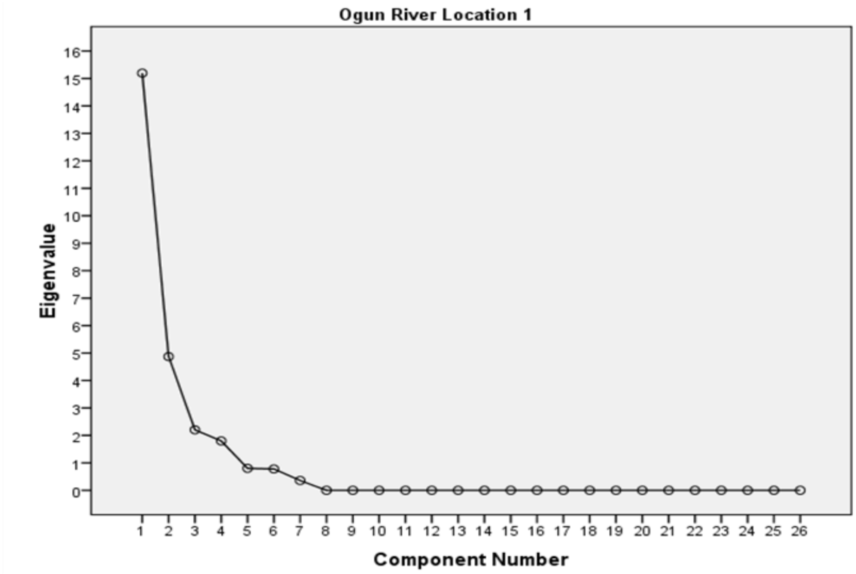

Fig. 2: Scree plot for delineation of PCs for location 1 on the Ogun River

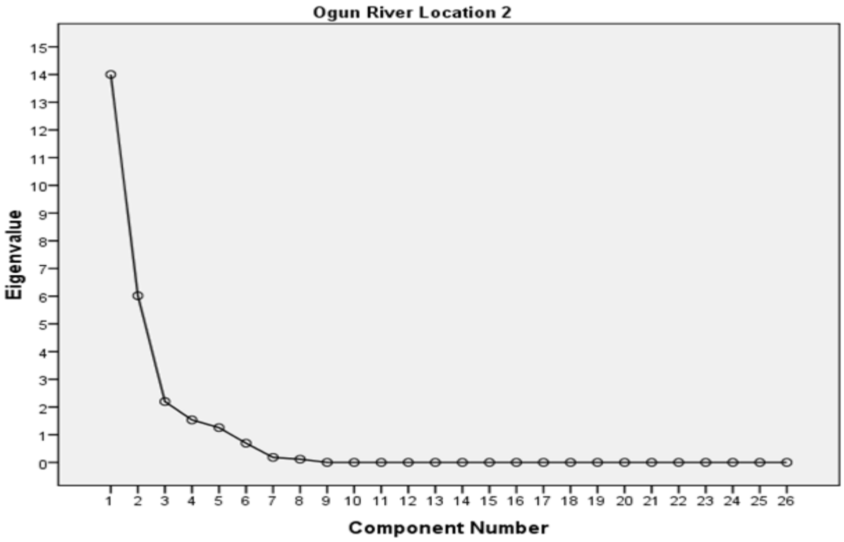

Fig. 3: Scree plot for delineation of PCs for location 2 on the Ogun River

River section of the watershed. Although industrial activities within the watershed are minimal, the land-use is mainly agricultural and the impact of Fe, Pb, Cd, Cr and Mn are significant. These heavy metals might have been from traffic and agricultural bio-chemical inputs, in addition to possible natural sources (Emoyan *et al*., 2006).

The water quality indicators constituting each of the PCs in OG2 are listed in Table 4. The major indicators of water quality variation in PC1 are nitrogen compounds, phosphate and heavy metals, which together explain 53.8% of the variations. This principal component reflects nutrient and heavy metals (Fe, Cd, Zn, Cu, Mn, Pb) pollutants in the location. For PC2, which explains 23.1%of the variation, the impact of organic load and particulate influx was evident while PC3 and PC5 have indicators of microbiological pollutants and conductivity. Agricultural land-use is predominant in this location while human settlement is dispersed comprising mainly of farmlands and villages. The observation of nutrient pollution is related to the use of organic and inorganic fertilizers. Iron and Zinc could be from natural occurrence while Cd may be related to the use of inorganic fertilizers (Nyenje *et al*., 2010). Similar to the upstream location (OG1) where heavy metals constitute part of the major pollutants observed, the use of PCA has revealed the influence of heavy metals as critical in water quality variation across the locations.

Component loading factor

Component loadings are the linear combinations for each principal component. It expresses the correlation between the original variables and the newly formed components. The components loadings are used to determine the relative importance of a variable under consideration as compared to other variables in a PC and do not necessarily reflect the importance of the component itself (Ouyang *et al.,* 2006). The varimax rotated component loadings for the observed variables listed in the PCs in OG1, which were considered significant at >0.70 are

Table 3: Principal components explaining water quality variation in location 1 of Ogun River

	PC1	PC2	PC3	PC4
	EC	Temp	DO	Turbidity
	NO_2	COD	BOD_5	Tacd
	Fe	PO_4	E-*coli*	
	Cd	Zn		
	Cu	Hg		
	Mn	F col		
	Pb			
	Cr			
	TVC			
Total Eigen value	15.194	4.87	2.203	1.798
% of Variance	58.439	18.73	8.473	6.915
Cumulative %	58.439	77.169	85.642	92.557

Table 4: Principal components explaining water quality variation in location 2 of Ogun River

	PC1	PC2	PC3	PC4	PC5
	NO_3	DO	Temp	Tacd	TVC
	NO_2	BOD_5	Ec		
	TN	COD	Ecol		
	PO_4	Turb	Fcol		
	Fe	TSS			
	Cd	Hg			
	Zn	Cr			
	Cu				
	Mn				
	Pb				
Total Eigen values	14.00	6.02	2.20	1.536	1.255
% of Variance	53.85	23.14	8.449	5.907	4.828
Cumulative %	53.85	76.99	85.439	91.346	96.174

shown in Fig. 4. Variables with such level of loadings were considered critical. The contributions from each of the PCs were different. In terms of percentage contributions to the variation, however, the listed parameters in each of the PCs all have high component loading factors (>0.70). High loading factors confer on the variable a high level of significance (Shreshta and Kazama, 2007). Fig. 5 similarly shows the component loading for the indicators

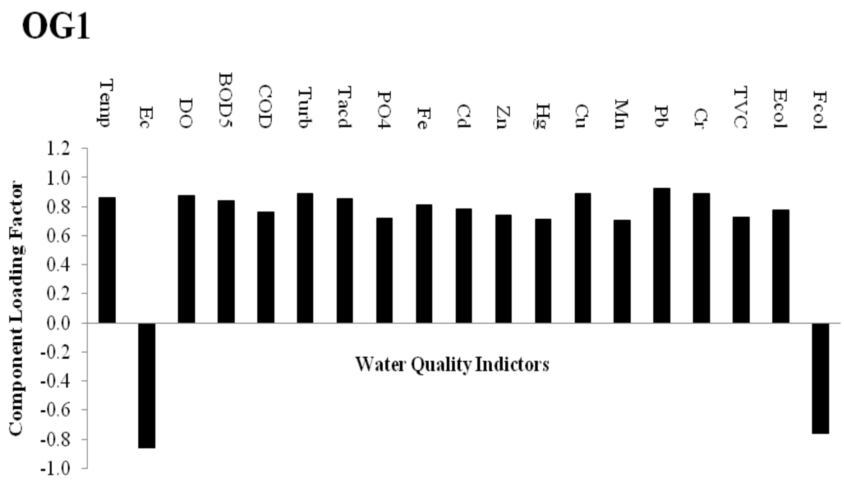

Fig. 4: Factor loading for location OG1 on Ogun River

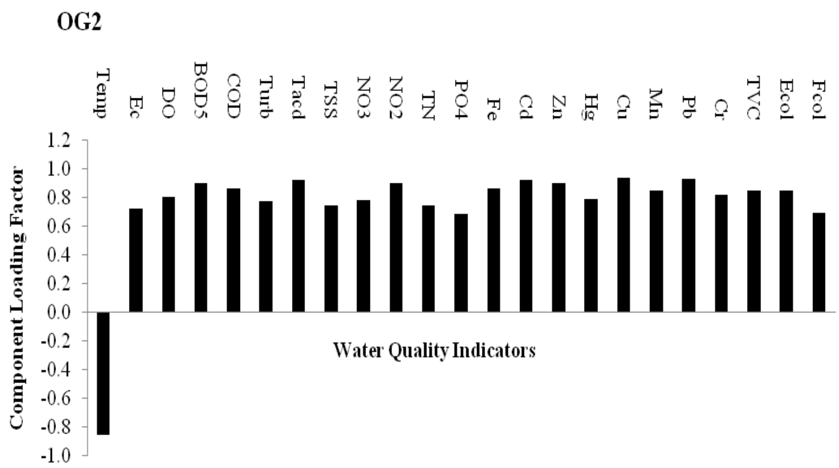

Fig. 5: Factor loading for location OG2 on Ogun River

identified in the PCs of OG2.

Other locations in Ogun Watershed

The summary of the contribution of variation and number of indicators implicated across the locations OG3, OG4, OG5 and OG6 on Ogun and OF1, OF2, OF3 and OF4 on Ofiki Rivers are presented in Table 5. The Ofiki River mainly drains agricultural and sub-urban settlements without much control of organic and inorganic fertilizer use, agrochemical inputs, grazing and sanitary systems. Indiscriminate disposal of dry cell batteries used by farmers to power transistor radios also increases the risk of Pb and Cd in the surface water system. The PCs generated for locations across Ofiki Rivers had a very close similarity to that obtained along Ogun River. Heavy metals were mainly listed in the PC1 for each of the locations showing the contribution and strategic importance of heavy metals as a pollutant in the Ogun and Ofiki river systems. Nutrients (TN, TP, PO_4), Organic load (BOD_5, COD) physical parameters (Turbidity, TSS, DO, Temperature) as well as E-*coli* and Fecal coliform are the major pollutants. These accounted for a high percentage (>90%) of the observed water quality variation in these rivers. Similarly, the component factor loadings of variables in PCs of Ofiki River are equally high.

Variable inclusion level and critical indicators in the watershed

Table 5 shows that in all the locations, between 90 and 96% of the variations were accounted for by the parameters listed under each loca-

Table 5: Summary of the PCA identified water quality indicators listed at each of the Locations and the Variable Inclusion Level (VIL)

	OG1	OG2	OG3	OG4	OG5	OG6	OF1	OF2	OF3	OF4	VIL
Temp	√	√			√	√	√		√		60.0
EC	√	√			√		√		√		50.0
pH			√			√	√	√		√	50.0
DO	√	√	√	√	√	√	√	√	√	√	100.0
BOD_5	√	√	√	√	√		√	√	√	√	90.0
COD	√	√	√	√	√		√	√	√	√	90.0
Turb	√	√	√	√	√	√		√	√	√	90.0
Tacd		√	√	√	√	√	√	√	√	√	90.0
TSS				√			√	√		√	40.0
NH_4-N			√	√		√	√	√	√	√	70.0
NO_3-N		√	√	√	√	√		√	√		70.0
NO_2	√	√	√	√	√	√	√	√	√	√	100.0
TN		√	√	√	√	√	√	√	√	√	90.0
TP			√	√	√	√	√			√	60.0
PO_4^{3-}	√	√		√	√	√	√		√	√	80.0
Fe	√	√	√	√	√	√	√	√	√	√	100.0
Cd	√	√	√	√	√	√	√	√	√	√	100.0
Zn	√	√	√	√	√	√	√	√	√	√	100.0
Hg	√	√	√			√			√	√	60.0
Cu	√	√	√	√	√	√	√	√	√	√	100.0
Mn	√	√	√	√	√	√	√	√	√	√	100.0
Pb	√	√	√	√	√	√	√	√	√	√	100.0
Cr	√	√	√	√	√	√	√	√	√	√	100.0
TVC	√	√	√			√	√	√	√	√	80.0
Ecol	√	√	√	√	√	√	√	√		√	100.0
Fcol	√	√	√	√	√	√	√	√	√	√	100.0
No of critical indicators	19	22	22	21	21	22	23	21	22	23	
% Cumulative variation explained	92.6	96.2	95.3	93.2	92.9	94.0	94.8	94.8	91.8	90.6	

tion. Out of 26 parameters monitored, the numbers of critical indicators listed by the PCs ranged from 19 – 23. OFI and OF4 had the largest indicators (23), while OG1 has the least (19).

From Table 5, the parameters that have variable inclusion level (VIL) of 70 – 100% are of significant importance in the watershed. Other variables have VIL that are less than 70%. The water quality monitoring therefore, may not employ all the parameters listed in each of the locations. This is contrary to the practice of using variables that are important in a watershed in the assessment of another watershed without answering the question of relevance and adequacy. The choice of indicators should be based on major factors driving pollution within the area. Ouyang *et al*. (2006) had earlier observed from a study of water quality in lower St John's river basin, USA that the variables that are important in a season are not exactly the same in another season.

Thus, 20 out of the 26 investigated variables are considered important and should be given utmost attention as basic indicators in monitoring and assessment of water quality in the Ogun watershed. This high number of pollutants not only confirms the extent of the pollution of the watershed, but also the near homogeneity of water quality impairment across the locations.

CONCLUSION

This study has shown that the management of water resources system is not complete without adequate assessment of variables that influence the surface water health status. The use of location PCA has shown that major pollutant of a river system could be identified without compromising the integrity of investigation. As a follow up to the PCA, evaluation of inclusion level of each variable enabled the spread of the critical variables in a watershed. The high number of parameters, which are of critical importance in monitoring water quality status in the Ogun watershed is an indication of high level of impairment of Ogun and Ofiki River systems. This calls for better attention to the management of land-use in the watershed and the enforcement of pollution control regulations.

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