Determination of the Factors Associated with Surface Water Quality Variations in a Sub-Sahara African City: Case of Enugu City, Nigeria

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Abstracts
In Nigeria, most cities contain a number of water bodies together with a small network of streams. Enugu urban is among the cities that have many surface water, these rivers are linked to one another across neighborhoods. Most of these freshwater ecosystems have been subjected to an increasing pollution load from contaminated urban run-off water. Unfortunately, studies that determine the factors associated with surface water quality variations in surface waters have been lacking in the body of literature. This study therefore sought to determine the factors associated with surface water quality variations. 12 surface water samples were collected from the six major rivers in Enugu urban. The six surface water in Enugu urban include- Ekulu river, Asata River, Aria River, Ikiriki river, Idaw River and Ogbete river. This study adopted the experimental research method. Being a monitoring of surface water quality, a number of water samples were collected bi-monthly from determinate sampling sites along the six rivers sampled for the study and sent to the laboratory for related physical-chemical-microbiological analysis. 21 selected physico-chemical and microbiological parameters were investigated in the study. Principal Component Analysis was used compress the perceived factors associated with surface water quality variability. The study found that six factors influenced surface water quality variability in Enugu urban and they were: Salinity (29.82%); trophicity (23.57%); organic pollution (13.05%); oxide-related (9.97%); erosion, (7.19%); and bacterial factors (6.10%). The knowledge of these factors will make for proper management and conservation of the surface water which is necessary to any living organism in the aquatic environment and preservation of biodiversity.

Keywords: *Seasonal, parameters, quality, component, river*

1. Introduction

In most societies people rely on surface water not only for the irrigation of crops, aquaculture and the transportation of goods, but also for daily domestic uses including for drinking. Poor water quality and inadequate pre-treatment of surface water before use can lead to serious health risks and may be a contributing factor to the high mortality rate of all deaths due to diarrhoea in Southeast Asia and Africa (WHO, 2013). Past studies have shown, for example, that pesticide residues, faecal pollution, high concentrations of various heavy metals like cadmium (Cd), copper (Cu), nickel (Ni) and lead (Pb), investigated in main waterways and coastal zones have been correlated with human hazards in the world. Another important source of water contamination is aquaculture, leading to high levels of (bio) chemical oxygen demand (COD, BOD) and nutrients in water as a result of the applied fish food (Anh, 2010). Furthermore, the effects of urbanization on surface water contamination are well recognized. Two independent studies in Ohio, USA showed clear correlations between electrical conductivity and concentrations of nutrients with urban land-uses (Wang and Yin, 1997; Tong and Chen et al, 2005). Similar findings were reported from urbanized areas in China (Wang et al, 2007), and a study conducted in Shanghai revealed that 94% of the variability in water quality was explained by industrial/domestic urban land uses (Ren et al, 2003).

Apart from these anthropogenic and soil type-related sources of pollutants, climatic and seasonal effects including hydrological factors have also been found to influence surface water quality through the variability in precipitation, flow discharge, mean water level and air temperature. These factors were found to strongly correlate with COD and dissolved oxygen concentrations in surface water bodies in China, Florida and Spain (Prathumratana et al, 2008; Ouyang et al, 2006). The quality of a given water body is controlled by its physical, chemical and biological factors, all of which interact with one another to influence its productivity (Keke *et al.* 2015). Water quality is often affected by the discharge of organic and inorganic materials or pollutants into a water body with observable changes in the biotic community, abundance (number of individuals) and diversity (Arimoro & Ikomi 2008, Arimoro et al. ,2015). In a study on the effects of environmental variability on surface water quality, it was revealed that the pollution level was comparatively higher in the mid-stations; where, the industrial activities are more compare to other parts; as a result, more effluents were adding to the stream and thus caused high pollution (Ghani et al, 2016). Considering the analytical results, it is clear that the major source of pollutant was the industrial wastes containing organic, inorganic pollutant and heavy metals, associated with some homesteads and a few agricultural practices.

Pollution of aquatic environment caused by the anthropogenic activities, degradation and misuse of natural resources has been increasing in our planet. This has been witnessed in the last few decades. Due to this, several countries have established policies that protect environment from anthropogenic threats and to provide a proper way of using water resources. On the other hand it is important to understand that the availability of clean freshwater is essential for all form of life in our planet. Henceforth, understanding the ecology of freshwater is vital not only because of its biological implications, but also because the proper management and conservation of freshwater is necessary to any living organism including human being. Though there are determines the many sources of natural pressures encountered by aquatic and terrestrial organisms in their habitats, human activities do generate other more environmental pressures (Moynihan, Baker, and Mmochi, 2012). However, in order to understand the status of surface water quality and reduce pollution rate in surface waters, the knowledge about the health status of aquatic environment including their biodiversity is important. This is robust when assessed along the seasonal and spatial variability of the water body (Mophin-Kani and Murugesan, 2014). This can be done, aside the physico-chemical parameters, by using various established bioindicators of water quality. There is no information on the factors associated with surface water quality variations (spatial and seasonal) in surface water in Enugu urban, Against this background, the purpose of this study is to determine the factors associated with surface water quality variations of surface water quality in Enugu metropolis. The surface water to be sampled in the study are the major six surface water bodies in Enugu urban and they are Ekulu river, Asata River, Aria River, Ikiriki river, Idaw River and Ogbete river. The findings of this study will educate, inform and develop policies or initiatives at helping health agencies and practitioners to mitigate the effects of surface water pollution in the developing countries in general and in Africa in particular.

2. Literature Review

Water quality, measured by assessing the physicochemical and biological properties of water against a set of standards, is used to determine whether water is suitable for consumption or safe for the environment. Some uses of water, e.g. for domestic purposes, agricultural production, industrial production, mining, power generation and forestry practices, cause deterioration in water quality and quantity.

2.1 Natural factors affecting water quality

The quality of both surface water and groundwater is affected by natural and anthropogenic factors. The composition of surface water and groundwater is dependent on e.g. geological, topographical, meteorological, hydrological and biological factors. It varies with seasonal differences in weather conditions, run-off volumes and water levels. Geological factors are due to the contribution of the geosphere to groundwater composition, mainly through the effect of chemical water–rock interactions in aquifers (Raburu, 2003; Price & Mance, 1978). The main factors affecting water quality in wells drilled into bedrock seem to be the rock type (Azzoni et al, 2001) and the mode of weathering of the particulate minerals (Capel et al. 2008).

The composition of the bedrock influences not only the chemical composition of the groundwater in the fissures and fractures, but also that of the groundwater in Quaternary deposits (Batley et. al. 1982). When there are no human influences, changes in water quality occur due to factors such as weathering of bedrock evapotranspiration and the deposition of dust and salt by wind. Furthermore, natural processes such as leaching of organic matter and nutrients from soil, hydrological factors leading to run-off and biological processes within the aquatic environment bring about changes in physical and chemical composition of water. Thus due to these natural processes, water in the natural environment may contain dissolved as well as undissolved solids. Dissolved salts and minerals are necessary components of good quality water as they help maintain the health and vitality of organisms that rely on this ecosystem service (Suratman et al. 2006). Natural water bodies such as lakes, rivers, streams and groundwater need to contain water of good quality because they are the only natural water sources on which life depends (Taub, 2004). However, natural waters contain a variety of contaminants arising from erosion, leaching and weathering processes; such contaminants can only have their concentrations reduced by normal water and wastewater treatment processes, so their presence in a particular water source may limit its use (Van der et al, 2006; Takashima, et al 2002)

Floods and droughts may bring about changes in water quality through dilution or concentration of dissolved substances. Where there are low river flow rates, the main effect on water quality is

when there is a temperature increase, increased concentration of dissolved substances and decreased concentration of dissolved oxygen (Prathumratana et al. 2008; Van Den et al, 2005.
Drought–rewetting cycles may impact water quality as they enhance decomposition and flushing of organic matter into streams (Evans et al. 2005). Droughts may have impacts on river water quality (Wright. &Welbourn, 2002; Slaveykova et al, 2003), that depend on the properties of compound, which could be as well either negative or positive. An increase in water temperature also has an impact on chemical processes in lakes, with an increase in pH (Puckett et al, 2008). Seasonal variations in surface run-off, precipitation, interflow, groundwater flow and pumped inflows and outflows have a strong effect on river discharge and subsequently on the concentration of pollutants in river water (Tong, & Chen, 2002). Dissolved organic matter (DOM) affects the functioning of aquatic ecosystems through its influence on acidity, trace metal transport, light absorbance and photochemistry, and energy and nutrient supply (Ezenwaji, 2008). The main source of DOM in surface waters is soil leaching which is governed by discharges following heavy rainfall, will tend to increase with climate change and consequently have an impact on lakes. Many rocks and minerals in the Earth's crust, e.g. fluorospar, cyyolite and fluorapatite (FanX et al, 2012), contain fluoride (Murray 1986; Loganathan et al. 2003) which can be leached out by natural weathering and rainwater, causing contamination of surface water and groundwater, and thus public water systems (Earman, S. & Dettinger, 2011). For example, Dickens, and Grahm, (2002) reported extremely high fluoride concentration (> 1000 mg l−1) in surface water in areas with fluoride-rich volcanic rocks. One method of reducing excessive concentrations of fluoride in water is to blend water with a high fluoride concentration with water that has a low fluoride concentration from an alternative source. If such a source is not available, defluoridation is the only means remaining to prevent fluorosis.

2.2 *Anthropogenic sources affecting water quality*

Urbanization is a pervasive form of land cover/land use alteration that is rapidly growing (Paquin, 2002). This involves conversion of croplands, forests, grasslands, pastures, wetlands and other cover types to residential, transportation, commercial and industrial uses, thereby increasing the areas of impervious surfaces (Tsegaye et al. 2006). Impervious surfaces are quantifiable indicators that correlate very closely with increases in nonpoint (diffuse) sources of polluted run-off which degrades the quality of aquatic resources (Umeham, 1992).
Urban areas are more polluted than rural ones due to industrialization, sewage discharge and other domestic activities. Human activities such as discharge of industrial and domestic effluents, the use of agricultural chemicals, land use and cover changes are the major factors that influence surface water quality (Vega et al, 1998). Change in land use and land cover is one of the major anthropogenic influences on ecosystems and affects the water flow and quality of rivers in particular. Changes in landscape pattern induced by human activities have major impacts on river conditions. Land use and land cover change is strongly correlated with water chemistry parameters, the species diversity of freshwater fish and macro-invertebrates and sediment metal concentrations. Highly fragmented urban land uses, with a large proportion of impervious surfaces, tend to increase river flow and negatively affect water quality (Saunders et al, 2002). The problem of soil erosion is severe in some areas because of rapid urban development in recent decades.

3. Research Methods and Procedure

This study adopted the experimental research method. Being a monitoring of surface water quality, a number of water samples were collected bi-monthly from determinate sampling sites along the six streams/rivers sampled for the study and sent to the laboratory for related physical-chemical-microbiological analysis. Water samples was collected from the banks of the river/stream. These samples were collected, appropriately stored and managed and taken to the laboratory for analysis of relevant physico-chemical parameters. The major six surface water in Enugu urban - Ekulu river, Asata River, Aria River, Ikiriki river, Idaw River and Ogbete river - that dissect and drain different areas of the metropolis were the research population that was used for the proposed monitoring and evaluation of the relevant physical, chemical, biological and ecological parameters in the study

Locations for surface water samplings were selected to obtain representative sites in the study area. These was identified using digital maps and satellite images as seen in table 1.

Table 1: Description of the sample location

S/n	station	Sample Locations/description	Latitude	Longitude	Depth (m)	Reach
1.	S1	Ekulu River at New market fly over	331160	15126	1.67	Upper
2.	S2	Ekulu River at Ujodo development centre	332483	715284	1.83	Lower
3.	S3	Asata River at Enugu Port-Harcourt Express Way, New Artisan	338568	71323	0.98	Upper
4.	S4	Asata River at Amigo Lane CIC.	335499	713803	1.32	Lower
5.	S5	Aria River at Works Road	332125	713009	1.55	Upper
6.	S6	Aria River at Access Bank, Garden Avenue	333501	713578	0.91	Lower
7.	S7	Idaw River at Maryland, Timber Shed	334454	709239	2.10	Upper
8.	S8	Idaw River at Abalukwu Street	33335	709384	2.34	Lower
9.	S9	Ikiriki River at Enugu Port-Harcourt Express Way, Ugwuaji Bridge	337584	708958	1.98	Upper
10.	S10	Ikiriki River at Amechi Road	333999`	707648	2.09	Lower
11.	S11	Ogbete River at Old UNTH	331781	711408	1.77	Upper
12.	S12	Ogbete River at Holy Ghost Cathedral	332946	71132	2.65	Lower

Source: field work, 2024

A total of 2 sampling locations were assigned in each of the river, one at the upper section (upstream) of each river, another one at the lower section (downstream) of the river. Thus, a total of 12 sampling location was used in the study been examination contacts since there are 6 water bodies in the study area. Each of the 12 locations was sampled between Feburary and Setember 2024 on a bi-monthly basis; meaning that monitoring took place two times on a monthly basis. Samples were collected from various sites in the early hours (7.00 a.m. to 9.00 a.m.) of the day during first week of the month. The sampling period covered both the dry (feburary –early april) and the wet seasons. (late april to september).

The 21 selected physico-chemical and microbiological parameters that was investigated in the study are listed below:

i. Temperature
ii. PH
iii. Turbidity

iv. Total Suspended solid (SS)
v. Electrical Conductivity
vi. Dissolved Oxygen (DO)
vii. Total dissolved Solid (TDS)
viii. Biochemical Oxygen Demand (BOD)
ix. Total Coliform
x. Nitrite
xi. Total solid
xii. Chemical Oxygen Demand
xiii. Total Nitrogen
xiv. Nitrate
xv. Ammonia
xvi. Faecal coliform
xvii. chloride
xviii. Sulphate
xix. Hardness
xx. Potassium
xxi. Phosphorus

The Principal Component Analysis was used to dimension the factors associated with surface water quality variability in Enugu urban

4. **Results**

4.1. ***Factors Associated with Surface Water Quality Variability in Enugu***

Efforts were made to present data that was used to answer question three which sought to consider the factors associated with surface water quality variability in Enugu. The data was elucidated from the ouput from the Principal Component Analysis (PCA) results. The PCA output showed that there were six component factors that were associated with surface water quality variability in the study area. Details are present in table 2 and 3

Table 2: PCA results that shows the factors that are associated with surface water quality variability

KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.931
Bartlett's Test of Sphericity	Approx. Chi-Square	2941.168
	df	351
	Sig.	.000

The results obtained from the KMO and Bartlett's sphericity test were 0.931 and 2941 (df=351, po0.001), respectively, implying that PCA would be effective in reducing dimensionality). Based on the correlation matrix of variables, the results of PCA were expressed in Table 2. The first six rotated factors with eigenvalue greater than 1(were extracted and explained 89.724% of the total variance.

Table 3: Total Variance Explained

Compon	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	6.263	29.824	29.824	6.263	29.824	29.824	4.446	21.169	21.169
2	4.950	23.571	53.394	4.950	23.571	53.394	3.571	17.002	38.172
3	2.741	13.054	66.448	2.741	13.054	66.448	3.126	14.887	53.059
4	2.095	9.977	76.425	2.095	9.977	76.425	2.669	12.707	65.766
5	1.512	7.198	83.622	1.512	7.198	83.622	2.639	12.568	78.334
6	1.281	6.102	89.724	1.281	6.102	89.724	2.392	11.390	89.724
7	.900	4.284	94.008						
8	.718	3.419	97.427						
9	.332	1.580	99.007						
10	.173	.822	99.829						
11	.036	.171	100.000						
12	4.06E-016	1.93E-015	100.000						
13	3.25E-016	1.55E-015	100.000						
14	2.66E-016	1.27E-015	100.000						
15	1.27E-016	6.06E-016	100.000						
16	1.00E-016	4.78E-016	100.000						
17	3.48E-019	1.66E-018	100.000						
18	-6.73E-017	-3.20E-016	100.000						
19	-9.23E-017	-4.39E-016	100.000						
20	-1.84E-016	-8.74E-016	100.000						
21	-2.56E-016	-1.22E-015	100.000						

Extraction Method: Principal Component Analysis.

	Component					
	1	2	3	4	5	6
Temp	-.961					
TSS_	-.961					
Ph	.826					
COD	.737					
Turbi	-.607					
Phos		.927				
Nitoge		.908				
Nitrat		-.753				
BOD			.953			
DO			.764			
Facilcoli				.587		
Tcoli				-.72		
condu					.966	
Nitrite					.966	
Sulphat					.882	
Chloridet					.850	
Hardness					.682	
Tsoild					.622	
Tds					.966	
Potassium						.677
Ammoni						.530

The PCA classified the predominant factors associated with surface water quality variability in Enugu urban into 5 components that explained 89.72 percent of observed variation. The classified predominant factors that influenced surface water quality variability in Enugu urban that accounted for the explained percentage variations were as follows: Salinity, 29.82%; trophicity,23.57%; organic pollution, 13.05%; oxide-related 9.97%; erosion, 7.19%; and bacterial factors 6.10%.

5. Discussions

The study shows that six factors were associated with the surface water variations. This was done with the output from the PCA data. The factors were

Factor One: Organic pollution factor

Factor 1, named the organic pollution factor, had strong positive loadings on Temperature, pH, turbidity, total suspended solid and COD. This factor has an eigen value of 6.263 and 29.82% variability. (table 5.5). The two main reaction conditions in redox and denitrification of organic matter (Jain, 2002), water temperature and pH regulated the concentrations of COD and NO3-N in the water, to some degree. On the other hand, the enhancement of denitrification also increased the pH.

Factor Two: Trophicity factor

Factor 2, designated as the trophicity factor, accounted for 12.6% of the total variance and reflected the nutrient level by the positive correlations with nitrogen (0.908) and phosphorous (0.927). Higher values of these parameters all occurred in the high-flow period, indicating the polluting effect of soil erosion runoff on river water quality during the rainy season (Koerselman et al 1995). The temporal changes of these parameters coincided with the local seasonal calendar of agricultural activities. Their highest concentrations occurred when farmers planted rice and corn on the steep upland fields and fertilized with nitrogen and phosphate in March of each year. Such results strongly imply that agricultural pollution from cultivated fields is collected in rivers through the action of rain erosion on farmland (Ikomi et al, 2005). Nutrients such as phosphorous and nitrogen are essential for the growth of algae and other plants. Aquatic life is dependent upon these photo synthesizers, which usually occur in low levels in surface water. Excessive concentrations of nutrients, however, can over stimulate aquatic plant and algae growth.

Factor Three – Oxidated-related factor.
Factor 3 was highly associated with negative DO (0.764) and positive BOD (0.953), indicating an oxide-related process. When organic matter of river water is oxidized at the expense of oxygen, the BOD concentrations increase with decreasing DO. The highest values of BOD were recorded where the human population is relatively centralized and water quality is influenced by local domestic waste.

Factor Four – Bacterial factor.
Factor 4, the bacterial factor, explained only 8.43% of the total variance and was strongly correlated with F coli, and coliforn, which may be attributed to the effects of soil erosion on water composition

Factor Five – Salinity factor.
Factor 5, accounting for 7.19% of the total variance, was highly correlated with major physicochemical variables (Electrical Conductivity, Total Solid, Sulphate, Hardness) and dissolved trace elements (Chloride, and Nitrite,). These variables, called salinity factors, represented the total soluble salt concentration and provided insight on chemical changes in relation to river recharge.

Factor six - Erosion factor
Factor 6, the erosion factor, explained only 8.43% of the total variance and was strongly correlated with potassium (0.677) and ammonia, (0.530) which may be attributed to the effects of soil erosion on water composition (Wu & Wang., 2007). Concentrations of potassium increased during the high-flow period, which can be explained by eluviation's of soils washed off by intensive rainfall in the wet season, yet decreased from the high-flow period to the mean-flow period, partially reflecting the fixation of silicate by the bottom sediment. The presence of NH4-N was attributed to run off of ammonia fertilizer (e.g. urea and ammonium nitrate) from agricultural land. The pollution sources in the river system can be identified by the representation of the factor scores in factor analysis.

6. Conclusion

Six factors were associated with the surface water variations and they are Salinity, 29.82%; trophicity,23.57%; organic pollution, 13.05%; oxide-related 9.97%; erosion, 7.19%; and bacterial factors. The monitoring of water quality which at present is inadequate and haphazard needs to be more organized and regular, covering municipal water reservoirs and their catchment areas, streams and rivers, irrigation schemes and domestic water wells. Standards for good quality water need to be set and used as yardstick for monitoring. In this way, it should be possible to detect outbreaks of diseases, for example, typhoid, cholera, bilharzias, or guinea worm and to take appropriate preventive measures.

Additionally, the study recommends that biological indicators and their indices should be adopted for use by relevant authorities as tools for assessing the condition of rivers and other streams in

Nigeria. The water quality parameters evaluated to observe the ability of the rivers to sustain the aquatic life revealed that it was not is in good status. The main factor for the eutrophication of the water bodies was high total colifom contents and loading. In general, the rivers shows highly contaminated and may not fit for drinking and recreational uses but with some great care it is good for irrigation and aquatic life. So, the local government administration and other service rendering sectors should provide the wastewater treatment plants in order to reduce the pollutants entering into the surface water bodies in the urban areas in general.

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