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Evaluation of the Water Quality of River Kaduna, Nigeria Using Water Quality Index

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Water is a natural resource of fundamental importance and supports all life forms. The study evaluated the water quality of River Kaduna using the Canadian Council of Ministers of the Environment (CCME) Water Quality Index. The study covered both raining and dry seasons in 10 sampling points. Water parameters analysed were turbidity, Zn, Pb, Cd, Cr, Cu, Mn, Fe, dissolved oxygen, electrical conductivity, pH, TDS and Ni using standard laboratory techniques. The data obtained were used to develop Water Quality Index (WQI) across the 10 sampling points and results showed that the water quality at Barnawa, Kudenda, Tudun Wada, Makera and Angwan Muazu are poor as their index values ranged between 31.8 – 42 while Kawo, Angwan Dosa, Malali, Kigo and Angwan Rimi are marginal as their index ranged between 45 – 61.3. The study concluded that the variety and level of contaminants in River Kaduna was related to the anthropogenic activities in the various parts of Kaduna Metropolis from where run-off and contaminants were received, hence, the water quality of River Kaduna is deteriorating. There is therefore the need for proper environmental education and discouragement in the use of toxic chemicals for farming so that pollution can be controlled at the source.

Keywords: water quality, environment, pollution, contaminants, variety, physicochemical

INTRODUCTION

Water is a universal solvent essential to man for various activities and the two main problems man contends with are the quantity and quality of water (Oluyemi *et al.*, 2010). Water is indispensable to man and the entire ecosystem. Freshwater availability and quality is one of the most critical environmental and sustainability issues of the present century. Freshwater is precious, as there cannot be live without it and human activities have profound impact on the quantity and quality of freshwater available (Udiba *et al.*, 2014). Aquatic environment exposed to various types of pollutants such as heavy metals, pesticides, detergents, petroleum products, and other materials, in additional to industrial, agricultural and medical wastes may lead to a negative impact on public health and biodiversity (Maitera *et al.*, 2010; Osibanjo *et al.*, 2011). Water pollution in Nigeria occurs in both rural and urban areas. Surface water pollution describes the introduction by man of foreign substances capable of causing harm to man, hazard to other living organism or interference with the legitimate use of the environment into the surface water bodies (Ojo *et al.*, 2012).

It is apparent that water quality and water quantity are inextricably linked, however water quality deserves special attention because of its direct implication in public health and quality of life (Hassan *et al.*, 2010). Water quality is changed and affected by both natural processes and human activities. Generally, natural water quality varies from place to place, depending on seasonal changes, climatic changes and with the types of soils, rocks and surfaces through which it moves. A variety of human activities e.g. agricultural activities, urban and industrial development, mining and recreation, potentially significantly alter the quality of natural waters, and changes the water use potential. The key to sustainable water resources is, therefore to ensure that the quality of water resources is suitable for their intended uses, while at the same allowing them to be used and developed to a certain extent (Mohammed, 2014).

Water quality refers to the overall quality of the aquatic environment (Chapman, 1996). The quality of freshwater at any point on a landscape reflects the combined effects of many processes along water pathways and both quantity and quality of water are affected by human activity on all spatial scales (Peters & Meybeck, 2000). An integral part in any environmental monitoring programme is the reporting of results to both managers and the general public. However, most water quality researchers report results by comparing the different analysed parameters with their respective permissible limits set by regulating bodies (local or international). For instance, over the years, several researchers such as Mohammed *et al*. (2015), Sadiq (2015) and Mahre *et al*. (2007) have reported the water quality of River Kaduna by describing the trends and compliance with official stated guidelines. Also, Al-Mayah (2009), Boniswa (2010) and Chaitali and Jayashree (2013) showed the impacts of contaminated water on human health by comparison of results with official guidelines. However, Carlos and Alejandra (2014) stated that in many cases, managers and the general public rather prefer statements concerning the general health or status of the system concern. Hence, the Canadian Council of Ministers of Environment (2001) reported that one possible solution to this problem is by employing an index that will mathematically combine all water quality measures and provide a general and readily understood description of the water. In other words, developing Water Quality Index (WQI) for River Kaduna will summarize the various analysed water ingredients (parameters) and rank the overall quality of the water. The ranking could be excellent, good, fair, marginal, or poor.

LITERATURE REVIEW

Pollution is the introduction of contaminants into the natural environment that can cause adverse changes (Fakayode, 2005). Akaniwor and Egwin (2006) described pollution as the deliberate or accidental contamination of the environment with man's waste. Fresh water is a finite resource, essential for agriculture, industry, and human existence (Boniswa, 2010). Liu *et al*. (2013) is of the opinion that human civilisation has led to dynamic shifts in the patterns of water use, resulting in inevitable discharge of liquid and solid wastes into water bodies resulting in adverse effects upon the receiving water bodies. Surface waters are an essential part of our natural environment but due to the activities of humans, the quality of surface waters is rapidly deteriorating. Many studies have been carried out in the areas of water quality by various people in different locations. Studies indicate that most of the World Rivers are contaminated, but to varying degrees. For example, the Rhine River becomes polluted which led to it being called the longest stream of dirty water in the world (Al- Haidarey, 2009).

Butu and Bichi (2013) posited that the rate of water pollution of all types has increased much more as compared to other fields of pollution due to discharge of all sorts of obnoxious matter into it. In developing countries, water pollution is among the most common form of environmental pollution. Nigeria as a developing country has witnessed unprecedented form of water pollution. Different studies on the forms of water body in the country have shown that most Nigerian water bodies are polluted. Surface water bodies are the most hit by this nefarious act of man within the country (Sadiq *et al.*, 2022). Besides the pollutants introduced by man and nature, flood carry chemicals from farmlands, waste materials on land, and empty them into surface water bodies especially during heavy rainfall (Ojo *et al*., 2012).

Water quality is changed and (or) affected by both natural processes and human activities. Generally, natural water quality varies from place to place, depending on seasonal changes, climatic changes and with the types of soils, rocks and surfaces through which it moves. A variety of human activities e.g. agricultural activities, urban and industrial development, mining and recreation, potentially significantly alter the quality of natural waters, and changes the water use potential. The key to sustainable water resources is, therefore to ensure that the quality of water resources is suitable for their intended uses, while at the same time allowing it to be used and developed to a certain extent (Mohammed, 2014). Water pollution causes water quality deterioration, ineffective use of water resources, ultimately affecting economic and social activities and impacts negatively on the ecological environment (Zhang, 2008).

The presence of heavy metals in the aquatic environment has been of great concern because of their toxicity at lower concentrations (Rahimi *et al.*, 2013). Heavy metals critically affect all water bodies. They last forever and do not disappear, but rather move around the environment (Chaitali & Jayashree, 2013). Valavanidis and Vlachogianni (2010) argued that the presence of these heavy metals in the aquatic ecosystem has far-reaching consequences on the biota and man; their toxic effects on man are related to lungs and nasal sinus cancers. The physicochemical characteristics of water determine its usefulness for various purposes. Physicochemical analysis of water includes the determination of the concentrations of inorganic constituent aside organic constituents. The analysis may also include measurement of total dissolved salt, dissolved oxygen among others (Singh *et al.*, 2012).

Water quality index (WQI) is a method of assessing water quality parameters on the overall quality of water (Singh *et al.*, 2013). This technique is very effective in assessing water quality used for drinking and other purposes (Tiwari *et al.*, 2014). This is very useful in water quality assessment because it has the capability of combining data from various water quality parameters into a single mathematical expression that generates a value to determine the water quality status (Singh & Kamal, 2014; Azua, 2018). Ogbozige *et al.* (2017) evaluated water quality of River Kaduna using the water quality index to analyse some water quality parameters such as Ph, TDS, Cr, Ec, Do, BOD, COD, Fe and Mn. The samples were collected on a monthly basis for one year. The study revealed that the water qualities of 4 sampling points were poor and this was attributed to anthropogenic activities.

Water is an essential natural resource that sustains life and is used up by all living organisms. Therefore, the knowledge of the status of rivers for use is quite essential for proper and effective management of water environments (Leslie, 2010). River Kaduna serves as a medium and source of water for fishing, farming, laundry, swimming, livestock watering, domestic and industrial purpose, thus making it necessary that it should be protected from any form of contamination. With all the wastes perceived to be discharged into the river, the water quality is progressively deteriorating and this can pose serious health hazards when consumed or used, the water can have an adverse effect on the residents or end-users.

THE STUDY AREA

River Kaduna is a tributary of the River Niger which originates from the Kajuma hills in Jos Plateau Nigeria and flows for about 200km before reaching Kaduna town and stretches down about 100km into Shiroro dam project area where it finally empties into River Niger at the northern shores of Pategi (Emere & Dibal, 2013). River Kaduna traverses the city, dividing it into north and south (Al-Amin, 2013). It covers a total distance of 540km from source to mouth where it empties its water into the River Niger as shown on Figure 1. The River is a perennial river. Most of its courses pass through open savannah woodland but its lower section has cut several gorges above its entrance into the extensive Niger floodplains. The drainage system of the study area is very complex as the study area is made up of rock outcrops in the plateau and sand bed (Saminu *et al.*, 2013). In addition to climatic factors, the flow regime of the river system depends upon topography, surficial geology, soil and vegetation cover of the drainage area. The drainage pattern is mostly dendritic. It's navigable in the dry season and sometimes carries as much waste as freshwater (Sadiq *et al.*, 2022).

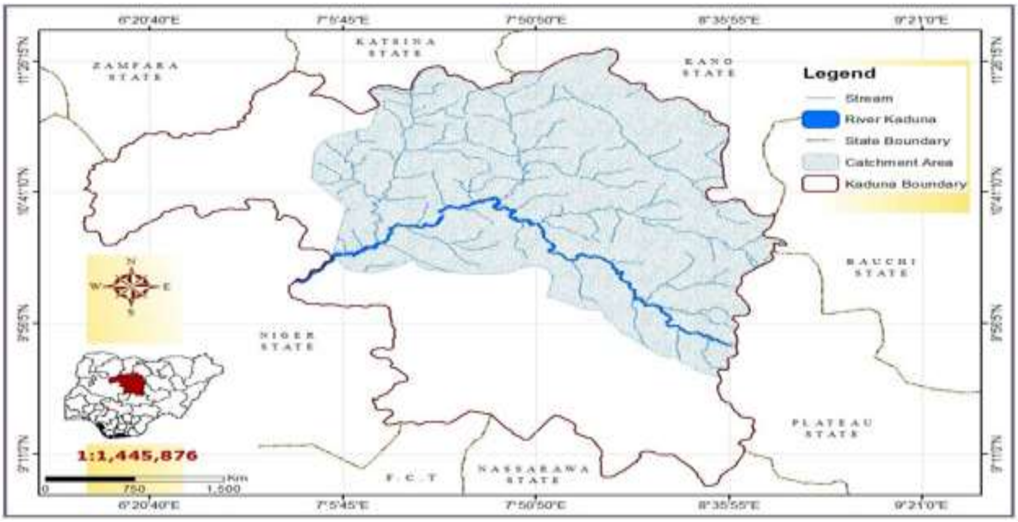

Figure 1: The Drainage Basin of River Kaduna
Source: Adapted from Department of Geography ABU (2012)

MATERIALS AND METHODS

Types and Sources of Data: The data generated were the water samples collected on site (simple grab method) and taken to the laboratory for analysis. Surface water sample was collected from 10 points and a control point. It was not possible to study the entire course of the river, therefore, about 24km of the study area was covered for this study from the upstream Kawo (Rafin Guza) to Kudenda which is the downstream point (Figure 2). This portion of the river dissects the entire Kaduna Metropolis. The choice for water is because water is considered an important indicator of environmental pollution (Sadiq *et al.*, 2022; Ogbozige *et al.*, 2017). The sampling points were selected because they represented the best points for gaining access to the River and also suitable for easy sampling of the current pollution status of the River due to possible mixing of the contaminants.

A total of 60 water samples were collected for the study. The samples were collected monthly (July, August, September, November, January and February). The sampling time was between 7 – 8 am. The grab sampling method was employed at each sampling point. To collect the water samples, 250ml plastic bottles was used as recommended in the standard methods for water and wastewater analysis (APHA, 1998). The sample bottles were disinfected with methylated spirit and then thoroughly rinsed with the sample water three times before sample collection to ensure no foreign substance was introduced into the samples as recommended by APHA (1998). The samples were collected by dipping the plastic bottles 30 cm below the water surface at the selected sampling locations and ensuring that the mouth of the bottle faces the water current and allowing it to overflow before withdrawal (Ogbozige *et al,* 2017; Sadiq *et al*., 2022). After collecting the samples, the bottles were labelled as to the source and date of collection before taken the samples to the laboratory at the National Research Institute for Chemical Technology (NARICT), Zaria.

The pH, Electrical Conductivity (EC), Turbidity, Total Dissolved Solids (TDS) and Dissolved Oxygen (DO) were determined using Atomic Absorption Spectrophotometer (AAS) and Garmin GPSMAP 78sc was used to ensure that samples were from the point. This was because these parameters have the tendency of changing characteristics overtime once collected from the River.
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Fifty millimetre (ml) of water was measured into a 250ml beaker and 15ml hydrogen chloride (HCl) and nitric acid (HNO3) was added. The beaker and the content were placed on a hot plate, heated at 100◦c to dry and digest until brown fumes of HNO3 escaped. The heating continued until the content was reduced to 10ml. The content was then washed into a 50ml volumetric flask, the digest obtained was preserved in a refrigerator till analysis. The study adopted this from Ogbozige *et al.* (2017) and Sadiq *et al.* (2022).

The analysis of the selected heavy metal concentration was carried out using Atomic Absorption Spectrophotometer (AAS) (AA-6800, Shedmazu, Japan) after digestion of samples at National Research Institute for Chemical Technology (NARICT), Zaria. This method is suitable for both dissolved and total metals in water. 100ml of the digest in each sample was run on the Atomic Absorption Spectrophotometer (AAS) which uses Air Acetylene Flame. By choosing the correct wavelength of the various elements and running a known standard curve of the various elements, the absorbance values of the chemical elements present in the samples were determined. Using the standard absorbance of the various elements, the absorbance from the various heavy metals contained in the samples was converted to parts per million (ppm) values as their levels of concentration. This was repeated three times for every element in every sample and the mean concentration was taken as the actual level of concentration of the elements in ppm (Butu *et al.*, 2019; Sadiq *et al.*, 2022)

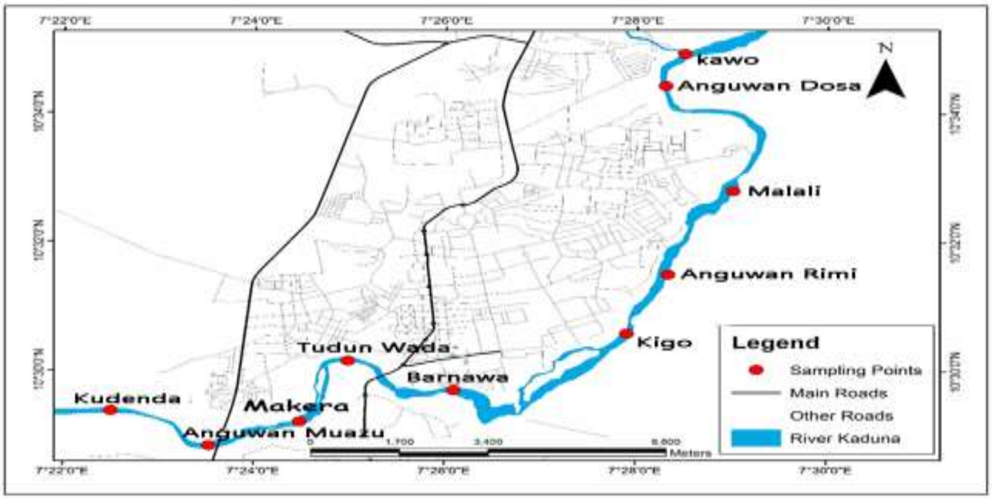

Figure 2: Location of Sampling Points (1-10)
Source: Adapted from Department of Geography ABU (2012)

Development of Water Quality Index: The Water Quality Index (WQI) developed was based on the Canadian Council of Ministers of Environment (CCME), which has been adopted by the Global Environmental Monitoring Systems. The detailed formulation of WQI, as described in the Canadian WQI Technical Report (CCME, 2007), is as follows:

$$CWQI = 100 - \sqrt{\frac{F1^2 + F2^2 + F3^2}{1.732}}$$

Calculation of the index is based on of three terms: scope (F1), frequency (F2) and amplitude (F3). Division of these terms by 1.732 is based on the fact that each of the three factors contributing to the index can reach the value of 100. Explanation of each term of the index:

Factor 1 (F1); Scope: This factor expresses the percentage of parameters did not comply with the corresponding guideline during the study period.

$$F1 = \frac{Number\ of\ failed\ Variables}{Total\ number\ of\ variables}\ X\ 100$$

Factor 2 (F2); Frequency: This factor represented the percentage of individual tests that do not meet the guidelines ('failed tests)

$$F2 = \frac{Number\ of\ failed\ test}{Total\ number\ of\ test}\ X\ 100$$

Factor 3 (F3); Amplitude: Represents the difference between the non-compliant analytical results with the guidelines to which they refer. The term F3 is an asymptotic function, representing the normalized sum of excursions (nse) in relation to guidelines within the range of values from 0 to 100.

$$F3 = \frac{Normalised\ sum\ of\ excusion(nse)}{0.01nse + 0.01}\ X\ 100$$

To calculate the overall degree of non-compliance, then add the excursions of non-compliant analytical results and divide the sum by the total number of analytical results. This variable is called the normalized sum of excursions (nse).

$$NSE = \sum \frac{excusion}{number\ of\ tests}$$

There are two possible ways of determining the excursion:

$$excusion = \left(\frac{failed\ test\ value}{objective}\right) - 1$$

When the test value must not fall below the objective:

$$excusion = \left(\frac{objective}{failed\ test\ value}\right) - 1$$

These values are combined to produce a single value that lies between 0 and 100 which represents the overall water quality at a given location. The various ranks are described as follows:

i. Excellent (95-100): Water quality is protected with virtual absence of threat or impairment; conditions very close natural or pristine levels.
ii. Good (80-94.5): Water quality is protected with only minor degree of threat or impairment; conditions rarely depart from natural or desirable levels.
iii. Fair (65-79.9): Water quality is usually protected but occasionally threatened or impaired; conditions sometimes depart from natural or desirable levels.
iv. Marginal (45-64): Water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels.
v. Poor (0-44): Water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels.

RESULTS AND DISCUSSION

Distribution of Contaminants in River Kaduna: The result in Table1 shows the concentration and distribution of the selected chemical properties in River Kaduna. The result shows that the mean concentration of Cadmium in River Kaduna was low (0.0129ppm). Sources of Cd can be attributed to usage of phosphate fertilizers, sewage sludge, and industrial effluents and from household wastes. Cd is very bio-persistent and is used for stabilizers for Polyvinyl chloride (PVC), in alloys and electronic compound. Cd is also present as an impurity in several products including detergents and refined petroleum products (Lekwot *et al.,* 2012). The mean concentration of Zn in River Kaduna is 0.1458ppm. The presence of Zn can be attributed to routing of debris containing Zn into the River by run off from the vast catchment area which covers several urban and semi-urban settlements. Chromium in the River has a mean concentration of 0.0105ppm. Cr can be drained into the River from soaps, detergents used for washing at homes and from dyes from textiles, from waste incineration, industrial effluents (Dan-Azumi & Bichi, 2010). Cr is one of those metals whose concentration steadily increases due to industrial growth, erosion of rocks and municipal wastes (Galadima & Garba, 2012). Cr is used in metal alloys and pigments for paints, cements and rubber and other materials (Butu, 2011). The mean concentration of Pb (0.0102) was relatively low in River Kaduna. This could be due to possible mixing of the metal in the surface water.

Table 1: Distribution of selected Chemical Properties in River Kaduna that traversed the Kaduna Metropolis

Parameter	Mean
Cadmium (mg/l)	0.0129
Zinc (mg/l)	0.1458
Chromium (mg/l)	0.0105
Lead (mg/l)	0.0102
Copper (mg/l)	0.006
Manganese (mg/l)	0.7142
Nickel (mg/l)	0.0134
Iron (mg/l)	0.3196
Turbidity (NTU)	11.1
TDS	216.9
pH	7.5
DO	4.3
EC (us/cm)	349.7

There was a considerable low concentration of Cu in this section of River Kaduna. The mean concentration was 0.0060ppm. Result also shows that Mn was high with a mean concentration of 0.07142ppm. The reason for high value of Mn in River Kaduna can be attributed to the draining of effluents that contain Mn into the River by surface flow from nearby settlements and also from geological formation. Mn is a common compound that can be found everywhere on earth. It is necessary for humans but also toxic at high concentrations. Other sources of Mn include burning of fossil fuels and sewage sludge (Al-Amin, 2013). The concentration of Ni was also high as observed from the analysis with a mean concentration of 0.0134ppm. Sources of Ni can be attributed to waste incinerators, household wastes, and farm runoffs. Ni can be carcinogenic and toxic in high concentrations. The concentration of Fe in River Kaduna was relatively high with a mean concentration of 0.3196ppm. Fe is one of the most abundant metals and it persists in the environment (Akan *et al.*, 2010). The reason for the presence of Fe in the River may be due to weathering and routing of lateritic materials into the River. Intensive agricultural activities in the study area have aided weathering and the release of Fe into the River as well.

The results show that the mean value of turbidity was 11.1. Turbidity in water is caused by presence of suspended particles such as clay, silt, finely divided organic matter, plankton, and other microscopic organisms. Turbidity refers to water clarity. The greater the amount of suspended solids in the water, the murkier it appears (Sataa *et al.*, 2017). The mean value of TDS in the River was 216.9. The mean value of pH was 7.5 which is within the recommended limits of NIS and WHO. The pH of an aquatic ecosystem is important because it is closely linked to biological productivity (Sataa *et al.*, 2017). The pH in rivers can be due to waste-water, municipal discharge, heavy rainfall and agricultural runoffs (Chikogu *et al.*, 2012). The mean value of Dissolved oxygen was 4.3. Table1 shows that the mean value of electrical conductivity was 349.7. High electrical conductivity (EC) is related to high TDS in water. Thus EC gives an indication of the amount of TDS in water (Yilmaz & Koc, 2014).

The calculated values of both chemical and physicochemical parameters in Table 1 were subjected into the Canadian water quality index models across all the sampling locations. Table 2 presents the summary of the Canadian Water Quality Index of the sampling locations.

Table 2: Summary of Canadian WQI of Sampling Points

Sampling Points	WQI	Interpretation
PI	61.3	Marginal
PII	46.4	Marginal
PIII	45	Marginal
PIV	51	Marginal
PV	46	Marginal
PVI	39.9	Poor
PVII	41.1	Poor
PVIII	31.8	Poor
PIX	42	Poor
PX	35.8	Poor

WQI – Water Quality Index

The result shows that of all the sampling points PVI – X (Barnawa, Tudun Wada, Makera, Angwan Mu’Azu and Kudende) recorded poor WQI. This means that the water quality here is almost always threatened or impaired. This could be attributed to the kind of anthropogenic activities around these areas that drains contaminants into the River; they include industrial effluents, agricultural and heavy municipal wastes, weathering among others. There is significant concentration of industries in Kakuri, Makera, and Kudenda industrial layouts of Kaduna Metropolis. From the above, it may tend to suggest that industrial in activities in these zones may have a remarkable effect on the water quality of River Kaduna. The WQI map also indicates that the water quality of the river upstream was marginal based on the Canadian WQI.

CONCLUSION AND RECOMMENDATIONS

The paper evaluated the water quality of River Kaduna using water quality index and selected water quality parameters were used; Cd, Cu, Pb, Ni, Cr, Zn, Mn, Fe, turbidity, TDS, DO, pH and EC. Based on the results obtained in the study, it could be concluded that the WQI of River Kaduna on the Canadian scale is mostly marginal. However, the areas with high impairment level (poor) along the river were located within Makera, Tudun Wada and Kudenda communities. The section of River Kaduna that traversed Kaduna metropolis was becoming contaminated by some chemical properties which could be due to anthropogenic activities such as use of chemical fertilizers and herbicides by farmers, indiscriminate dumping of wastes and also weathering processes. Heavy metals are known to be carcinogenic to humans because they bio-accumulate from the intake over the life span, they also affect growth rate in children and sometimes lead to death. To overcome this problem, the contaminants have to be controlled at the source. It is more economical in many cases to maintain the quality of waters through source protection. In the light of the findings, the paper recommends that Villages downstream of River Kaduna should abstain from direct consumption of such waters. Kaduna Environmental Protection Agency should employ proper monitoring of effluents in River Kaduna as an integral part of water management of the river to enable verification of whether or not imposed standards and regulations are met as the water is used as potable water. Also, Environmental and health impact assessments should be conducted regularly.

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