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Examination of Surface Water Along River-Rima Floodplain in Wamakko, Sokoto State, Nigeria

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ARTICLE INFO	ABSTRACT
	This study examined the hydrochemistry of surface water along the River-Rima floodplain area. Five sampling locations were purposively selected, and, in each point, three samples were taken from surface water (river). The sampling was repeated after 20 days. Thus, a total of 30 samples were collected. Water samples obtained were subjected to laboratory tests. Results revealed that BOD, TDS, Mg^{2+}, and Fe^{3+} are above the World Health Organization (WHO) and Standard Organization of Nigeria (SON) reference guidelines for drinking water quality. Isolates detected from the coliform bacteriological analysis include *Enterobacter aerogene, Escherichia coli*, and *Citrobacter freundii* with most of the samples showing coliform bacteria growth above the SON standard for drinking water. Hence, the water in the River-Rima floodplain of the Wamakko area is of low quality and unsafe for drinking. Results of principal component analysis (PCA) revealed external influences such as pollutant wash off and rock weathering as controls on hydrochemistry of surface water. There is some indication of anthropogenic inputs (Cl^-, NO_3^-, and PO_4^{2-}) based on hierarchical cluster analysis. Elements including Cl-, NO3-, and PO42- are increasingly added into surface water from human activities, mainly agriculture, and municipal sewage.

1. Introduction

Freshwater resource deterioration is now a global problem and is increasing at a faster rate [1-3]. According to [4] one of the most critical crises in developing countries is the lack of adequate potable water. In some remote communities, surface water is consumed raw with little or no water treatment. Surface water is easily polluted and requires treatment before use [5-9].

Water pollution occurs when water becomes overloaded with chemicals and the aquatic organisms cannot keep up with their cleaning responsibilities [10-12]. Some may die and others may grow too fast. There are many types and sources of pollutants that can pollute surface and groundwater [13-17]. The use of fertilizers and pesticides on cropland, gardens, and yards help farms and homeowners, but can also be damaging to aquatic and marine life when not properly applied or managed [18-20]. Poorly managed

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animal wastes from farms can also add excess nutrients to rivers and lakes. The pollution of water bodies from pollutant transport through surface runoff and uncontrolled discharge of untreated and partially treated sewage and domestic wastes have been widely reported [21-25].

Agricultural activities have appeared to be the major source of pollutants in surface water [26-35]. The effects of agricultural activities on rivers include nutrient enrichment, deterioration of the water quality, destruction of spawning grounds for aquatic and marine life, and general fish destruction [21,36]. Agricultural run-off rich in agro-chemicals is the main source of surface water pollutants globally [37-39]. River-Rima which is a tributary of River Niger provides means of livelihood and transport to its dwellers. People living along the river are mostly farmers and fishermen, producing mainly foodstuffs (rice, millet, corn, vegetables) and rearing animals (goats, cows, ships, camels). Agricultural activities in the study area are carried out along the bank of the river [40-43]. Agricultural wastes (corn cobs, livestock manure, chemical fertilizers, pesticides, etc.) are discharged directly into the river or as seepage or from surface runoff.

The use of multivariate statistical methods for the evaluation of surface water showed the usefulness of multivariate statistical assessment of hydrochemical data to get clearer information on the quality of surface water [44]. Risk evaluation, seasonal variation, and statistical source detection of metals in the Subarnarekha River, India indicated using PCA indicated that initial eigenvalue suggested both natural and anthropological activities are causal factors of heavy metal abundance in Subarnarekha River [45]. Contamination assessment in rivers using water quality indices revealed a threat of eutrophication based on the newly developed water quality index using was developed using DO, o-PO_4-P, NO_3-N, NO_2-N, BOD_5, and COD parameters [46]. Evaluation of heavy metal and nutrient pollution in-stream and sediments of the upper Tigris River, Turkey indicates that heavy metals originated from anthropogenic sources, mainly metallic emissions from mining activities [47]. This study seeks to examine the hydrochemistry and identify the sources of pollutants in River-Rima, Wamakko area of Sokoto State.

2. The Study Area

The study was conducted along the Sokoto-Rima floodplain of the Wamakko area of Sokoto State. Wamakko is located 10 kilometers west of the state capital Sokoto. It is situated between Latitude 13° 9′ N and 13° 19′N, Longitude 5° 17′ E and 5°27′ E. It is drained by River Rima; the most important perennial river in the northwest of Nigeria [41,42,48]. Its major tributaries are Rivers Bunsuru and

Gagare. The River takes its course from Katsina State and flows through Zamfara and the Sokoto States to join the Sokoto-River before flowing to River Niger in Kebbi State [48,49]. The climate of the study area is tropical continental, with much of the rain occurred between June and September. The dry season is between October and May. Rainfall is torrents that are short-lived and at the beginning of the season, usually accompanied by storms. The mean annual rainfall is about 600mm with most of it falling in July and August. The highest temperature is 40° C [50-53].

Figure 1. Map of Wamakko L.G.A. showing the study area

Relief and Geology

The topography of the study area is characterized by distinct features of the vast *Fadama* low land, and the rather flat elevated upland area [54]. The area is endowed with limestone minerals and it was based on the sedimentary formation, but generally, the topography within the area is rather flat (≤ 300 meters above seas level). There are distinct sedimentary sequences that have been deposited under varied environmental situations ranging from continental to marine events. The oldest is Gundumi formation which overlies the basement complex rock, while the youngest being the Gwandu formation [55,56]. Wamakko is characterized by the Sokoto Plains, a lowland topography, with an average height of about 300 meters above sea level. In a few places, the lowland is interrupted by isolated hills and escarpments such as those around Kalambaina [57,58]. Recent alluvial deposits along the river valley during the Quaternary era were observed by [55]. According to [59], the minerals obtained in the area include limestone, clay,

gold, kaolin, gypsum, and marble.

3. Materials and Methods

3.1 Sample Collection

This study covers Kwalkwalawa, Marmaro, Asare, Boye, and Kaura Abdu villages. Five sampling points were selected (Figure 1). Global Positioning System (GPS) was used to locate the sampling points. At each point, three samples were taken from the surface water. The sampling was repeated after 20 days. Thus, a total of 30 samples were collected for laboratory analysis. The sampling was carried out between October and November 2015 at the cessation of rains, to avoid the influence of runoff. At the sampling points, the sample bottles were rinsed with the sample water twice before water samples were taken. The bottles were corked tightly and labeled for identification and taken to the laboratory.

3.2 Laboratory Analysis

The Physicochemical analyses conducted include the determination of pH (Digital pH meter), Dissolved Oxygen (DO) (Iodometric titration method), Biochemical Oxygen Demand (BOD) (Incubation bottles), Total Dissolved Solids (TDS) (Glass fiber filter method), Total Suspended Solids (TSS) (Filter paper method), Chloride (Cl^-) (Titration method), Phosphate (PO_4^{3-}) (Spectrophotometer), Nitrate (NO_3^-) (Macro – Kjeldhl flask method), Potassium (K^+) (Flame photometer), Magnesium (Mg^{2+}) (Titration method), Calcium (Ca^{2+}) (Titration method) and Iron (Fe^{3+}) (Atomic Absorption Spectrometer). The WHO and SON standards were used to compare the levels of pollutants for drinking purposes. The bacteria indicators of surface water pollution were analyzed using the Most Probable Number (MPN) to find the number of coliforms. Isolate method was also used to identify and detect various coliform bacteria found in the water samples.

3.3 Statistical Analysis

Data obtained from the laboratory tests were summarized (mean±standard deviation) and standardized. This was followed by multivariate analysis (Principal Component Analysis; and Hierarchical Cluster Analysis). PCA was used to reduce the studied parameters to more interpretable form [60-64]. It is used to reduce huge and complex datasets by finding a small number of variables that define the utmost variance. PCA was carried out on a subset of 11 chosen hydrochemical parameters (pH, DO, BOD, TDS, TSS, Cl^-, PO_4^{2-}, NO_3^-, K^+, Ca^{2+}, Mg^{2+}, Fe^{3+}, which characterized the general groundwater composition. Hierarchical

cluster analysis (HCA), was conducted to classify sampling locations [65-67]. In clustering, locations with comparable surface water composition or otherwise parameters with typical properties would be gathered into identical clusters [60-64]. Ward's-algorithmic grouping technique after the Euclidean distance was used. This method does not account for data validity and disconnected values and neglects credible and possible connections or resemblances (statistical meddling) between variables, which are somewhat clear in most hydrochemical data [60-64].

4. Results and Discussion

4.1 Physicochemical Characteristics

Tables 1 and 2 summarized the results (mean±standard deviation) physicochemical and bacteriological analysis. The mean values for the sampling locations were compared with the World Health Organization (WHO), and the Standards Organization of Nigeria (SON) standards. The pH level ranged between 6.6 -7.1. The highest mean concentration of 7.1± 0.1 was detected at Kaura Abdu and the lowest is 6.6 ± 0.1 was detected at Kwalkwalawa. Since pH is one of the most significant operational water quality parameters, (its range affects the workability of other parameters), moderate pH levels are required (Duvbiama and Egbuna, 2013). The pH values from all the five (5) locations are within the WHO reference limits of 6.5- 8.5.

Dissolved Oxygen (DO) ranged from 5.7 to 7.4 mg/l. The highest concentration of DO was observed in Asare and the lowest level was observed in Marmaro. The DO concentration was generally within the WHO reference limits, indicating water of good quality. Low DO is evidence of reduced bacterial activity within the water ecosystem. Biological Oxygen Demand (BOD) ranged from 23.4 mg/l to 14.7 mg/l. The BOD levels for all sites were above the WHO maximum permissible limits, indicating water that is unsafe for drinking. The low value for BOD at Boye might be due to low organic matter, while that for Kaura Abdu water might be due to a high concentration of pollutants and organic matter. The mean concentrations of BOD values were higher compared to the values recorded by [68] and [69] who recorded lower values (7.38 mg/l and 0.7 mg/l respectively).

Total Dissolved Solids (TDS) ranged from 7.2 mg/l to 2.2. The mean concentrations indicated that all the sampled locations had TDS values below the SON maximum allowable limits (500 mg/l). Dissolved solids in water can be used water as an indication of its suitability for domestic use [70]. TDS in drinking water is not of health

Table 1. Summary of Physicochemical parameters

Sampling Points	Parameters											
	pH	DO	BOD	TDS	TSS	Cl⁻	PO4³⁻	NO₃⁻	K+	Ca²⁺	Mg²⁺	Fe³⁺
Kwalkwalawa	6.6 ± 0.1	7.1± 1.1	20.1 ± 1.4	7.2 ± 2.5	5.8 ± 0.3	0.8± 0.2	0.2 ± 0.0	1.1± 0.1	1.9 ± 0.1	0.7 ± 0.1	0.4 ± 0.0	4.5 ± 0.0
Marmaro	6.7 ± 0.1	5.7 ± 2.0	16.7 ± 3.6	5.3 ± 0.6	3.3 ± 0.3	1.1 ± 0.3	0.2 ± 0.0	1.0 ± 0.1	2.0 ± 0.1	0.7 ± 0.0	0.5 ± 0.1	2.0 ± 0.0
Share	6.8 ± 0.0	7.4 ± 2.3	16.8 ± 3.9	5.2 ± 0.8	5.2 ± 0.3	1.1 ± 0.1	0.2 ± 0.0	1.2 ± 0.2	2.1 ± 0.1	0.8 ± 0.1	0.5 ± 0.1	2.0 ± 0.0
Boye	6.7 ± 0.0	7.1 ± 1.3	14.7 ± 1.3	3.2 ± 0.6	2.3 ± 0.6	1.4 ± 0.3	0.2 ± 0.0	1.6 ± 0.2	2.0 ± 0.0	0.7 ± 0.0	0.4 ± 0.0	2.1 ± 0.0
Kaura Abdu	7.1 ± 0.1	7.1 ± 0.6	23.4 ± 1.7	2.2 ± 0.3	1.2 ± 0.3	1.1± 0.1	0.2 ± 0.0	0.9 ± 0.1	2.0 ± 0.1	1.2 ± 0.1	0.6 ± 0.0	0.3 ± 0.0
WHO	6.5-8.5	7.5	10	1	10	250	5	10	250	250	-	0.3
SON	6.5-8.5	-	-	500	-	250	-	50	-	-	0.2	0.3

concern, but it affects palatability levels above 600 mg/l[71]. Total Suspended Solids (TSS) were high at Kwalkwalawa (5.8 ± 0.3 mg/l) mg/l perhaps due to high silt and organic matter contents. Low values were recorded at Kaura Abdu (1.2±0.3). Chloride (Cl⁻). The highest concentration was observed at Boye (1.4±0.3 mg/l). Chloride increases with the increasing degree of eutrophication [72,73]. The lowest values recorded in this study are from Kwalkwalawa (0.8±0.2 mg/l). All the samples showed satisfactory levels of WHO and SON standard limits.

The phosphate ion (PO₄³⁻) concentration was low. Values obtained were within the maximum allowable limits by the WHO (5 mg/l). The highest concentrations of 0.2±0.0 mg/l were observed for all the surface samples. Phosphate occurs naturally in low concentrations in natural water while higher concentrations may pollution from human activities [70]. Nitrate (NO₃⁻) ranged from 0.9 mg/l to 1.6 mg/l. The concentrations were below the WHO and SON permissible limits. Nitrate is mainly derived from organic matter and oxidation of ammonia. However, NO₃⁻ is increasingly added to surface water from chemical fertilizers. The effects of leached fertilizers on water environments and their health implications have been reported [74,75].

Potassium Ion (K⁺) ranged from 2.1 mg/l to 1.9 mg/l. Both samples have potassium concentrations below the WHO maximum permissible limits of 250 mg/l. Calcium Ion (Ca²⁺) ranged from 1.2 mg/l 0.7 mg/l. Ca²⁺ concentration is below the maximum allowable WHO limits (250 mg/l). Calcium is an indication of hardness in water, but it has no known effect on the health of human beings. Magnesium (Mg²⁺) ranged from 0.6 to 0.4 mg/l. The concentrations were above the SON limit of 0.2mg/l. A high concentration of Mg²⁺ gives an unpleasant taste to drinking water [75]. Iron (Fe³⁺) was detected in appreciable quantities. The highest concentration was found in Kwalkwalawa (4.5 ± 0.0), and the lowest was found in Kaura Abdu (0.3). These samples are above the WHO and SON allowable limits.

4.2 Bacteriological Analysis

Coliform growth was higher in all samples. The three coliform bacteria detected are *Citrobacter freundii, Enterobacter aerogene*, and *Escherichia coli.* Table 2 shows the rate of contamination of surface water concerning coliform bacteria isolated from surface water samples. The rate of contamination of surface water samples as presented in Table 2 showed Kwalkwalawa had 655, Marmaro 625, Asare 625, Boye 180, and Kaura Abdu 26, respectively. In this study, all five samples showed a positive presumptive test. Therefore, the entire samples collected were not suitable for drinking because concentrations exceed the rate of 10 as recommended by [76]. Water samples collected from Kwalkwalawa have the highest rate of contamination compared to the other sample. Therefore, a potential health risk exists due to the presence of microbial pathogens in the water. The *Enterobacter aerogene* population was 33.33%, *Escherichia coli* had 11.11%, while *Citrobacter freundii* had 55.6%, respectively. The main sources of these microbial contaminants in wastewater are human and animal wastes.

Table 2. Mean MPN of Coliforms and Bacteria Isolated from surface water

|		
Kwalkwalawa	655	*Enterobacter aerogene & Citrobacter freundii*
Marmaro	625	*Citrobacter freundii & Enterobacter aerogene*
Share	625	*Citrobacter freundii*
Boye	180	*Enterobacter aerogene & Escherichia coli*
Kaura Abdu	26	*Citrobacter freundii*

4.3 Multivariate Analysis

4.3.1 Principal Component Analysis

Principal component analysis (PCA) is a valuable statistical tool that can be used to reduce hydrochemical data and relates it to sources of solutes in surface water. PCA was carried out on 13 subsets of elements (Table 3). Com-

ponent 1 explained 58.63 % of the total variance and had high positive loadings (≥0.65) on BOD. Component 2 had moderate loading on BOD, TDS, and TSS, it explained 36.08 % of the total variance. Significant loading on DO occurred in Component 3 with moderate loading on TSS. Components 1-3 relate to external influences on surface water quality. Component 4 had significant loading on Fe^{3+}. This component can be related to rock weathering. High Fe^{3+} concentrations exceeding WHO reference guidelines in surface and groundwater were reported from different parts of the Sokoto basin [77-80]. Figure 2 further illustrates a biplot of PC 1 and PC 2. It is difficult to identify any pattern.

Table 3. Principal components (PCs) of hydrochemical data

Variables	PC 1	PC 2	PC 3	PC 4
pH	0.046	-0.025	0.055	-0.077
DO	0.030	0.031	0.759	0.283
BOD	0.873	0.476	-0.019	0.022
TDS	-0.291	0.570	-0.376	-0.204
TSS	-0.300	0.537	0.490	-0.394
Cl^-	-0.011	-0.072	0.035	0.035
PO_4^{2-}	0.000	0.000	0.000	0.000
NO_3^-	-0.048	-0.042	0.117	0.198
K^+	-0.003	-0.013	0.042	-0.070
Ca^{2+}	0.057	-0.014	0.055	-0.049
Mg^{2+}	0.018	-0.007	-0.001	-0.073
Fe^{3+}	-0.231	0.388	-0.138	0.814
% variance	58.626	36.075	3.061	2.238
Eigenvalue	13.033	8.020	0.680	0.498
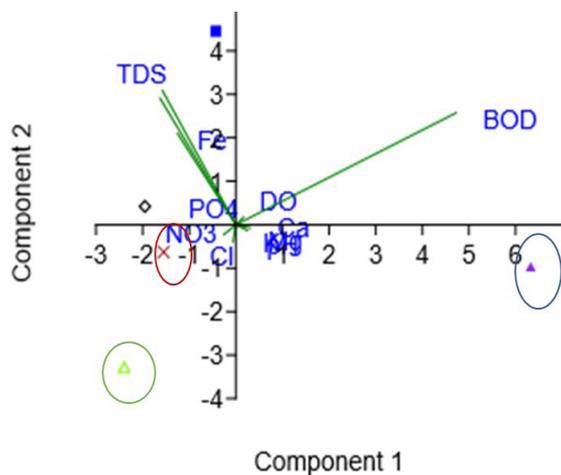
Figure 2. Further illustrates a biplot of PC 1 and PC 2

4.3.2 Hierarchical Cluster Analysis

Hierarchical cluster analysis (HCA) is a commonly used procedure in water quality analysis since it is capable of differentiating sampling locations [65-67,81-86]. By means, HCA, the sampling locations with comparable characteristics can be grouped into a cluster. The graphic assembly of the grouping process is shown in Figure 3. Cluster 1 is comprised of sampling locations with similar concentrations of pH, Ca^{2+}, Mg^{2+}, and BOD. Cluster 2 is comprised of locations with similar concentrations of DO, K^+, Cl^-, PO_4^{3-} and NO_3^-. Cluster 3 contained locations with similar TDS, TSS, and Fe^{3+} concentrations. Cluster 2 can be related to anthropological influences, since Cl^-, PO_4^{2-} and NO_3^- are increasingly added into surface water by human activities [87,88].
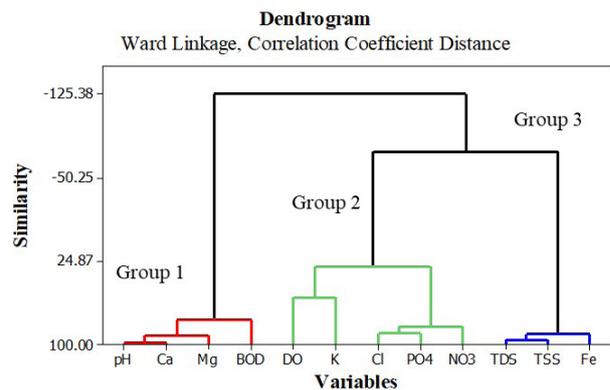
Figure 3. Dendrogram produced from cluster analysis based on the sampling locations to identify the major surface water characteristics

5. Conclusion

This study aimed at examining the hydrochemistry of surface water along River-Rima floodplain at Wamakko, Sokoto State, Nigeria. The study discovered that BOD, TDS, Mg^{2+}, and Fe^{3+} are not following the WHO and SON standards. The presence of Cl^-, NO_3^-, and PO_4^{3-} in detectable quantities, indicated high toxicity levels in surface water. Coliform and total bacteria count indicated microbial pollution from anthropogenic activities. The isolates bacteria detected include *Enterobacter aerogene, Escherichia coli*, and *Citrobacter freundii*. The presence of *E. coli* in detectable quantities indicated high contamination and therefore posed a serious risk to human and animal health. Finally, the quality of the water is deteriorating due to the continuous contamination of the water by farmers in the process of fertilizer application, dumping of agricultural waste, and defecation by animals. Hence, the water in the Sokoto River Rima floodplain of the Wamakko local area of Sokoto State is of low standard and unsafe for drinking.

Acknowledgments

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