environmental sciences proceedings

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Proceedings Paper

Quality of Surface and Ground Water in Three States of Nigeria: Assessment of Physicochemical Characteristics and Selected Contamination Patterns †

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† Presented at the 7th International Electronic Conference on Water Sciences, 15–30 March 2023; Available online: https://ecws-7.sciforum.net.

Abstract: The study of water quality is crucial given the amount of industrial, agricultural, and other human activities in the sampling sites. The aim of the study was to assess the physicochemical characteristics and selected contamination patterns of water samples in Nigeria. This study used conventional analytical techniques to analyze the physicochemical parameters in water samples from 33 sampling sites (dug wells, boreholes, rivers, and rainwater) in three different states (Ekiti, Osun, and Ondo) of Nigeria. These parameters included pH, Total Dissolved Solids (TDS), Electrical Conductivity (EC), Temperature, Relative Humidity (RH), and four elemental parameters (Ca, Na, Fe, and Cu). The Enrichment Factor (EF), Contamination Factor (CF), and Metal Index (MI) were used to characterize the data. Temperature (28.17 °C), TDS (130.2 mg/L), EC (260.0 μS/cm), pH (6.88), Na (14.47 ppm), Ca (25.74 ppm), Fe (0.49 ppm), and Cu (0.08 ppm) were the average values from the results. Na and Ca had relationships with one another. The levels of heavy metals were below those recommended by Nigerian Industrial Standard for Drinking Water Quality (NISDQW) and the World Health Organization (WHO). The metal levels in the water samples were over 1.5, which is the threshold value indicated by the EF classifications. Particularly, EFs were moderate to significantly enriched. All element CFs were below the 1-level pollution threshold. The water samples are pure based on the MI's rating of water quality. Human and natural activities may represent a risk to the local public health, hence it is highly advised that all stakeholders adopt rapid and long-lasting collective action to limit pollution levels as part of the water quality governance system.

Keywords: anthropogenic activities, water samples, heavy metals, TDS, enrichment factor, WHO, SON

Citation: Abulude, F.O.; Akinnusotu, A.; Adeoya, E.A.; Mabayoje, S.O.; Arifalo, K.M.; Adamu, A. Quality of Surface and Ground Water in Three States of Nigeria: Assessment of Physicochemical Characteristics and Selected Contamination Patterns. *Environ. Sci. Proc.* **2023**, *5*, x. https://doi.org/10.3390/xxxxx

Academic Editor(s):

Published: 15 March 2023

1. Introduction

The accessibility and sustainablity of water and sanitation for everybody by 2030 are one of the sustainable development objectives (Goal 6) [1,2]. The objectives are to provide everyone with equitable access to clean, inexpensive drinking water; achieve adequate and equitable access to sanitation and hygiene; improve water quality by reducing pollution, eliminating dumping, and minimizing the release of hazardous chemicals and materials; achieve half as much untreated wastewater; implement integrated water resources management at all levels; and achieve protection and restoration [3].

For continued population expansion and development, access to a secure and reliable water supply is a crucial requirement [4]. Both surface and ground waters are essential sources of water for the entire world's population. About 90% of the world's readily usable freshwater resources are found in groundwater, with the other 10% being found in lakes, reservoirs, rivers, and wetlands. Again, the expansion of an estimated 40% of the world's agricultural production is supported by groundwater irrigation of arable lands [4]. Groundwater is the most dependable source of drinking water in Sub-Saharan Africa [5].

Southwest Nigeria faces a number of difficulties, including how to accomplish Sustainable Development Goals and provide drinkable water for its expanding population. Due to the scarcity of surface water supplies in some regions, people are forced to use underground water, which presents a problem in those areas. In the states, groundwater and surface water are significant natural resources that have an impact on both human and animal health and welfare. As a result, primary research and quality control efforts should be directed at the quality of these resources. On this premise, it will not be out of place if the qualities of the water samples are determined. The major goal of this study was to assess the quality (Physicochemical Characteristics and selected contamination patterns) of ground and surface water samples (borehole, dug well, rainwater, and river) from various communities in chosen areas of three states (Osun, Ondo, and Ekiti) in the South-West of Nigeria.

2. Materials and Methods

Osun, Ekiti, and Ondo States of Nigeria, which make up the study area, are situated in the country's southwest. The research area's climate generally follows a pattern. In terms of population, transportation, industry, housing, and agriculture, the states are rapidly expanding. For this experiment in November 2022, thirty-three water samples were selected from rivers (10), hand-dug wells (14), boreholes (7), and rain (2). The samples were obtained in polyethylene bottles, cleaned properly with distilled water, and then treated with nitric acid before being filtered through membrane filters with pores measuring 0.45 microns. A Garmin global positioning system was used to determine the coordinates of the sampling locations. A portable multi-parameter meter called the Temp/pH/TDS/EC meter (model MI 1399) was used to measure the temperature, electrical conductivity, pH, temperature, and TDS in situ immediately after sample collection in the field. To stop the precipitation of trace elements, nitric acid was used to acidify the water samples. The elements (Na, Ca, Cu, and Fe) were evaluated utilizing conventional methods (AAS, Buck Scientific GVP 210, USA) in the Central Laboratory of Quality Monitoring at Afe Babalola University in Ado-Ekiti, Ekiti State, Nigeria. The metal index, contamination factor, and enrichment factor (EF) were determined. EF was calculated using this factor [6]:

$$EF = \frac{(C_i/C_{ref})\ \text{sample}}{B_i/B_{ref})\ \text{Background}} \qquad (1) \qquad (1)$$

where Bi is the background value of an element of interest and Bref is the background value of the reference element in the study area, Ci is the concentration of trace elements in the sample, Ci is the concentration of the reference element in the sample, and Cref is the background value of the reference analyte in the sample. The reference element used in this study was Fe, which is most widely used for normalization [6]. EF classification: EF < 2 (Deficiency to minimal enrichment), 2 ≤ 5 (moderate enrichment), 5 ≤ EF < 20 (significant enrichment), 20 ≤ EF < 40 (very high enrichment), and EF ≥ (extremely high enrichment).

CF was calculated using this factor [9]:

$$CF = C_i / B_i \quad (2) \tag{2}$$

These values were obtained by calculating the ratio of the element's background concentration to the concentration of the element present in the sample [7]. C*i* = concentration of the examined element *i*, and B*i* = geochemical background value of the element. The contamination values in increasing order of contaminations are 0 = none, 1 = none to medium, 2 = moderate, 3 = moderate to strong, 4 = strongly polluted, 5 = strong to very strong, 6 = very strong [8]. In terms of metal and metalloid contamination, MI shows an overall trend in water quality [9]. where *Hc* is the ith parameter's monitored value (in mg/L), and *Hmac* is the ith parameter's maximum permissible concentration [10]. According to the MI, the water is either lowly polluted (MI < 10) or moderately polluted (10 < MI < 20) [11]. MI was calculated by Equation (3) [11]:

$$\mathbf{MI} = \sum_{i=1}^{n} \frac{Hc}{Hmac} \tag{3}$$

The MI classification for water samples are: <0.3 = Very pure (Class I), 0.3–1.0 Pure (Class II), 1.0–2.0 Slightly affected (Class III), 2.0–4.0 Moderately affected (Class IV), 4.0–6.0 Strongly affected (Class V), >6.0 Seriously affected (Class VI).

3. Results and Discussion

The recorded mean pH of the water did not differ from one another statistically ($p > 0.05$). The pH in the water samples ranged from 5.66 to 7.89, with a mean value of 6.88 0.60 (Table 1). Dug well had the lowest pH reading, whereas the borehole had the highest. Except for the lowest pH, water's pH was within the range of 6.5–8.5 allowed by WHO [12] and SON [13] for drinking water. The outcome is consistent with Appiah-Opong et al. [14]. Water with a pH below 6.5 is considered to be acidic for human consumption which could lead to conditions like acidosis and harm the digestive and lymphatic systems [6]. Statistical analysis revealed that the means were not different ($p > 0.05$) from one another despite the fact that the electrical conductivity of the water was generally higher in the dug well than in other samples. The mean EC values in the water samples ranged thus: Dug-well (84–1003 µS/cm), borehole (136–386 µS/cm), rain (54–59 µS/cm), and rivers (76–297 µS/cm). The overall mean was 260 µS/cm.

Table 1.

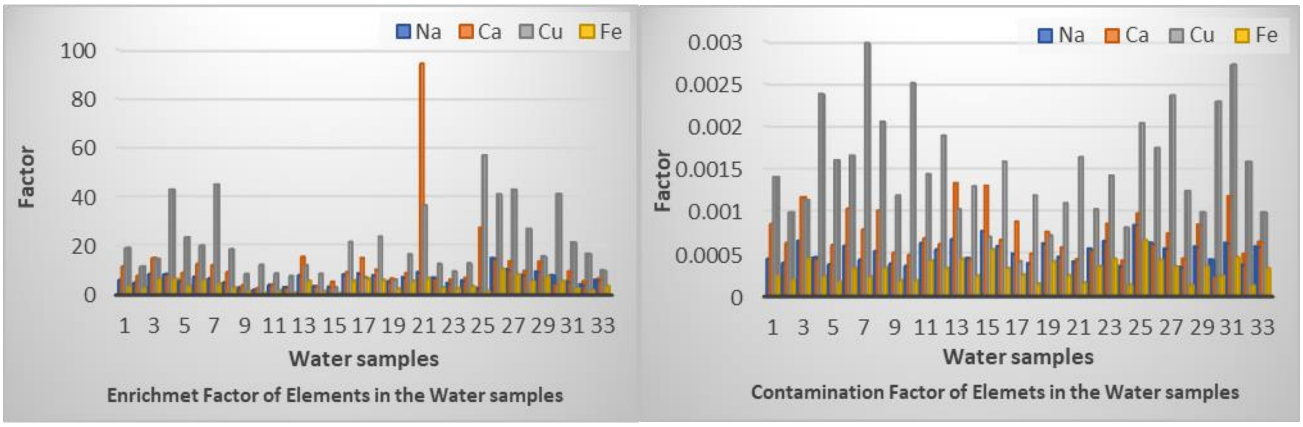
Variable	Mean	SE Mean	StDev	CoefVar (%)	Min	Q1	Median	Q3	Max	Skewness	Kurtosis
Temperature (°C)	28.17	0.28	1.67	5.93	24.80	26.90	28.60	29.30	31.20	−0.38	−0.72
TDS (mg/L)	130.20	15.60	89.80	68.99	27.00	71.00	118.00	162.00	511.00	2.49	9.39
EC (µS/cm)	260.00	30.70	176.40	67.86	54.00	144.00	239.00	314.50	1003.00	2.45	9.10
pH	6.88	0.10	0.60	8.00	5.66	6.47	7.02	7.27	7.89	−0.52	−0.46
Na (mg/L)	14.47	0.63	3.62	24.98	9.40	11.05	14.80	17.40	23.50	0.46	−0.36
Ca (mg/L)	25.74	1.74	10.02	38.92	8.20	17.80	22.90	31.15	48.30	0.69	−0.18
Fe (mg/L)	0.49	0.05	0.30	60.14	0.18	0.29	0.40	062	1.35	1.62	2.29
Cu (mg/L)	0.08	0.01	0.04	41.48	0.02	0.06	0.08	0.11	0.16	0.57	−0.27

WHO (2011)—Temperature (22–29 °C), TDS (1000 mg/L), EC 1000 (mg/L), pH (6.5–8.5), Na (200), Ca (75), Fe (0.03), Cu (200 mg/L); NISDQW (2015)—Temperature (22–29 °C), TDS (1000 mg/L), EC 1000 (mg/L), pH (6.5–8.5), Na (200), Ca (75 mg/L), Fe (0.03), Cu (200 mg/L).

The EC results fell below the 1000 µS/cm drinking water limit set by WHO [12] and SON [13]. Although EC is not a worry for human or aquatic health, it might be a sign of other issues with water quality [14]. The high values of EC in the dug well could be linked to anthropogenic activities as well as the soil's mineral or salt dissolution [15]. TDS values ranged between 27 and 511 mg/L, with 260 mg/L being mean. The considerable high variability in the water samples was shown by the coefficient of variation in percent. No differences in water temperature were found to be statistically significant ($p > 0.05$). The results showed the range, standard error, Skewness, and Kurtosis of temperature as 24.80–31.20 °C, 0.28, −0.38, and −0.72 respectively. The minimum value was recorded in a stream. The reason could be due to the activities of the sampling which assisted in the aeration of the water. In addition to the time of the sample, other factors that may affect temperature include water depth, season, groundwater influx, and air circulation [16]. These findings concur with those made in the Ivory Coast by Koffi et al. [15].

The concentrations of Na, Ca, Fe, and Cu in the thirty-three sampling points ranged from 9.40 to 23.50 mg/L, 8.20 to 48.30 mg/L, 0.18 to 1.35 mg/L, and 0.02 to 0.16 mg/L, respectively. The elements' average concentrations fell in the following order: Ca > Na > Fe > Cu (Table 1). These results agree with those found by Koffi et al. [15] in Ivory Coast. The number of components was below what is considered to be acceptable for drinking and irrigation water on a national and international level. Only a few of the water samples had iron contents that are above the WHO limit (0.3 mg/L), over 90% of the samples are regarded as suitable for use in irrigation and human consumption. Undesirable tastes and smells are typically connected to underground water that contains more iron [17]. It's possible that the iron in water samples came from natural sources as well [18]. The concentration of copper was higher in river sample waters than in others. This shows that the rivers are either naturally high in copper or absorbed from soils with Cu fertilizers. Calcium concentration was greater than sodium content for more than 90% of the water samples gathered. The amount of carbonate minerals that make up the water-bearing formations, ion exchange mechanisms, and the precipitation of calcite in the aquifer can all be used to explain this [19].

Enrichment factors of elements followed this order Ca > Cu > Na > Fe. The metal levels in the water samples were over 1.5, which is the threshold value indicated by the EF classifications. Particularly, EFs were moderate to significantly enriched. Figure 1 displays the water sample histogram. The samples fell within very pure and Class I. This result was compared with that of Khosnam et al. [20] for the Silakhor River in Iran.



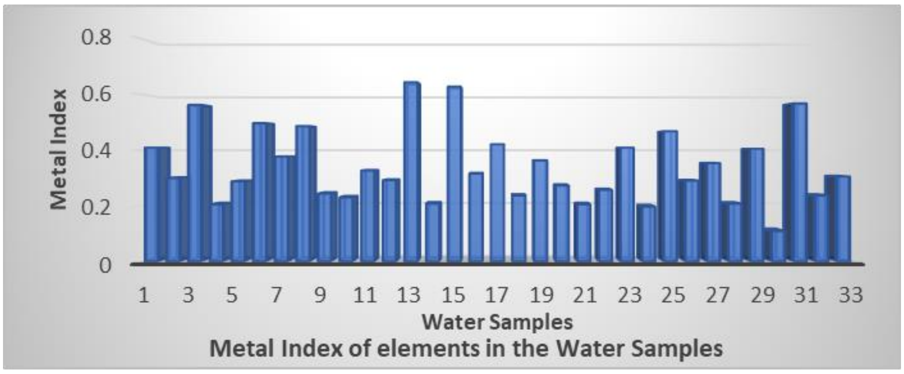


Figure 1. The Metal Index, Contamination Factors, and Enrichment Factor of the Water Samples.

Figure 2 depicted the matrix correlation (Pearson correlation). This showed the correlations between the physicochemical parameters and the elements. There were strong positive relationships between EC and TDS (r = 0.99) and Ca and Na (r = 0.72) depicting that an increase in EC causes an increase in TDS showing a direct relationship between the variables. Ca and Na had a substantial correlation, which suggested that the components in the water samples might have come from identical origins.

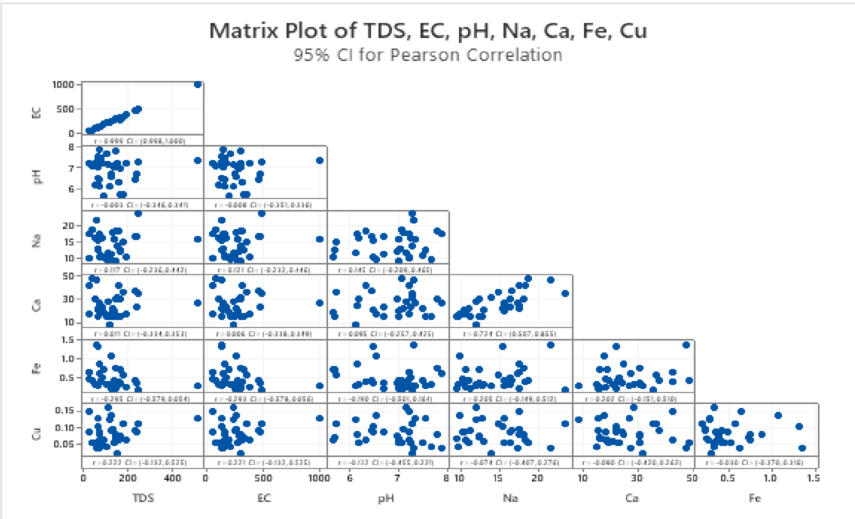


Figure 2. The matrix correlation of the water samples (Pearson correlation).

4. Conclusions

This study assessed the physicochemical characteristics and selected contamination patterns of thirty-three water samples from three Southwest states, Nigeria. Also, in the study, EF, CF, and MI were determined. The physicochemical and elemental levels obtained were within the standard limits of WHO and NISDQW. The EFs of the water samples were moderate to significantly enriched. All elemental CFs were below the 1-level pollution threshold. The MI's rating showed that they are pure for human and animal consumption and also for irrigation purposes. Although the present study concluded that the water samples were good, but efforts should be put in place to sustain them to avoid being polluted.

Author Contributions: Conceptualization, F.O.A.; methodology, A.A. (Akinyinka Akinnusotu); formal analysis, E.A.A.; investigation, S.O.M.; data curation, K.M.A.; writing—original draft preparation, F.O.A.; writing—review and editing, E.A.A., K.M.A., A.A. (Akinyinka Akinnusotu); supervision, A.A. (Ademola Adamu), S.O.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Data Availability Statement: The raw data are available upon request. Please contact the corresponding author.

Acknowledgments: The authors are grateful for the permissions granted by owners of dug wells and boreholes to obtain them from their homes and offices.

Conflicts of Interest: The authors declare no conflict of interest.

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