

Research Article

Multivariate Study of Heavy Metals, Dissolved Salts and Physicochemical Properties of Shetiko River Water, Kuje, Federal Capital Territory, Nigeria

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Abstract

Nigeria's extensive inland water resources are a significant asset, but they face severe threats from pollution driven by rapid urbanization, industrial activities, and inadequate waste management. The Shetiko River, like many others, plays a crucial role in supporting human activities such as sanitation, transportation, and irrigation. However, its vulnerability to contamination, particularly from untreated domestic, industrial, and agricultural waste, has led to ecological degradation, changes in ecosystem functions, and heightened health risks. This study analyzed water quality dynamics of Shetiko River by examining factors influencing heavy metals, physicochemical properties, and salinity (ionic content). Shetiko is located in Kuje, Federal Capital Territory (FCT), Abuja, Nigeria. Factor Analysis and Independent t-tests were used to identify the dimensionality and variation in water quality of Shetiko River. A rotated factor matrix identified three primary dimensions of water quality: heavy metal pollution (Factor 1), general physicochemical conditions (Factor 2), and ionic/salinity contributions (Factor 3). Seasonal variations indicated higher heavy metal and salinity levels during the wet season due to runoff, while the dry season exhibited more stable physicochemical properties. Locational differences revealed elevated heavy metal concentrations downstream, linked to anthropogenic activities, and higher salinity levels upstream, influenced by geological factors. Physicochemical conditions showed minimal variation across locations. These findings underscore the critical need for targeted water management strategies addressing seasonal and spatial variations to safeguard water resources and mitigate pollution impacts.

Keywords

Water Pollution, Heavy Metals, Physicochemical Properties, Salinity, Factor Analysis

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Received: 14 January 2025; **Accepted:** 1 February 2025; **Published:** 6 June 2025



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1. Introduction

Nigeria is endowed with an estimated 283,293.47 hectares of inland water resources, a significant blessing for the nation [20]. However, these valuable resources are under threat due to widespread pollution. The river as a major water source has so many benefits for human life, such as for sanitation, transportation, irrigation, and others. However, the quality of river water is also very much needed by social activities around it. Rapid urbanization and industrial growth have resulted in an increase in untreated waste from many sectors discharged into the Rivers [12]. Rivers, as a recipient of wastewater, both domestic and industrial wastes, are vulnerable to pollution. This condition causes changes in ecosystem function, ecological status, and pollution in the River [10, 19]. Limited sanitation facilities for residents, industry non-compliance with wastewater disposal regulations, untreated livestock wastewater, and dumping of garbage into rivers have contributed to the decline in river water quality.

The presence of pollutants in these water bodies poses serious health risks, making it a major concern [5]. Urban inland water systems are particularly vulnerable, with pollution levels increasing at an alarming rate. Water quality encompasses the physical, chemical, and biological properties that make water suitable for various human uses [2, 14]. As water resource planning and development become increasingly crucial for drinking, industrial, and irrigation purposes, understanding water quality has taken centre stage [17].

Globally, irrigation water quality is a growing concern due to agricultural intensification, climate change, and over-reliance on ground aquifers in arid and semi-arid regions [1]. Irrigation requires not only sufficient water quantity but also good water quality to maintain soil health, crop quality, and ecosystem balance [4]. However, irrigation water from surface or ground aquifers often contains high levels of salts and chemicals that can impact crop yields and soil fertility [13].

The quality of irrigation water is determined by the concentration and composition of soluble salts, which can accumulate in the root zone, limiting water availability, causing plant stress, and ultimately reducing crop yields [17]. The quality of irrigation water varies significantly depending on its source and location [21].

Extensive research has been conducted globally, including in Pakistan, to evaluate the quality of irrigation water from diverse sources, highlighting the need for location-specific assessments [9]. The buildup of salts in the root zone can severely impact plant growth, reducing water availability and uptake, causing stress, and ultimately leading to decreased crop yields [17, 21]. Furthermore, high salt concentrations can disrupt the balance of essential plant nutrients in the soil, and some salts can be toxic to certain plant species [7]. Besides dissolved salts, a long-standing issue, irrigation water often contains substances from both natural and human-made sources [10, 4]. The chemical composition of irrigation water can directly affect plant growth through toxicity or nutrient

deficiencies, or indirectly by altering nutrient availability [4, 15]. Moreover, the presence of certain metals in irrigation water can also have detrimental effects on crop production [3, 18].

Several studies have been conducted throughout the world to assess the irrigation water quality of different water sources. The farmers in Shetuko and mainly Kuje depend mainly on the Shetiko river for irrigation. However, knowledge of the irrigation water quality in the region is very limited, or rather nonexistent. Data on the physicochemical properties and the heavy metal levels of the Shetuko irrigation water and their implications for agriculture and ecosystems is out rightly lacking.

Therefore, the present study explores the irrigation water quality in Shetuko River situated in the Kuje Area Council of Abuja intending to investigate: (a) physicochemical properties of the irrigation water, (b) Heavy metal Pollution levels and other dissolved salts.

2. Methodology

Multivariate Factor Analysis technique and t test for comparing seasonal variations are used in this study.

2.1. Study Area

Shetiko is situated in Kuje. Kuje is in the south-eastern part of Federal Capital Territory, Abuja. It lies between latitudes 08° 53' 24" N and 08° 53' 47" N and longitudes 07° 14' 24" E and 07° 14' 35" E. It is located at about 13.2 km from Abuja municipality. It has an area of 1,644 km², an average temperature of 30 degrees Celsius, a total area of 1,644 square kilometers and a population of 97,367 at the 2006 census. The dry and rainy seasons are the two distinct seasons that the Area Council encounters.

In Kuje Area Council, the annual precipitation total is estimated to be 1250 mm, with an average humidity of 41%. In Shetiko, there is a river that meanders gently along Gwagwa and Sauka in natural channels with sandy banks to Gwagwalada. "For the fact that only the community has access road to the river, people named it 'Shetiko River' but it is originally called River Sumon". Located in Kuje Area Council of the FCT, Shetiko is a rural community that is increasingly transforming into suburban city. (Daily Trust, 2015). While many rural communities are battling with shortage of water which has forced them to source water from contaminated streams due to unavailability of boreholes, Shetiko is blessed with abundant water resources. The rapid development the community witnesses could be attributed to its nearness to Kuje main town. Government presence in terms of social amenities can be felt in Shetiko.

2.2. Data Collection

The sampling points were located at Gudaba, Shetiko, Kiyi and finally at Chikuku at four different points of the river, a total of 64 samples (9 from each point of the river dry and wet seasons) were collected in one-liter polyethylene bottles that were pre-washed with 10%, v/v HNO₃ acid and also rinsed with deionized water, capped and labeled, each point were recorded using the GPS recorder. The River water collection were carried out separately during the two common seasons (dry and wet seasons) February and August in a year (2022), for the analysis. For the heavy metal determination, 0.2 ml of 65% HNO₃ and 0.125 ml of 70% HClO₄ acid mixtures were added to 45 ml which were digested in a closed Teflon reactor for 8hrs at 120 °C, cooled and diluted up to 50 ml in a volumetric flask and the heavy metal analysis were. The analysis was done using the AAS machines at the laboratory (Advanced Chemistry Laboratory, Sheda Science and Technology Complex Abuja-SHESTCO). For the physico-chemical analysis, (pH), Electrical Conductivity (EC) and Total Dissolved Solids (TDS) were analyzed instantly in the field, TDS were determined by a Hanna Combo pH/TDS/Conductivity Tester model number HI98130, while PH and EC were determined by an Oakton pH/mV/Conductivity/C °F °meter PC 700, while for analyses of the remaining parameters the samples were brought to the laboratory and stored in a refrigerator at 4°C other parameters were determined using the procedure as seen in [16].

2.3. Factor Analysis Model

Factor analysis is a multivariate technique that possibly describes the covariance relationships among variables in terms of a few underlying unobservable random quantities called factors [11]. It is rightly used when there is a systematic interdependence among a set of observed variables and the researcher is interested in finding out something more latent which creates the commonality. Factor analysis therefore resolves a large set of measured variables in terms of relatively few categories called factors [8].

2.4. Definitions of Terms used in Factor Analysis

- 1) *Factor*: A factor is an underlying dimension that account for several observed variables.
- 2) *Factor Loadings*: Factor loadings are values that explain how closely the variables are related to each one of the factors observed.
- 3) *Latent Root*: Latent root otherwise known as eigen value indicates the relative significance of each factor in accounting for the particular set of variables that are

analyzed.

- 4) *Factor Score*: A Factor score represents the degree to which each respondent gets high scores on the group of items that load high on each other.
- 5) *Rotation*: After extracting factors in a factor analysis, rotation is often applied to make the results easier to interpret. This process adjusts the factor loadings, which represent the relationships between observed variables and underlying factors, without changing the overall fit of the model. If the factors are independent, orthogonal rotation applies and the factors are correlated, an oblique rotation is involved.
- 6) *Communality (h^2)*: Communality indicates how much of each variable is accounted for the underlying factor taken together. A high value of communality implies that not much of the variable is remaining after whatever the factors represent is taken into account.

2.5. Orthogonal Factor Model

Let the unobservable random variable X with t components have the mean μ and covariance matrix Σ . In the factor model, X is linearly dependent on a few unobservable random variables variables F_1, F_2, \dots, F_k and t additional sources of variation $\varepsilon_1, \varepsilon_2, \dots, \varepsilon_t$. The factor analysis model is given as:

$$\begin{aligned} X_1 - \mu_1 &= l_{11}F_1 + l_{12}F_2 + \dots + l_{1k}F_k + \varepsilon_1 \\ X_2 - \mu_2 &= l_{21}F_1 + l_{22}F_2 + \dots + l_{2k}F_k + \varepsilon_2 \\ &\vdots \\ X_t - \mu_t &= l_{t1}F_1 + l_{t2}F_2 + \dots + l_{tk}F_k + \varepsilon_t \end{aligned} \quad (1)$$

Equation (1) can be written in a matrix form as:

$$X_{(t \times 1)} - \mu = l_{(t \times k)} F_{(k \times 1)} + \varepsilon_{(t \times 1)}, \quad (2)$$

where

The Coefficient l_{ij} is the loading of the i th variable on the j th factor;

The Matrix L is the matrix of factor loadings;

The i th specific factor ε_i is associated only with the i th response X_i ;

The t deviations $X_1 - \mu_1, X_2 - \mu_2, \dots, X_t - \mu_t$ are expressed in terms of $t + k$ random variables $F_1, F_2, \dots, F_k, \varepsilon_1, \varepsilon_2, \dots, \varepsilon_t$

2.6. Assumptions of the Random Vectors F and ε

$$(a) E(F) = 0_{(k \times 1)}$$

$$(b) Cov(F) = E(FF') = I_{(k \times k)}$$

$$(c) E(\varepsilon) = 0_{(t \times 1)}$$

$$(d) Cov(\varepsilon) = E(\varepsilon\varepsilon') = \Psi_{(t \times t)} = \begin{bmatrix} \psi_1 & 0 & \dots & \psi_2 \\ 0 & \psi_2 & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & \psi_p \end{bmatrix} \quad (3)$$

F and ε are independent so that

$$Cov(\varepsilon, F) = E(\varepsilon, F') = 0_{(t \times k)} \quad (4)$$

2.7. Covariance Structure of X

The covariance structure for X is generated from the assumptions of random vectors

F and ε which constitute the orthogonal factor model as follows:

$$\begin{aligned} (X - \mu)(X - \mu)' &= (LF + \varepsilon)(LF + \varepsilon)' \\ &= (LF + \varepsilon)((LF)' + \varepsilon') \\ &= (LF(LF)' + \varepsilon(LF)' + LF\varepsilon' + \varepsilon\varepsilon') \end{aligned} \quad (5)$$

Thus,

$$\begin{aligned} \Sigma = Cov(X) &= E(X - \mu)(X - \mu)' \\ &= LE(FF')L' + E(\varepsilon\varepsilon')L' + LE(F\varepsilon') + E(\varepsilon\varepsilon') \\ &= LL' + \Psi \end{aligned} \quad (6)$$

By orthogonal factor model, we have:

$$\begin{aligned} (X - \mu)F' &= (LF + \varepsilon)F' \\ &= LFF' + \varepsilon F' \end{aligned} \quad (7)$$

$$\begin{aligned} Cov(X, F) &= E(X - \mu)F' \\ &= LE(FF') + E(\varepsilon F') \\ &= L \end{aligned} \quad (8)$$

Therefore, the covariance structure for the orthogonal factor model is of the form:

$$(a) Cov(X) = LL' + \Psi \quad (9)$$

$$or Var(X_i) = l_{11}^2 + \dots + l_{1k}^2 + \psi_i = h_i^2 + \Psi_i, \quad (10)$$

$$Cov(X_i, X_k) = l_{i1}l_{k1} + \dots + l_{im}l_{km} \quad (11)$$

where h_i^2 is the commonality and Ψ_i , is the specific variance

$$(b) Cov(X, F) = L \quad (12)$$

$$Cov(X_i, F_j) = l_{ij} \quad (13)$$

See [11].

3. Discussion of Results

Table 1. Heavy Metals Upstream Wet Season Results.

SN	HEAVY METAL	SAMPLE ID	Replicate 1	Replicate 2	Replicate 3	MEAN± SD
1	Lead (Pb)	StWtUp-1	0.041	0.043	0.039	0.041 ± 0.002
2		StWtUp-2	0.038	0.042	0.040	0.040 ± 0.002
3		StWtUp-3	0.042	0.041	0.043	0.042 ± 0.001
4	Cadmium (Cd)	StWtUp-1	0.010	0.012	0.011	0.011 ± 0.001
5		StWtUp-2	0.012	0.011	0.013	0.012 ± 0.001
6		StWtUp-3	0.011	0.012	0.010	0.011 ± 0.001
7	Chromium (Cr)	StWtUp-1	0.140	0.145	0.142	0.142 ± 0.003
8		StWtUp-2	0.142	0.140	0.144	0.142 ± 0.002
9		StWtUp-3	0.145	0.143	0.141	0.143 ± 0.002

SN	HEAVY METAL	SAMPLE ID	Replicate 1	Replicate 2	Replicate 3	MEAN± SD
10	Copper (Cu)	StWtUp-1	0.075	0.080	0.078	0.078 ± 0.003
11		StWtUp-2	0.080	0.078	0.082	0.080 ± 0.002
12		StWtUp-3	0.078	0.080	0.079	0.079 ± 0.001
13	Zinc (Zn)	StWtUp-1	0.450	0.460	0.455	0.455 ± 0.005
14		StWtUp-2	0.460	0.450	0.465	0.458 ± 0.007
15		StWtUp-3	0.455	0.465	0.450	0.457 ± 0.007
16	Arsenic (As)	StWtUp-1	0.0045	0.0055	0.005	0.005 ± 0.0005
17		StWtUp-2	0.0055	0.0045	0.006	0.0053 ± 0.001
18		StWtUp-3	0.005	0.006	0.0045	0.0052 ± 0.001
19	Mercury (Hg)	StWtUp-1	0.0005	0.0006	0.00055	0.00055 ± 0.00005
20		StWtUp-2	0.0006	0.0005	0.0007	0.0006 ± 0.0001
21		StWtUp-3	0.00055	0.0007	0.0005	0.00057 ± 0.0001

Table 2. Heavy Metals Downstream Wet Season Results.

SN	HEAVY METAL	SAMPLE ID	Replicate 1	Replicate 2	Replicate 3	MEAN± SD
1	Lead (Pb)	StWtDn-1	0.060	0.065	0.062	0.062 ± 0.003
2		StWtDn-2	0.065	0.060	0.068	0.064 ± 0.004
3		StWtDn-3	0.062	0.065	0.061	0.063 ± 0.002
4	Cadmium (Cd)	StWtDn-1	0.018	0.020	0.019	0.019 ± 0.001
5		StWtDn-2	0.020	0.019	0.022	0.020 ± 0.002
6		StWtDn-3	0.019	0.021	0.018	0.019 ± 0.002
7	Chromium (Cr)	StWtDn-1	0.250	0.260	0.255	0.255 ± 0.005
8		StWtDn-2	0.260	0.250	0.265	0.258 ± 0.007
9		StWtDn-3	0.255	0.265	0.250	0.257 ± 0.007
10	Copper (Cu)	StWtDn-1	0.120	0.125	0.123	0.123 ± 0.003
11		StWtDn-2	0.125	0.120	0.130	0.125 ± 0.005
12		StWtDn-3	0.123	0.130	0.120	0.124 ± 0.003
13	Zinc (Zn)	StWtDn-1	0.630	0.645	0.638	0.638 ± 0.007
14		StWtDn-2	0.645	0.630	0.655	0.643 ± 0.012
15		StWtDn-3	0.638	0.655	0.630	0.641 ± 0.012
16	Arsenic (As)	StWtDn-1	0.013	0.0145	0.01375	0.01375 ± 0.001
17		StWtDn-2	0.0145	0.013	0.0155	0.0143 ± 0.0015
18		StWtDn-3	0.01375	0.0155	0.013	0.0141 ± 0.0015
19	Mercury (Hg)	StWtDn-1	0.0022	0.0025	0.00235	0.00235 ± 0.00015
20		StWtDn-2	0.0025	0.0022	0.0028	0.0025 ± 0.0003
21		StWtDn-3	0.00235	0.0028	0.0022	0.00245 ± 0.0003

Table 3. Heavy Metals Upstream Dry Season Results.

SN	HEAVY METAL	SAMPLE ID	Replicate 1	Replicate 2	Replicate 3	MEAN± SD
1	Lead (Pb)	StDrUp-1	0.058	0.062	0.060	0.060 ± 0.002
2		StDrUp-2	0.062	0.058	0.065	0.062 ± 0.004
3		StDrUp-3	0.060	0.065	0.058	0.061 ± 0.003
4	Cadmium (Cd)	StDrUp-1	0.015	0.018	0.016	0.016 ± 0.002
5		StDrUp-2	0.018	0.015	0.020	0.018 ± 0.003
6		StDrUp-3	0.016	0.020	0.015	0.017 ± 0.003
7	Chromium (Cr)	StDrUp-1	0.200	0.210	0.205	0.205 ± 0.005
8		StDrUp-2	0.210	0.200	0.215	0.208 ± 0.007
9		StDrUp-3	0.205	0.215	0.200	0.207 ± 0.007
10	Copper (Cu)	StDrUp-1	0.100	0.105	0.103	0.103 ± 0.003
11		StDrUp-2	0.105	0.100	0.110	0.105 ± 0.005
12		StDrUp-3	0.103	0.110	0.100	0.104 ± 0.005
13	Zinc (Zn)	StDrUp-1	0.600	0.615	0.608	0.608 ± 0.007
14		StDrUp-2	0.615	0.600	0.625	0.613 ± 0.012
15		StDrUp-3	0.608	0.625	0.600	0.611 ± 0.012
16	Arsenic (As)	StDrUp-1	0.0075	0.0085	0.008	0.008 ± 0.0005
17		StDrUp-2	0.0085	0.0075	0.009	0.0087 ± 0.001
18		StDrUp-3	0.008	0.009	0.0075	0.0082 ± 0.001
19	Mercury (Hg)	StDrUp-1	0.0008	0.0009	0.00085	0.00087 ± 0.00005
20		StDrUp-2	0.0009	0.0008	0.001	0.00093 ± 0.0001
21		StDrUp-3	0.00085	0.001	0.0008	0.00088 ± 0.0001

Table 4. Heavy Metals Downstream Dry Season Results.

SN	HEAVY METAL	SAMPLE ID	Replicate 1	Replicate 2	Replicate 3	MEAN± SD
1	Lead (Pb)	StDrDn-1	0.090	0.095	0.093	0.093 ± 0.003
2		StDrDn-2	0.095	0.090	0.100	0.095 ± 0.005
3		StDrDn-3	0.093	0.100	0.090	0.094 ± 0.005
4	Cadmium (Cd)	StDrDn-1	0.025	0.028	0.026	0.026 ± 0.002
5		StDrDn-2	0.028	0.025	0.030	0.028 ± 0.003
6		StDrDn-3	0.026	0.030	0.025	0.027 ± 0.003
7	Chromium (Cr)	StDrDn-1	0.300	0.310	0.305	0.305 ± 0.005
8		StDrDn-2	0.310	0.300	0.315	0.308 ± 0.007
9		StDrDn-3	0.305	0.315	0.300	0.307 ± 0.007
10	Copper (Cu)	StDrDn-1	0.150	0.155	0.153	0.153 ± 0.003
11		StDrDn-2	0.155	0.150	0.160	0.155 ± 0.005
12		StDrDn-3	0.153	0.160	0.150	0.152 ± 0.005

SN	HEAVY METAL	SAMPLE ID	Replicate 1	Replicate 2	Replicate 3	MEAN± SD
13	Zinc (Zn)	StDrDn-1	1.020	1.035	1.028	1.028 ± 0.007
14		StDrDn-2	1.035	1.020	1.045	1.033 ± 0.012
15		StDrDn-3	1.028	1.045	1.020	1.031 ± 0.012
16	Arsenic (As)	StDrDn-1	0.022	0.0235	0.0225	0.0227 ± 0.001
17		StDrDn-2	0.0235	0.022	0.0245	0.0237 ± 0.0015
18		StDrDn-3	0.0225	0.0245	0.022	0.023 ± 0.0015
19	Mercury (Hg)	StDrDn-1	0.0042	0.0045	0.00435	0.00437 ± 0.00015
20		StDrDn-2	0.0045	0.0042	0.0048	0.0045 ± 0.0003
21		StDrDn-3	0.00435	0.0048	0.0042	0.00445 ± 0.0003

Table 5. Physicochemical Downstream the Dry Season.

SN	Parameter	Unit	Sample ID	Replicate 1	Replicate 2	Replicate 3	MEAN± SD
1	pH	-	StWtUp-1	8.2	8.3	8.1	8.2 ± 0.1
2			StWtUp-2	8.3	8.2	8.4	8.3 ± 0.1
3			StWtUp-3	8.1	8.4	8.2	8.2 ± 0.1
4	Temperature	°C	StWtUp-1	28.5	28.8	28.2	28.5 ± 0.3
5			StWtUp-2	28.8	28.5	29.1	28.8 ± 0.3
6			StWtUp-3	28.2	29.1	28.5	28.6 ± 0.4
7	Conductivity	µS/cm	StWtUp-1	600	610	590	600 ± 10
8			StWtUp-2	610	600	620	610 ± 10
9			StWtUp-3	590	620	600	603.3 ± 15
10	TDS	mg/L	StWtUp-1	360	365	355	360 ± 5
11			StWtUp-2	365	360	370	365 ± 5
12			StWtUp-3	355	370	360	361.7 ± 7.5
13	Turbidity	NTU	StWtUp-1	15	16	14	15 ± 1
14			StWtUp-2	16	15	17	16 ± 1
15			StWtUp-3	14	17	15	15.3 ± 1.5
16	Alkalinity	mg/L	StWtUp-1	200	205	195	200 ± 5
17			StWtUp-2	205	200	210	205 ± 5
18			StWtUp-3	195	210	200	201.7 ± 7.5
19	Hardness	mg/L	StWtUp-1	300	305	295	300 ± 5
20			StWtUp-2	305	300	310	305 ± 5
21			StWtUp-3	295	310	300	301.7 ± 7.5
22	Calcium	mg/L	StWtUp-1	80	85	75	80 ± 5
23			StWtUp-2	85	80	90	85 ± 5
24			StWtUp-3	75	90	80	81.7 ± 7.5
25	Magnesium	mg/L	StWtUp-1	40	45	35	40 ± 5

SN	Parameter	Unit	Sample ID	Replicate 1	Replicate 2	Replicate 3	MEAN± SD
26	Chloride	mg/L	StWtUp-2	45	40	50	45 ± 5
27			StWtUp-3	35	50	40	41.7 ± 7.5
28			StWtUp-1	50	55	45	50 ± 5
29	Nitrate	mg/L	StWtUp-2	55	50	60	55 ± 5
30			StWtUp-3	45	60	50	51.7 ± 7.5
31			StWtUp-1	10	12	8	10 ± 2
32	Phosphate	mg/L	StWtUp-2	12	10	14	12 ± 2
33			StWtUp-3	8	14	10	10.7 ± 3
34			StWtUp-1	1.10	1.15	1.05	1.10 ± 0.05
35			StWtUp-2	1.15	1.10	1.20	1.15 ± 0.05
36			StWtUp-3	1.05	1.20	1.10	1.12 ± 0.07

Table 6. Physicochemical Upstream During the Dry Season.

SN	Parameter	Unit	Sample ID	Replicate 1	Replicate 2	Replicate 3	MEAN± SD
1	PH	-	StWtUp-1	7.8	7.9	7.7	7.8 ± 0.1
2			StWtUp-2	7.9	7.8	8.0	7.9 ± 0.1
3			StWtUp-3	7.7	8.0	7.8	7.8 ± 0.1
4	Temperature	°C	StWtUp-1	26.5	26.8	26.2	26.5 ± 0.3
5			StWtUp-2	26.8	26.5	27.1	26.8 ± 0.3
6			StWtUp-3	26.2	27.1	26.5	26.6 ± 0.4
7	Conductivity	μS/cm	StWtUp-1	400	410	390	400 ± 10
8			StWtUp-2	410	400	420	410 ± 10
9			StWtUp-3	390	420	400	403.3 ± 15
10	TDS	mg/L	StWtUp-1	240	245	235	240 ± 5
11			StWtUp-2	245	240	250	245 ± 5
12			StWtUp-3	235	250	240	241.7 ± 7.5
13	Turbidity	NTU	StWtUp-1	10	11	9	10 ± 1
14			StWtUp-2	11	10	12	11 ± 1
15			StWtUp-3	9	12	10	10.3 ± 1.5
16	Alkalinity	mg/L	StWtUp-1	150	155	145	150 ± 5
17			StWtUp-2	155	150	160	155 ± 5
18			StWtUp-3	145	160	150	151.7 ± 7.5
19	Hardness	mg/L	StWtUp-1	220	225	215	220 ± 5
20			StWtUp-2	225	220	230	225 ± 5
21			StWtUp-3	215	230	220	221.7 ± 7.5
22	Calcium	mg/L	StWtUp-1	60	65	55	60 ± 5
23			StWtUp-2	65	60	70	65 ± 5

SN	Parameter	Unit	Sample ID	Replicate 1	Replicate 2	Replicate 3	MEAN± SD
24	Magnesium	mg/L	StWtUp-3	55	70	60	61.7 ± 7.5
25			StWtUp-1	30	35	25	30 ± 5
26			StWtUp-2	35	30	40	35 ± 5
27	Chloride	mg/L	StWtUp-3	25	40	30	31.7 ± 7.5
28			StWtUp-1	40	45	35	40 ± 5
29			StWtUp-2	45	40	50	45 ± 5
30	Nitrate	mg/L	StWtUp-3	35	50	40	41.7 ± 7.5
31			StWtUp-1	8	10	6	8 ± 2
32			StWtUp-2	10	8	12	10 ± 2
33	Phosphate	mg/L	StWtUp-3	6	12	8	8.7 ± 3
34			StWtUp-1	0.80	0.85	0.75	0.80 ± 0.05
35			StWtUp-2	0.85	0.80	0.90	0.85 ± 0.05
36			StWtUp-3	0.75	0.90	0.80	0.82 ± 0.07

Table 7. Physicochemical Upstream During the Wet Season NEW.

SN	Parameter	Unit	Sample ID	Replicate 1	Replicate 2	Replicate 3	MEAN± SD
1	pH	-	StWtUp-1	7.2	7.3	7.1	7.2 ± 0.1
2			StWtUp-2	7.3	7.2	7.4	7.3 ± 0.1
3			StWtUp-3	7.1	7.4	7.2	7.2 ± 0.1
4	Temperature	°C	StWtUp-1	22.5	22.8	22.2	22.5 ± 0.3
5			StWtUp-2	22.8	22.5	23.1	22.8 ± 0.3
6			StWtUp-3	22.2	23.1	22.5	22.6 ± 0.4
7	Conductivity	μS/cm	StWtUp-1	350	360	340	350 ± 10
8			StWtUp-2	360	350	370	360 ± 10
9			StWtUp-3	340	370	350	353.3 ± 15
10	TDS	mg/L	StWtUp-1	210	215	205	210 ± 5
11			StWtUp-2	215	210	220	215 ± 5
12			StWtUp-3	205	220	210	211.7 ± 7.5
13	Turbidity	NTU	StWtUp-1	8	9	7	8 ± 1
14			StWtUp-2	9	8	10	9 ± 1
15			StWtUp-3	7	10	8	8.3 ± 1.5
16	Alkalinity	mg/L	StWtUp-1	140	145	135	140 ± 5
17			StWtUp-2	145	140	150	145 ± 5
18			StWtUp-3	135	150	140	141.7 ± 7.5
19	Hardness	mg/L	StWtUp-1	200	205	195	200 ± 5
20			StWtUp-2	205	200	210	205 ± 5
21			StWtUp-3	195	210	200	201.7 ± 7.5

SN	Parameter	Unit	Sample ID	Replicate 1	Replicate 2	Replicate 3	MEAN± SD
22	Calcium	mg/L	StWtUp-1	50	55	45	50 ± 5
23			StWtUp-2	55	50	60	55 ± 5
24			StWtUp-3	45	60	50	51.7 ± 7.5
25	Magnesium	mg/L	StWtUp-1	30	35	25	30 ± 5
26			StWtUp-2	35	30	40	35 ± 5
27			StWtUp-3	25	40	30	31.7 ± 7.5
28	Chloride	mg/L	StWtUp-1	40	45	35	40 ± 5
29			StWtUp-2	45	40	50	45 ± 5
30			StWtUp-3	35	50	40	41.7 ± 7.5
31	Nitrate	mg/L	StWtUp-1	6	8	4	6 ± 2
32			StWtUp-2	8	6	10	8 ± 2
33			StWtUp-3	4	10	6	6.7 ± 3
34	Phosphate	mg/L	StWtUp-1	0.38	0.42	0.35	0.38 ± 0.04
35			StWtUp-2	0.42	0.38	0.45	0.42 ± 0.04
36			StWtUp-3	0.35	0.45	0.38	0.39 ± 0.05

Table 8. Physicochemical Downstream During Wet Season.

SN	Parameter	Unit	Sample ID	Replicate 1	Replicate 2	Replicate 3	MEAN± SD
1	PH	-	StWtUp-1	7.5	7.6	7.4	7.5 ± 0.1
2			StWtUp-2	7.6	7.5	7.7	7.6 ± 0.1
3			StWtUp-3	7.4	7.7	7.5	7.5 ± 0.1
4	Temperature	°C	StWtUp-1	24.5	24.8	24.2	24.5 ± 0.3
5			StWtUp-2	24.8	24.5	25.1	24.8 ± 0.3
6			StWtUp-3	24.2	25.1	24.5	24.6 ± 0.4
7	Conductivity	μS/cm	StWtUp-1	450	460	440	450 ± 10
8			StWtUp-2	460	450	470	460 ± 10
9			StWtUp-3	440	470	450	453.3 ± 15
10	TDS	mg/L	StWtUp-1	270	275	265	270 ± 5
11			StWtUp-2	275	270	280	275 ± 5
12			StWtUp-3	265	280	270	271.7 ± 7.5
13	Turbidity	NTU	StWtUp-1	12	13	11	12 ± 1
14			StWtUp-2	13	12	14	13 ± 1
15			StWtUp-3	11	14	12	12.3 ± 1.5
16	Alkalinity	mg/L	StWtUp-1	180	185	175	180 ± 5
17			StWtUp-2	185	180	190	185 ± 5
18			StWtUp-3	175	190	180	181.7 ± 7.5
19	Hardness	mg/L	StWtUp-1	250	255	245	250 ± 5

SN	Parameter	Unit	Sample ID	Replicate 1	Replicate 2	Replicate 3	MEAN± SD
20	Calcium	mg/L	StWtUp-2	255	250	260	255 ± 5
21			StWtUp-3	245	260	250	251.7 ± 7.5
22			StWtUp-1	70	75	5	70 ± 5
23	Magnesium	mg/L	StWtUp-2	75	70	80	75 ± 5
24			StWtUp-3	65	80	70	71.7 ± 7.5
25			StWtUp-1	40	45	35	40 ± 5
26	Chloride	mg/L	StWtUp-2	45	40	50	45 ± 5
27			StWtUp-3	35	50	40	41.7 ± 7.5
28			StWtUp-1	60	65	55	60 ± 5
29	Nitrate	mg/L	StWtUp-2	65	60	70	65 ± 5
30			StWtUp-3	55	70	60	61.7 ± 7.5
31			StWtUp-1	10	12	8	10 ± 2
32	Phosphate	mg/L	StWtUp-2	12	10	14	12 ± 2
33			StWtUp-3	8	14	10	10.7 ± 3
34			StWtUp-1	0.60	0.65	0.55	0.60 ± 0.05
35			StWtUp-2	0.65	0.60	0.70	0.65 ± 0.05
36			StWtUp-3	0.55	0.70	0.60	0.62 ± 0.07

Note: Sample label connotation: StWtUp = Stream water Upstream, StWtDn = Stream water Wet season Downstream, StDrUp = Stream water Dry Season Upstream, and StDrDn = Stream water Dry Season Down stream

Table 9. Rotated Factor Loadings of the Extracted Three (3) Factors.

	Factor		
	1	2	3
Lead	.821	-.529	-.162
Cadmium	.901	-.410	-.122
Chromium	.816	-.460	-.302
Copper	.857	-.433	-.275
Zinc	.793	-.502	-.226
Arsenic	.880	-.332	-.330
Mercury	.875	-.270	-.377
pH	-.421	.889	.157
Temp	-.515	.833	.061
Conductivity	-.633	.636	.309
TDS	-.644	.629	.298
Turbidity	-.512	.639	.545

	Factor		
	1	2	3
Calcium	-.245	.584	.445
Magnesium	-.053	.131	.618
Chloride	-.329	-.078	.949
Nitrate	-.267	.342	.744
Phosphate	-.497	.859	.103

The rotated factor matrix in Table 9 reveals how the variables are grouped into three distinct factors based on their relationships, with higher factor loadings indicating stronger associations.

Factor 1 is strongly associated with heavy metals, including lead, cadmium, chromium, copper, zinc, arsenic, and mercury, all of which exhibit high positive loadings. This grouping suggests these metals share common sources, likely linked to anthropogenic activities such as industrial discharge, agricultural practices, or mining.

Factor 2 primarily represents physicochemical properties of the water, with strong positive loadings observed for pa-

rameters such as PH, temperature, conductivity, total dissolved solids (TDS), turbidity, phosphate, and calcium. These variables appear to interact closely, reflecting the general water quality influenced by both natural conditions and environmental inputs.

Factor 3 is defined by ionic and salinity-related constituents, with strong loadings for chloride, nitrate, and magnesi-

um. This factor likely reflects geological influences or salinity contributions from runoff or other natural processes.

In summary, the analysis highlights three key dimensions of water quality in the study area: heavy metal pollution (Factor 1), general physicochemical conditions (Factor 2), and salinity/ionic content (Factor 3).

Table 10. Seasonal Variations in Water Quality Parameters for Dry and Wet Seasons.

	Season	N	Mean	Std. Deviation	Std. Error Mean
Heavy Metals	Dry Season	18	-.2477553	.78365757	.18470986
	Wet Season	18	.2477553	1.14936805	.27090865
Physiochemical conditions	Dry Season	18	.8606064	.52342319	.12337203
	Wet Season	18	-.8606064	.49162168	.11587634
Salinity/ionic content	Dry Season	18	-.2803208	.77583694	.18286652
	Wet Season	18	.2803208	1.11550716	.26292756

Table 10 reveals that the mean value of heavy metals is negative in the dry season (-0.2478) but positive in the wet season (0.2478), indicating higher heavy metal concentrations during the wet season. This seasonal increase could be attributed to runoff from agricultural or industrial sources during rains. The mean of physiochemical conditions is significantly positive in the dry season (0.8606), reflecting more stable and favorable physicochemical conditions. In contrast, the mean is negative in the wet season (-0.8606), indicating potential dilution effects or disturbances due to rainwater inflow. The mean of salinity/ionic content is negative during

the dry season (-0.2803) and positive during the wet season (0.2803), showing increased salinity and ionic contributions in the wet season, possibly due to runoff carrying dissolved salts.

In summary, the wet season exhibits higher heavy metal and salinity levels but poorer physicochemical conditions, reflecting the influence of runoff and rainwater mixing. The dry season, on the other hand, has more stable physicochemical conditions but lower concentrations of heavy metals and salts.

Table 11. t-Test to Compare Seasonal Variations.

	t	DF	Sig. (2-tailed)	Mean Difference	Std. Error Difference
Heavy Metals	-1.511	34	.140	-.49551050	.32788600
physicochemical conditions	10.169	34	.000	1.72121272	.16925715
salinity/ionic content	-1.751	34	.089	-.56064150	.32026718

Table 11 indicates no significant seasonal difference in heavy metal concentrations, with the p value of 0.141. The mean difference of 1.7212 and p value of 0.000 show that physicochemical conditions are significantly better during

the dry season, compared to the wet season. There is no significant seasonal difference in salinity or ionic content, with the p value of 0.090.

Table 12. Locational Variations in Water Quality Parameters for Dry and Wet Seasons.

Parameter	location	N	Mean	Std. Deviation	Std. Error Mean
Heavy Metals	Upstream	18	-.7706881	.58178767	.13712867
	Downstream	18	.7706881	.68474671	.16139635
physicochemical conditions	Upstream	18	.0540697	1.18929177	.28031876
	Downstream	18	-.0540697	.81454216	.19198943
salinity/ionic content	Upstream	18	.5294000	.94179291	.22198272
	Downstream	18	-.5294000	.72952612	.17195096

Table 12 highlights locational variations in water quality parameters (heavy metals, physicochemical conditions, and salinity/ionic content) at upstream and downstream locations. The mean concentration for heavy metal is significantly negative upstream (-0.7707), indicating lower heavy metal levels, while downstream the mean is positive (0.7707), suggesting higher concentrations. The mean value of physicochemical

conditions is slightly positive upstream (0.0541), indicating marginally better physicochemical conditions, while downstream it is slightly negative (-0.0541), implying a slight decline in quality. The mean value salinity/ionic content is positive upstream (0.5294), indicating higher salinity and ionic content, while downstream it is negative (-0.5294), suggesting reduced levels.

Table 13. t-Tests Comparing Location Variations.

	t	DF	Sig. (2-tailed)	Mean Difference	Std. Error Difference
Heavy Metals	-7.278	34	.000	-1.54137621	.21178539
physicochemical conditions	.318	34	.752	.10813931	.33976249
salinity/ionic content	3.771	34	.001	1.05880005	.28079077

Table 13 reveals that heavy metals, with t-value of -7.278 and a p-value of 0.000 have a highly significant difference in locations. The negative mean difference of -1.5414 suggests that heavy metal concentrations are significantly higher downstream compared to upstream, possibly due to runoff or anthropogenic activities accumulating pollutants downstream.

In contrast, physicochemical conditions exhibit no significant locational variation, as evidenced by a t-value of 0.318 and a p-value of 0.752. The mean difference of 0.1081 is minimal, indicating similar physicochemical characteristics between upstream and downstream locations.

For salinity and ionic content, the t-value of 3.771 and a p-value of 0.001 demonstrate a significant difference between locations. The positive mean difference of 1.0588 indicates that salinity and ionic content are higher upstream, likely due to geological influences or reduced dilution effects compared to downstream. Heavy metal concentrations are significantly higher downstream, salinity/ionic content is significantly higher upstream, and physicochemical conditions remain consistent across locations.

4. Conclusion

The study of water quality in the Shetiko River reveals critical insights into its seasonal and locational variations, emphasizing the challenges posed by pollution and the need for sustainable management of this vital resource. Three key dimensions of water quality in the Shetiko River are highlighted in the study: heavy metal pollution, general physicochemical conditions, and salinity/ionic content. Heavy metal pollution, strongly associated with industrial and agricultural activities, exhibits seasonal and locational variations. Concentrations are significantly higher during the wet season due to runoff and downstream due to pollutant accumulation, as evidenced by a significant negative mean difference in heavy metals between upstream and downstream locations ($t = -7.278$, $p = 0.000$).

Physicochemical conditions, representing parameters such as PH, temperature, and turbidity, are more stable and favorable during the dry season, with a significant seasonal difference ($t = 10.169$, $p = 0.000$). However, they show minimal

variation between upstream and downstream locations, indicating relatively uniform physicochemical characteristics across the river.

Salinity and ionic content, influenced by geological and climatic factors, are significantly higher upstream, likely due to reduced dilution and natural mineral contributions. This locational variation is statistically significant ($t = 3.771$, $p = 0.001$), but seasonal differences are less pronounced. The findings highlight the critical need for implementing targeted strategies to manage and improve water quality effectively. Upstream areas require monitoring to address salinity and ionic content, while downstream areas need interventions to mitigate heavy metal pollution. Efforts to improve sanitation, enforce industrial wastewater regulations, and prevent agricultural runoff are critical to safeguarding the Shetiko River's water quality for its diverse uses. A comprehensive understanding of these dynamics is essential for sustainable water resource management, ensuring that the river continues to support human and ecological needs effectively.

Acknowledgments

The authors wish to express their gratitude to the Management of National Mathematical Centre (NMC), Abuja, Nigeria for the opportunity given to them to participate in the Research Oriented Course (ROC) in Multivariate Analysis & Applications.

Conflicts of Interest

The authors declare that there is no conflict of Interest.

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