



Seasonal Variations in Surface Water Quality in River Njoro and Lake Nakuru, Kenya

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Water pollution from rivers and lakes has resulted in serious environmental issues on a global scale. The public's growing concern over the decline in river and lake water quality makes it more important than ever to assess the water quality of these bodies of water over a prolonged period of time. During the rainy and dry seasons of 2022, 120 water samples were collected from 5 monitoring stations located within River Njoro and Lake Nakuru. The samples underwent physicochemical analysis of selected water parameters, which included salinity, temperature, pH, turbidity, total nitrogen (TN), total phosphorus (TP), electric conductivity (EC), and total dissolved solids (TDS). The results were compared using the National Environmental Management Authority (NEMA) of Kenya's guidelines and the results showed that the water quality of the Njoro river and Lake Nakuru fluctuated with the seasons, particularly in the lower water column of river Njoro. The

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quality parameters had the following values; EC values range between $73.33 \pm 0.55 \mu\text{s/cm}$ - $533.33 \pm 0.64 \mu\text{s/cm}$, respectively for both seasons; Salinity values range from $0.085 \pm 0.02 \text{ ppt}$ - $2.59 \pm 0.03 \text{ ppt}$; pH values were between 8.8 – 9.3; Temperature was $23.69 \pm 0.07 \text{ }^\circ\text{C}$ – $14.22 \pm 0.07 \text{ }^\circ\text{C}$; Turbidity varied significantly – $13.95 \pm 0.27 \text{ NTU}$ - $36.03 \pm 0.35 \text{ NTU}$; TDS between $46.67 \pm 0.11 \text{ ppm}$ - $243.33 \pm 0.04 \text{ ppm}$; TN ranges between $5.97 \pm 3.24 \text{ mg/L}$ - $8.57 \pm 3.18 \text{ mg/L}$ and TP 7.49 ± 1.7 - $9.41 \pm 1.84 \text{ mg/L}$ in the dry and rainy seasons, for River Njoro and Lake Nakuru respectively. This study showed that the degree to which human activity affects water quality varies with the season. Therefore, most of these factors should be considered while controlling rivers downstream in order to ensure the health of aquatic life, also it is essential to increase lake water quality monitoring and regulate human activity. Additionally, the results revealed that water pollution resulted primarily from domestic wastewater, agricultural runoff and industrial effluents.

Keywords: Kenya; lake; physicochemical parameters; river; water quality; environmental pollution.

1. INTRODUCTION

Water plays a very vital role in the existence of all living things. Human beings need water in running their day-to-day activities and with increase in population over the years, there is a growing water demand all over the world that has led to recent water shortages around the globe. There is a prediction that by 2030 global water demand be more than supply by 40% and also that 50% of nations in the sub-Saharan part of Africa most especially will suffer from water crisis [1]. In Kenya, water scarcity has resulted from limited access to water resources as a result of climate change, floods, forest degradation, insufficient rainfall, improper disposal of wastes, increase in human and animal population, improper management of available water resources which affects a large number of people who rely on water for agriculture and fishing [2,3]. Many rural households lack access to enough water for their daily need. Studies have been made on the current water status of Kenya and reports identified that Kenya is amongst water-scarce nations having water per capita availability of below 1000 m^3 yearly [3]. In the Njoro sub-county of Kenya, drinking water is obtained mostly by harvesting from rain, boreholes, springs, wells, and rivers [4,5]. These outlined sources are often contaminated through disposal of untreated liquid wastes from industries, leakages from sewage systems, run-offs from agricultural activities, and wastes from livestock. The water quality of a river is often determined by its physicochemical properties and is most likely than not affected by pollution which subsequently affects the food chain and in a more general note the whole ecosystem of the river. The pollution of a river and a lake requires a multidisciplinary study as it involves several

aspects in order to effectively manage and control it.

In Kenya, as cities and rural regions become more urbanized, home, industries and agricultural water use has increased as well [6]. This has resulted in declining water quality and subsequent water scarcity. However, addressing water scarcity is one of Kenya's priorities under Agenda 2030, therefore it complies with their regulations. The primary river feeding Lake Nakuru, the quality of river Njoro water status was examined in this study together with its effects on the aforementioned and the environment as a whole. The premise of the study is to improve the understanding of the quality of water directed towards the health of the freshwater ecosystem. This is essential because it affects how users and policymakers view the urgency of the water situation and the most effective courses of action. As future water solutions that will help with protecting and managing water resources, including river Njoro and Lake Nakuru, the rules and regulations put in place to ensure that water laws are followed and investigated further.

2. MATERIALS AND METHODS

2.1 Land Use and Land Cover (LULC)

The River Njoro watershed's water supplies have deteriorated as a result of the watershed's unstable environment and rapid population increase [7]. The Middle portion of the River Njoro watershed is constantly changing due to land use/land cover change (LULCC), endangering the people's capacity to feed themselves and their way of life. The need to conserve biodiversity is becoming more and more at odds with the need to advance economic

growth as a result of extensive competition between people and biodiversity [8]. Surface water quality has been negatively impacted by a confluence of unchecked industrial growth, dense infrastructure, urban migration, ineffective enforcement of environmental legislation, and ambiguous institutional responsibilities for water quality management [9]. Growing agricultural activity and human population have been proven to have both direct and indirect effects on riparian vegetation, such as biomass loss and water pollution [10]. According to [7] utilizing Landsat data for land cover classification shows that the watershed lost 20% or so of its wooded areas between 1986 and 2003. Large-scale agricultural and wooded lands have primarily been transformed into small-scale mixed agricultural and habitations. Pressure is placed on land use and land cover by the expanding socioeconomic needs and population [11]. This pressure causes unanticipated and unregulated changes in LULC [10], and changes have had a negative impact on the ecological integrity and hydrologic processes in the watershed in general and more specific on the water quality.

2.2 Study Area and Sampling Stations

The study was conducted at river Njoro to the Fisher's point in Lake Nakuru, Nakuru County, Kenya, illustrated in Fig. 1. The source of river Njoro is in Mau Forest and flows downstream into Lake Nakuru. River Njoro also known as river Ndarugu flows for about 60 kilometres from its source in the Eastern Mau Escarpment's native forests (2700-3000 meters above sea level) to its mouth at Lake Nakuru (1759 m above sea level). The river's long-term mean annual rainfall ranges from 1200 mm in the upper reaches to 800 mm at lake Nakuru, with peaks in April (largest), August (second largest), and November (smallest) [12]. Lake Nakuru on the other hand is an alkaline lake on the southern outskirts of Nakuru town, in Kenya's rift valley, with a surface elevation of 1,754 meters (5,755 feet). It is protected by the Lake Nakuru National Park. The lake is located at 0.3667 south latitude and 36.0833 east longitude [13]. Lake Nakuru is fed by freshwater springs and five rivers namely: Njoro, Nderit, Larmudiak, Makalia, and Naishi in addition to direct rainfall and groundwater [14]. It is the heart of a well-known Kenyan national park

known for its exciting bird fauna (495 species), especially the large flock of lesser flamingos (*Phoeniconaias minor*). Since it is located in the Rift Valley, which has experienced unusual tectonic and volcanic activity, as well as climatic changes, the lake has undergone significant changes in recent geological epochs [14].

2.3 Field Collection and Laboratory Analysis

While total nitrogen and total phosphorus were examined in a laboratory, the other physicochemical characteristics of surface water samples, such as temperature, pH, electrical conductivity, total dissolved solids, and salinity, were evaluated in situ. For the points along the river Njoro (Logoman, Kenyatta, Nga'mbo, and the mouth of the river Njoro), a bottle sampler was used to collect triplicate composite water samples. A Schindler sampler was utilized for the fisher's point in Lake Nakuru. For all measures, the APHA 2012 methodology was followed [1]. In order to measure the pH, electrical conductivity, and TDS, a multi-probe meter (MW801, Milwaukee) was employed. On the other hand, a turbidity meter, an OHAUS ST10s salinity meter, and an insertion thermometer were used to test turbidity and salinity, respectively. All samples were transported to the lab in an ice chest for total nitrogen and total phosphorus analyses. The modified Kjeldahl method [15] was used to determine total nitrogen (TN), in which the sample were digested in sulfuric acid, ammonia, and distilled water before the excess acid was titrated. The water samples were filtered using a 47mm glass fibre filter (Whatman GF/A), and then the total phosphorus was calculated using the molybdenum blue-ascorbic acid method [15]. At each sampling location, the probes were washed with distilled water after use (APHA, 2012). Glass beakers were cleaned with distilled water and placed in an airtight container to prevent contamination [16]. The samples were immediately placed in airtight containers and maintained at 4°C in the refrigerator when they weren't being processed. All experimental procedures were conducted out in a lamina flow hood to prevent environmental contamination, and the procedure was finished as rapidly as feasible. All of this data was gathered between March and July of 2022.

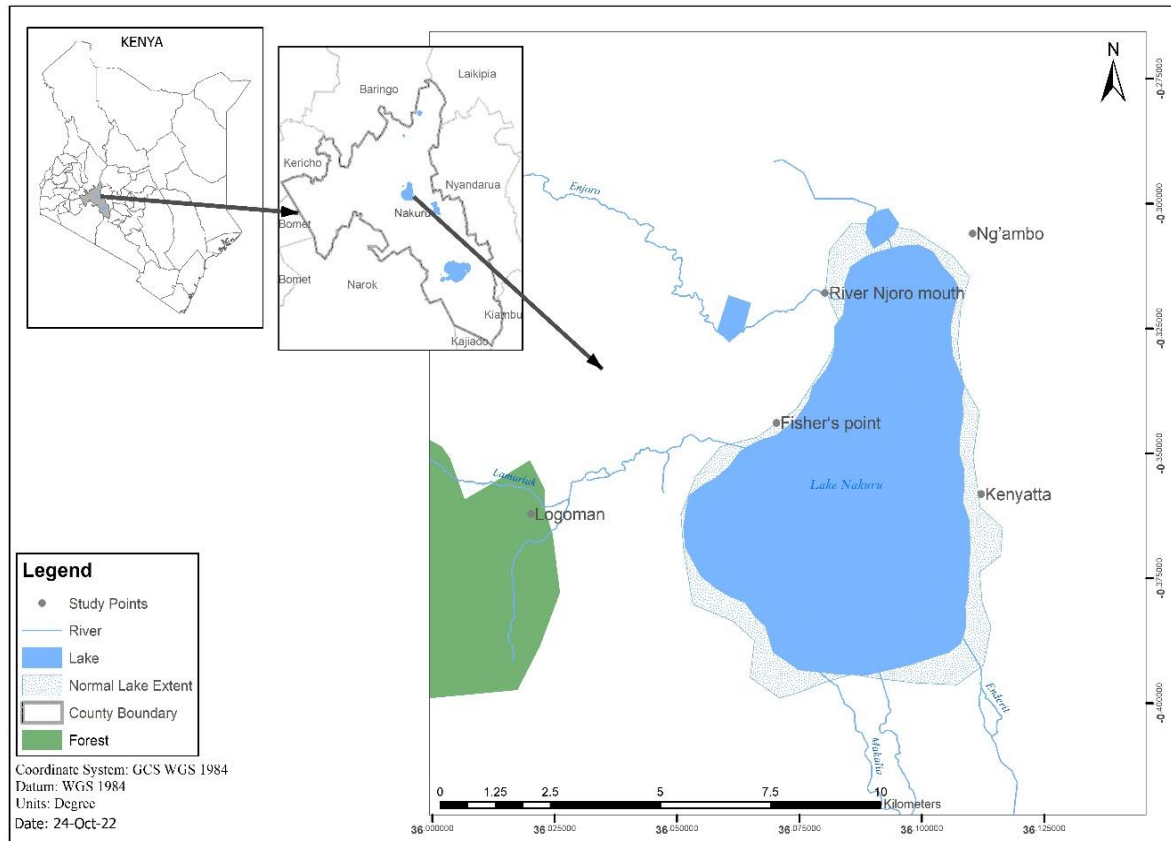


Fig. 1. Map of study area showing sample sites

3. RESULTS AND DISCUSSION

3.1 Results

Mean electrical conductivity levels recorded for sample points in river Njoro (Logoman, Kenyatta, Ng'ambo, and mouth of river Njoro) and fisher's point in Lake Nakuru was statistically significant (Tables 1 and 2). The highest mean electrical conductivity recorded in river Njoro was at the mouth of river Njoro with a value of $(533.33 \pm 0.64 \mu\text{s}/\text{cm})$ for the dry season and $(222.50 \pm 0.62 \mu\text{s}/\text{cm})$ in the rainy season. The lowest mean electrical conductivity still in the river ecosystem was recorded at Logoman station found within the Mau Forest with values of $(240.00 \pm 0.51 \mu\text{s}/\text{cm})$ and $(86.67 \pm 0.54 \mu\text{s}/\text{cm})$ for the dry and rainy seasons respectively.

The fisher's point in Lake Nakuru recorded significantly higher mean electrical conductivity in the dry season $(482.5 \pm 129.14 \mu\text{s}/\text{cm})$ than in the rainy season $(336.67 \pm 114.11 \mu\text{s}/\text{cm})$. The

trend of electrical conductivity is illustrated in Fig. 2.

The pH recorded from Logoman, Kenyatta, Ng'ambo, and mouth of river Njoro varied significantly amongst sample sites as seen in Table 1. The pH in river Njoro varied from sample sites with the highest pH recorded at the mouth of river Njoro 9.1 – 10.1 for the dry season and (9.4 – 9.8) in the rainy season whereas the least was recorded at Ng'ambo (7.9 – 8.4) in the dry season and (8.1- 8.5) in the wet season. The pH value recorded at Fisher's point Lake Nakuru were (9.3-9.4) in the rainy season and (9.7-9.8) in the dry season.

The mean value of salinity for mouth of river Njoro sample point was higher than all the other sample locations for the river ecosystem with the mean salinity in the dry season being $(2.53 \pm 0.02 \text{ ppt})$, and the rainy season $(2.59 \pm 0.03 \text{ ppt})$ whereas the least values were recorded in Kenyatta in the rainy season $(0.12 \pm 0.03 \text{ ppt})$ and Logoman in the dry season $(0.18 \pm 0.01 \text{ ppt})$ as seen in Table 1. The Fisher's point in Lake Nakuru had values $3.73 \pm 1.49 \text{ ppt}$ and $3.38 \pm$

1.44 ppt in the dry and rainy season respectively as can be seen in Table 2. Fig. 3 illustrates the salinity trend from upstream (Logoman) to midstream (Kenyatta), through downstream (mouth of river Njoro) and then finally into Lake Nakuru (Fisher's point).

The mean temperature showed significant differences between the sampling sites in river Njoro with mouth of river Njoro (downstream) being the warmest ($23.64 \pm 0.06^\circ\text{C}$) in the dry season and, ($23.69 \pm 0.07^\circ\text{C}$) in the rainy season

while Logoman (upstream) was recorded as the coldest with values of ($14.45 \pm 0.05^\circ\text{C}$) in the dry season and in the ($14.22 \pm 0.07^\circ\text{C}$) rainy season as seen in Table 2. Fisher's point at Lake Nakuru recorded ($23.69 \pm 3.71^\circ\text{C}$) in the dry season ($23.80 \pm 4.28^\circ\text{C}$) in the rainy season as seen in Table 2. The temperature recorded at Logoman, Kenyatta, and Ng'ambo and, the mouth of river Njoro were statistically different. Fig. 4 illustrates the temperature trend in sample points in river Njoro from upstream, midstream, downstream, and Lake Nakuru (Fisher's point).

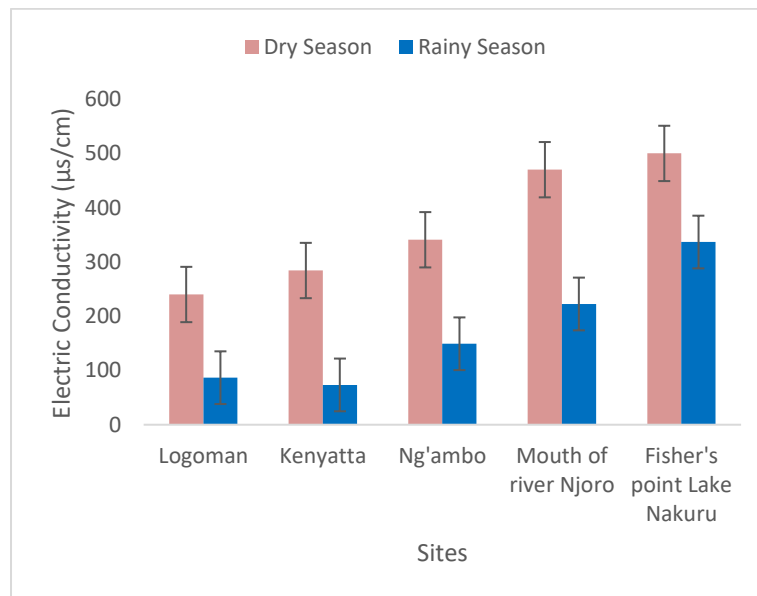


Fig. 2. Mean ± SE variations in EC for River Njoro and Lake Nakuru sample points

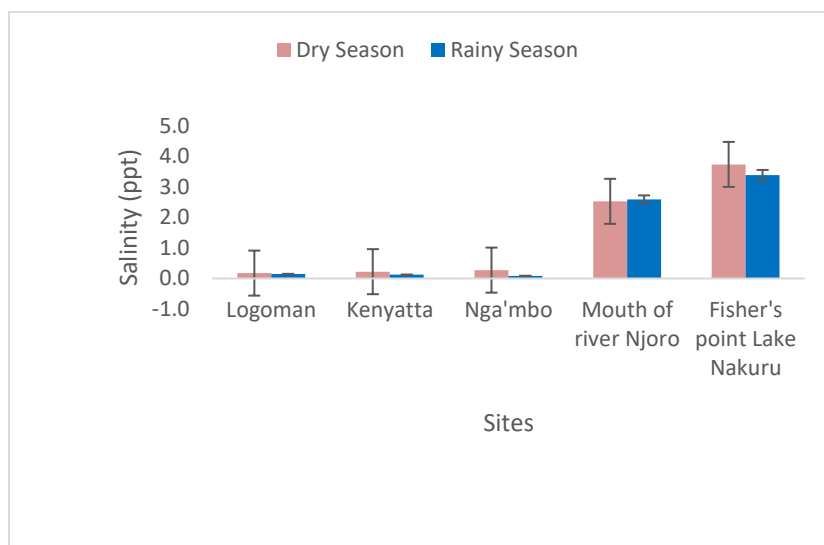


Fig. 3. Mean ± SE salinity for River Njoro and Lake Nakuru sample points

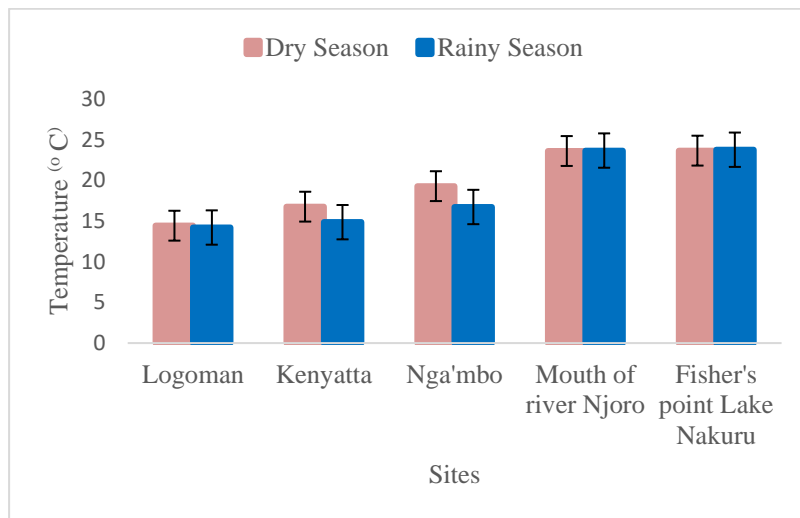


Fig. 4. Mean ± SE temperatures for River Njoro and Lake Nakuru sample points

The mean turbidity values recorded in Logoman, Kenyatta, Ng'ambo, and the mouth of river Njoro recorded exhibited significant differences between the sampled locations (Fig. 5). The highest turbidity levels were recorded at the mouth of river Njoro (23.48 ± 0.15 NTU) and (36.03 ± 0.35 NTU) for the dry and rainy seasons respectively, whereas the least was recorded at Logoman point (14.59 ± 0.12 NTU) and (13.95 ± 0.27 NTU) for the dry and rainy seasons respectively (Table 1). The Fisher's point in Lake Nakuru recorded (24.27 ± 3.81 NTU) for the dry season and (23.63 ± 18.66 NTU) for the rainy season (Table 2). Fig. 5 illustrates the turbidity trend for the sample points in river Njoro and Lake Nakuru.

The total dissolved solids (TDS) levels recorded in Logoman, Kenyatta, Ng'ambo, and mouth of river Njoro were found to be statistically different between seasons. The highest mean TDS value was recorded at the mouth of river Njoro (243.33 ± 0.04 ppm) for the dry season and (140.8 ± 0.09 ppm) for the rainy season while lowest recorded value was in Mau Forest at the Logoman point (120.83 ± 0.10 ppm) in the dry season and (46.67 ± 0.11 ppm) in the rainy season as seen in Table 1. Fisher's point in Lake Nakuru recorded (243.33 ± 25.57 ppm) in the dry season and (136.67 ± 19.72 ppm) in the rainy season. Fig. 6 illustrates the trend of TDS from upstream (Logoman), midstream (Kenyatta, Ng'ambo), downstream (mouth of river Njoro), and Fisher's point Lake Nakuru.

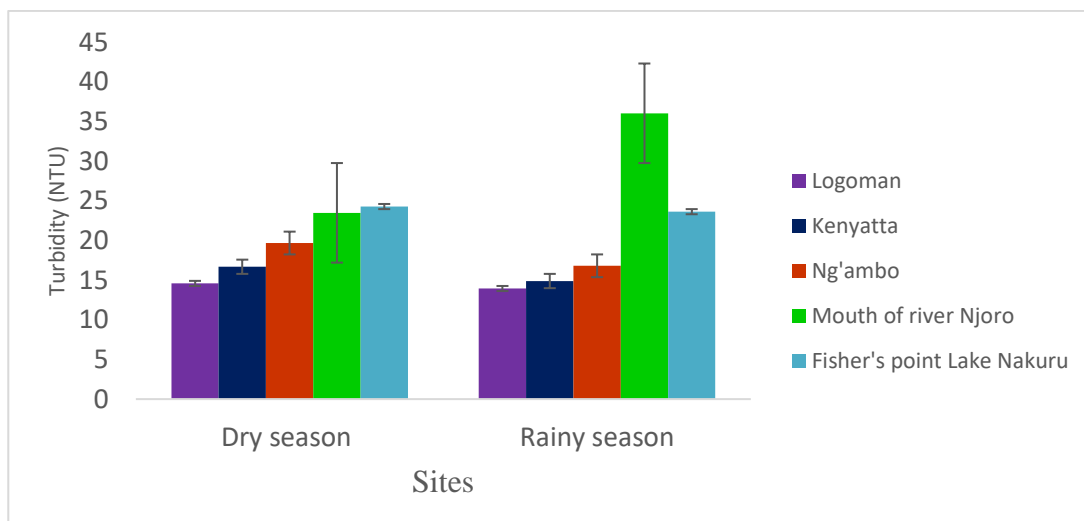


Fig. 5. Mean ± SE turbidity for River Njoro and Lake Nakuru sample points

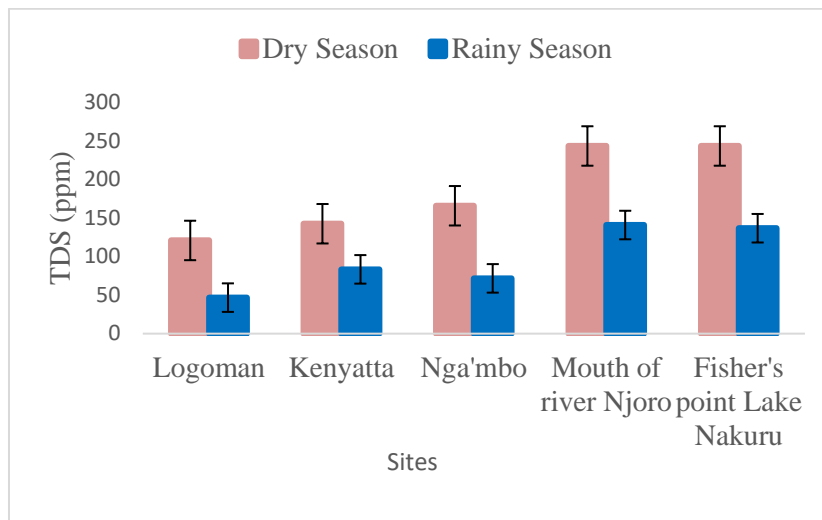


Fig. 6. Mean ± SE TDS for River Njoro and Lake Nakuru sample points

The total nitrogen (TN) levels recorded at Logoman, Kenyatta, Ng'ambo, and mouth of river Njoro were found to be statistically different between the dry and rainy seasons (Table 1). The highest TN levels were recorded at Logoman 8.57 ± 3.18 mg/L in the rainy season and 6.94 ± 3.75 mg/L in the dry season. The lowest levels were recorded at the mouth of river Njoro 6.41 ± 3.55 mg/L in the rainy season and at Ng'ambo 5.97 ± 3.24 mg/L in the dry season (Table 1). The Fisher's point Lake Nakuru (7.95 ± 0.94 mg/L) in the rainy season and (6.70 ± 0.72 mg/L) in the dry season. Fig. 7 illustrates the TN trend from river Njoro to Lake Nakuru.

Total phosphorus (TP) levels were significantly different between Logoman, Kenyatta, Ng'ambo and the mouth of river Njoro for both seasons. TP levels were high in the rainy season with the mouth of river Njoro recorded highest level 9.41 ± 1.84 mg/L and Logoman recorded the lowest level 7.49 ± 1.75 mg/L. While for the dry season, Logoman recorded the lowest level 7.57 ± 2.11 mg/L and Ng'ambo recorded the highest level 9.21 ± 1.75 mg/L as shown in Table 1. The Fisher's point in Lake Nakuru recorded in the dry 10.32 ± 1.07 mg/L and 15.13 ± 3.00 mg/L rainy seasons respectively.

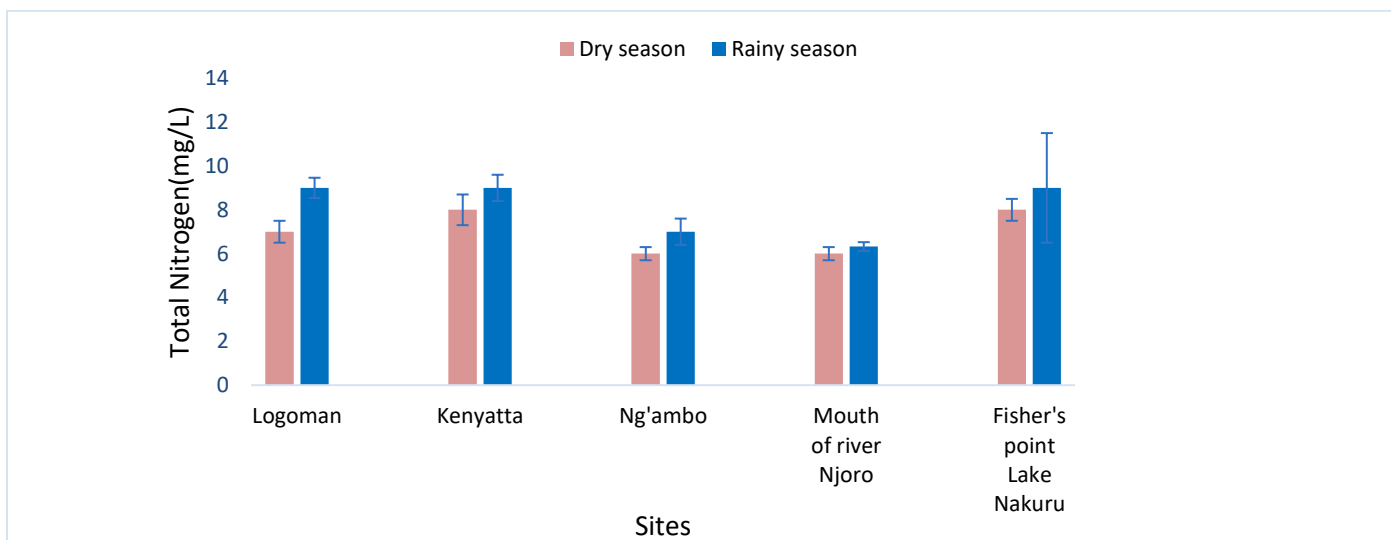


Fig. 7. Mean ± SE TN for River Njoro and Lake Nakuru sample point

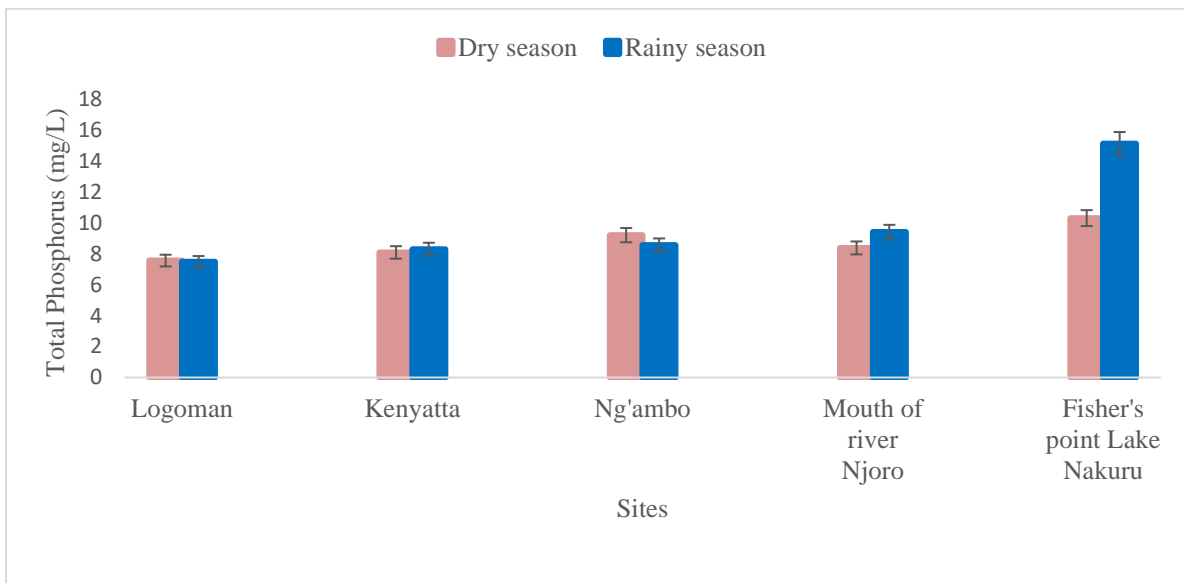


Fig. 8. Mean ± SE TP for River Njoro and Lake Nakuru sample points

3.2 Discussion

In comparison to past research, the conductivity range of 533-73 $\mu\text{s}/\text{cm}$ obtained in this investigation was generally low. The conductivity range found in this study was less than that found in previous investigations in the same lake, including (Ochieng et al., 2007). The different sample times, locations, and seasons may be to blame for the variations in conductivity levels found.

The high pH levels in Lake Nakuru are attributed to excessive nutrients entering the lake, degradation caused by deforestation, and inappropriate land use changes causing siltation [17]. Generally, salinity increases when no inflows of rainwater and so is the trend between sample sites with fisher's point Lake Nakuru recording the highest due to its saline nature.

In the principal component analysis (PCA), three principal components which were significant, both by the broken stick model and the randomization test are retained in the solution with Eigenvalue greater than 1 as shown in Table 3 below. It is observed that 49.70% of the variance is explained by the first component and is positively correlated to all the water parameters except TN which was negatively correlated. Component 2 and component 3 are not as dominant as component 1. The second component (explaining 17.3% of the variance) is negatively correlated to the TN and was not correlated with the pH. The third component (explaining 13.22% of the variance) is negatively

correlated to EC and not correlated to pH and TDS. The three components cumulatively explained 80.23% of the variance in the data as illustrated in Fig. 9.

In addition, with the increased population around the Lake, there is increased pressure on the waste disposal facilities, land, and soil fertility. This results in forest clearance and the inevitable use of pesticides and fertilizers by both small-scale farmers and large-scale horticultural farms [18]. These activities increase the nitrogen and phosphorus levels which are transported into Lake Nakuru through the inflow-rivers and especially during the heavy rains.

The sample points in river Njoro and Lake Nakuru, the surface water physicochemical parameters were found to have significant differences between the sampling locations along river Njoro and Lake Nakuru. These were attributed to the presence of water macrophytes and human activities, along the main inflow river (river Njoro) or around the lake. The high amounts of precipitation in the wet season affected some water parameters such as pH, and salinity, as a result of the dilution effect brought about by the high influx of freshwater. Similarly, although the total nitrogen and phosphorus levels were high above the WHO maximum permissible levels for water, the high concentrations recorded and mostly at the main inflow (mouth of River Njoro) into Lake Nakuru were attributed to anthropogenic activities such as waste disposal, and the intensive agricultural use of fertilizers and pesticide [19-23].

Table 1. Mean ± SE of water variables for River Njoro sample points

Parameter	Season	Logoman	Kenyatta	Ng'ambo	Mouth of River Njoro
EC (µs/cm)	Dry	240.00 ± 0.51	284.17 ± 0.53	340.83 ± 0.63	533.33 ± 0.64
	Wet	86.67 ± 0.54	73.33 ± 0.55	149.17 ± 0.62	222.50 ± 0.62
pH	Dry	7.9 – 10.1	8.4 – 8.5	7.9 – 8.4	9.1 – 10.1
	Wet	8.1 – 10.4	8.5- 8.7	8.1- 8.5	9.4 - 9.8
Salinity (ppt)	Dry	0.18 ± 0.01	0.22 ± 0.02	0.27 ± 0.01	2.53 ± 0.02
	Wet	0.14 ± 0.04	0.12 ± 0.03	0.085 ± 0.02	2.59 ± 0.03
Temperature oC	Dry	14.45 ± 0.05	16.79 ± 0.05	19.32 ± 0.08	23.64 ± 0.06
	Wet	14.22 ± 0.07	14.88 ± 0.06	16.75 ± 0.06	23.69 ± 0.07
Total Dissolved Solids(ppm)	Dry	120.83 ± 0.10	142.50 ± 0.07	165.83 ± 0.05	243.33 ± 0.04
	Wet	46.67 ± 0.11	83.33 ± 0.15	71.67 ± 0.03	140.8 ± 0.09
Turbidity (NTU)	Dry	14.59 ± 0.12	16.69 ± 0.18	19.68 ± 0.13	23.48 ± 0.15
	Wet	13.95 ± 0.27	14.89 ± 0.25	16.81 ± 0.33	36.03 ± 0.35
Total Nitrogen (mg/L)	Dry	6.94 ± 3.75	6.20 ± 3.68	5.97 ± 3.24	6.32 ± 3.19
	Wet	8.57 ± 3.18	7.96 ± 3.66	7.33 ± 3.98	6.41 ± 3.55
Total Phosphorus (mg/L)	Dry	7.57 ± 2.11	8.09 ± 1.17	9.21 ± 1.75	8.39 ± 2.99
	Wet	7.49 ± 1.75	8.31 ± 2.2	8.57 ± 2.69	9.41 ± 1.84

Table 2. Mean ± SE of water variables for Fisher's point, Lake Nakuru

Season	EC (µs/cm)	pH	Salinity (ppt)	Temperature oC	Total Dissolved Solids(ppm)	Turbidity (NTU)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)
Dry Season	482.5 ± 129.14	9.3 – 9.4	3.73 ± 1.49	23.69 ± 3.71	243.33 ± 25.57	24.27 ± 3.81	6.70 ± 0.72	10.32 ± 1.07
Wet Season	336.67 ± 114.11	9.7- 9.8	3.38 ± 1.44	23.80 ± 4.28	136.67 ± 19.72	23.63 ± 18.66	7.95 ± 0.94	15.13 ± 3.00

Table 3. Eigenvalues, variance explained, and factors loading of the three principal components

Component	Total Variance Explained								
	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.976	49.698	49.698	3.976	49.698	49.698	3.118	38.977	38.977
2	1.385	17.311	67.010	1.385	17.311	67.010	1.764	22.055	61.032
3	1.058	13.223	80.233	1.058	13.223	80.233	1.536	19.201	80.233
4	0.708	8.855	89.087						
5	0.477	5.958	95.046						
6	0.232	2.899	97.945						
7	0.117	1.464	99.409						
8	0.047	0.591	100.000						

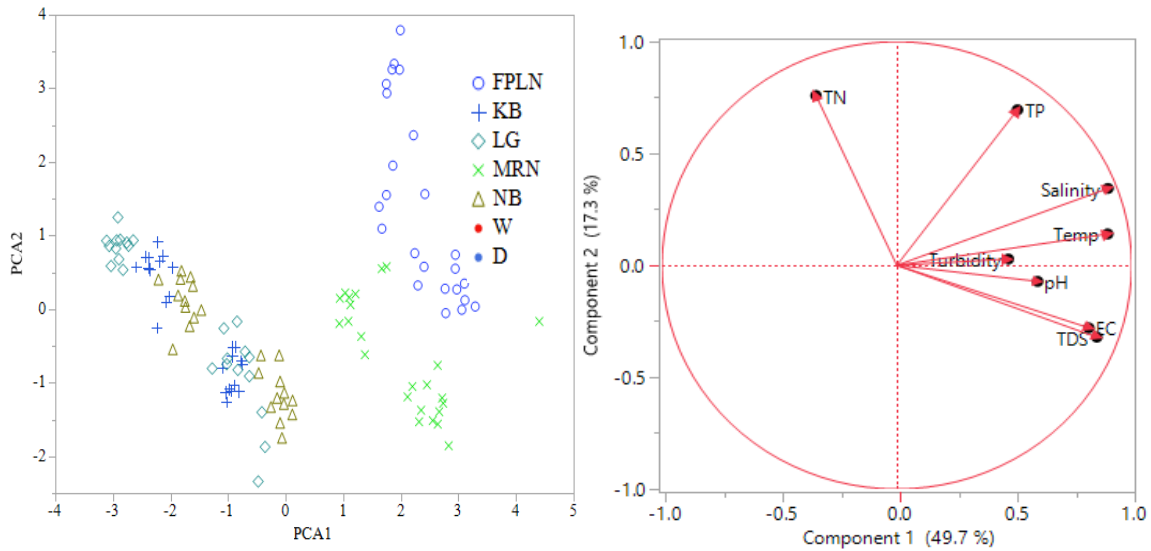


Fig. 9. PCA biplot (biplot shows both PC scores of samples and loadings of variables)

Table 4. Pearson correlation coefficients among the water parameters

	EC	pH	Salinity	Temp	TDS	Turbidity	TN	TP
EC	1							
pH	0.442**	1						
Salinity	0.627**	0.529**	1					
Temp	0.605**	0.370**	0.861**	1				
TDS	0.874**	0.485**	0.674**	0.638**	1			
Turbidity	0.185*	0.161	0.356**	0.567**	0.191*	1		
TN	-0.336**	-0.127	-0.013	-0.291**	-0.425**	-0.246**	1	
TP	0.221*	0.158	0.633**	0.522**	0.217*	0.172	0.151	1

** : $p < 0.01$, * : $p < 0.05$; EC: electrical conductivity; Temp: Temperature; TDS: total dissolved solids; TN: total nitrogen; TP: total phosphorus

According to Pearson correlational analysis, seasonal TDS is significant difference with $p < 0.05$ showed significant amongst water parameters as seen below in (Table 4). A relationship between TDS and turbidity was found, as TDS values increases, turbidity values also increase and vice versa. The values of total nitrogen and phosphorus varied significantly between the two seasons.

4. CONCLUSIONS

In this study, water quality parameters were measured over two seasons to examine the degree of water contamination along river Njoro and Lake Nakuru was assessed with the PCA. The findings showed that natural hydrologic processes, industrial effluents, home waste water, and agricultural runoff were the main causes of water contamination.

The significance of multivariate statistics for the analysis and interpretation of intricate water quality data sets was illustrated by this study. It also helps locate the origins of pollutants. The findings improve our knowledge of the seasonal fluctuations in river water systems' water quality. The water quality along the river followed the trend as follows; dry season > wet season with higher values recorded at Mouth of river Njoro and the lowest values recorded at Logoman point for the river system. Similarly, although the total nitrogen and phosphorus levels were high above NEMA maximum permissible levels for river and lake water, with high concentrations recorded mostly at the main inflow (mouth of River Njoro) into Lake Nakuru. The study recommends proper treatment, management and disposal of waste into the river which eventually flows into the lake, this will reduce the level of water contamination, and furthermore it will decrease the degradation of the River Njoro and Lake Nakuru systems.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available upon request from the corresponding author.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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