SEASONAL ASSESSMENT OF WATER QUALITY OF RIVER OSUN USING WATER QUALITY INDEX

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ABSTRACT

This paper considered Fourteen (14) water parameters for the Osun river quality assessment and water quality index (WQI) tool to classify it and to see if it required treatment before usage. Samples from three different points were collected in November, 2022, April and July 2023 representing dry and wet seasons, respectively, and in accordance with American Public Health Association, APHA (Publications on standard methods for the examination of water and wastewater, pp 123–189, 2005) standard procedures. Most of the parameters were within maximum permissible limits of the World Health Organization (WHO), Food and Agriculture Organization (FAO) and Nigeria Standards for Agricultural use water with the exception of total dissolved solid, turbidity, electrical conductivity and total coliform in both seasons. The water quality of the river is generally poor with exception at a few sampling stations during the dry season. The average pH values were found to be within the permissible limit and fall within the standard expected. In this study, EC (in µS/cm) values varied from 115 to 232 µS/cm with a mean value of 156.44 µS/cm in the dry season and varied from 228 to 367µS/cm with a mean value of 281.5556 µS/cm in the wet season. EC values of all the water samples recorded are below 750 µS/cm, which is in compliance with both WHO value and FAO regulation and thus indicate good quality of irrigation water. The box and whisker plots of the water revealed that pH, acidity, EC, TA, Ca, Mg, Cl, carbonates, phosphates and nitrates have almost the same trend. These parameters do not vary significantly along the sampling stations at different sampling locations within the study area. The magnesium hazard values of all the samples during the sampling periods have values below the permissible limit and, therefore, considered *suitable for irrigation purpose. Overall, the water of Osun River is good for industrial and agricultural purposes.*

***Keywords*:** Water Quality, Osun River, Pollution, Water Quality Index.

Introduction

Water pollution is the contamination of water bodies, usually as a result of human activities, in such a manner that negatively affects its legitimate uses. Mateo-Sagasta *et al*., (2017) explained water pollution as a global challenge that has increased in both developed and developing countries, undermining economic growth as well as the physical and environmental health of billions of people. Human settlements, industries, and agriculture are the major sources of water pollution. Globally, 80 percent of municipal wastewater is discharged into water bodies untreated, and industry is responsible for dumping millions of tonnes of heavy metals, solvents, toxic sludge, and other wastes into water bodies each year ((Sonone, et al., 2020; Karri et al., 2021; Tariq & Mushtaq 2023). Agriculture, which accounts for 70 percent of water abstractions worldwide, plays a major role in water pollution. Farms discharge large quantities of agrochemicals, organic matter, drug residues, sediments, and saline drainage into water bodies. The resultant water pollution poses demonstrated risks to aquatic ecosystems, human health, and productive activities (Bashir *et al*., 2020; Häder *et al*., 2020). Osun river is an important source of domestic and agricultural uses in Osogbo and its environs (Anifowose *et al*., 2023). The river receives and transport untreated domestic and industrial wastes from settlement and industries located along the river course. Due to its strategic location within the two zones and availability for agricultural purposes, industrial and commercial consumption, the river has witnessed tremendous change in quality as a result of both human and industrial wastes. According to Akinsete & Ajala (2022), the polluting industries such as chemical complexes, fish processing plants, steel and paper mills, rayon mill complexes, cement factories, paint and dye manufacturing plants, several soap and detergent factories and a number of light industrial units directly discharge untreated toxic effluent in to the water bodies. Besides, the release of untreated toxic effluents are the major sources of heavy metals in any aquatic ecosystem. Unfortunately, very little research has been conducted to assess the level of metal pollution of the Osun River mainly in Osogbo including its biotic resources, sediment and water quality. The site of study is at Osogbo where the mystic belief of Osun river goddess is proposed to have emerged and also celebrated yearly as the culture and heritage of indigenes till date (Amusa 2019).

According to Olajire and Imeokparia (2001) who studied heavy metal concentrations and physico-chemical properties of Osun River, there were reports of high pollution with Pb, Cd, Ni, Cr, Zn, cyanide ion, and ammonia which were mainly from farming, industrial activities, and domestic discharges into this river. Equally, Wahab *et al*. (2012) reported a high occurrence of pathogenic organisms in the river which could be a result of unregulated activities such as defecating into the river. Due to the significance of this river as an international cultural heritage as well as a national monument and its usefulness for both recreational and religious activities, there is a need to assess the environmental impact of river water pollution in Osun River in Osun State. And specifically, the study sought to achieve the following objectives: 1. to carry out physiochemical and microbial (bacteriological assay) analyses of water samples obtained from River Osun, and 2. to ascertain the suitability of River Osun for municipal and agricultural use using the water quality index

Materials and Methods

3.1 Description of the Study Area

Osun State is an inland state in South-Western Nigeria. Its capital is Osogbo. It is bounded in the North by Kwara State, in the East partly by Ekiti State and partly by Ondo State, in the South by Ogun State and in the West by Oyo State. The Osun river (sometimes, spelt Oshun) is a river that flows southwards through Yoruba land in southwestern Nigeria into the Lagos Lagoon and the Atlantic Gulf of Guinea. It is one of the several rivers ascribed in local mythology to have been women who turned into flowing waters some traumatic event frightened or angered them. According to Anifowose & Oyebode (2019), "Osun River originates from Igede-Ekiti (in Ekiti State) and flows southwards through Southwestern Nigeria into the Lagos lagoon and the Atlantic Gulf of Guinea. Before flowing across Osogbo town in Osun State, the river meanders through many rainforests, farmlands and villages". The river flows across the southern part of Osogbo city (Figure 1) and houses various fauna, especially catfish which are trapped and sold by local fishermen. According to 2006 population census, Osogbo has a population of 156,694 with an average annual rainfall of 350 mm (Anifowose & Oyebode, 2019).

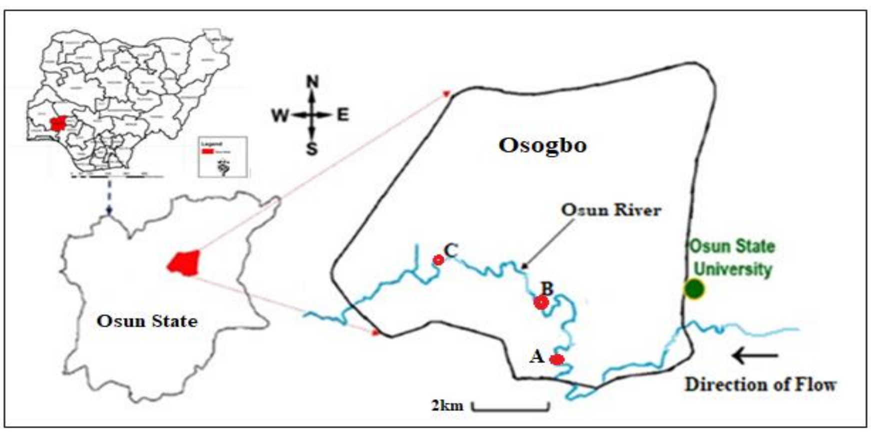

Figure 1: Location of Study area shown the Sampling Points, A, B, C.
Source: Anifowose & Oyebode (2019).

Water Sampling

Three sampling locations in this study were designated as A, B, and C as shown in Figure 1. Location A represents a sampling point about 1 km from Fountain University, where location B represents a sampling point B about 300 m from Osun State University College of Health, Osogbo. Location C represents a sampling point about 350 m from Ebunoluwa International School, Osogbo. Sampling was done in both dry and wet seasons covering November 2022 and July 2023. Three water samples were collected from each sampling point for each sampling period in both dry and wet seasons along the river course. For Sampling location A, the three samples were labeled A1, A2, and A3. Samples collected at sampling location B were labeled BI, B2 and B3 while that of sampling location C were labeled C1, C2 and C3.

At each sampling location, water samples were collected in polythene bottles for the determination of physic-chemical properties of water samples. All the sampling polythene bottles were washed with non-ionic detergent and rinsed with deionized water prior to sample collection. Before the final water sampling were done, the polythene bottles were rinsed three times with the river water at the point of collection. The sample bottles were labeled according to sampling locations. All samples were then preserved at 4 ^{o}C and transported to the laboratory for analyses.

Laboratory Analysis

The physico-chemical analyses of the selected water quality parameters were conducted following standard analytical methods (APHA 1992). The important parameters that are of interest in this study are; colour, pH, Total Hardness, Calcium, Magnesium, Total Alkalinity, and Electrical Conductivity, Phosphate, Nitrates, and Manganese. These are important parameters in evaluating the degree of pollution and indices of self-purification of a river body, according to Tyagi *et al*., (2013). Results of laboratory analyses were subjected to data evaluation by standard statistical methods (Chapman 1992). The modified Streeter-Phelps shall be used to predict the dissolve oxygen at critical point, the critical point, the critical time, the DO at inflection, and the time at inflection. The biological, chemical and physical properties of the water samples shall also be analyzed for.

Physicochemical Analysis

The analyses of various physical and chemical parameters such as pH, Total Hardness, Calcium, Magnesium, Total Alkalinity, Electrical Conductivity, Phosphate, Nitrates, and Manganese were carried out according to descriptions by APHA (1992).

Water Quality Index Calculation

In calculating the WQI, the weighted arithmetic index method was applied to assess water suitability for drinking purposes. In this method, water quality rating scale, relative weight, and overall WQI were calculated using the following formular.

$q_i = \left(\frac{C_i - C_{id}}{S_i - C_{id}} \right) \times 100$

1

Where q_i, C_i, S_i and C_{id} indicate quality rating scale, concentration of I_{th} parameter, standard value of I_{th} parameter and ideal concentration of I_{th} parameter respectively. C_{id} is zero for all parameters except in PH and BOD with a value of 7.0 and 14.6 mg/l respectively.

Unit weight was then derived as;

$w_i = k / S_i.$

2

Where the standard value of the I_{th} parameter is inversely proportional to the unit weight.

K is a constant value calculated as; k = $\frac{1}{\sum_i^n \frac{1}{S_i}}$, where n represents number of parameters considered for analysis.

Overall WQI is then calculated as;

WQI = $\sum_{i=1}^{n} q_i w_i / \sum_{i=1}^{n} w_i.$

3

The Table 1 below gives a description of classification of water quality based on Weighted Arithmetic Water Quality Index method due to Brown et al (1972), Rana & Ganguly (2020).

Table 1: Classifications in Water Quality index

WQI	STATUS
0-25	Excellent
26-50	Good
51-75	Poor
76-100	Very Poor
Above 100	Unsuitable for drinking

Results

Physiochemical and microbiological analyses of water sample

The physiochemical and microbial (bacteriological) parameters such as pH, total hardness, calcium, magnesium, total alkalinity, and electrical conductivity, phosphate, nitrates, and manganese and organic matter, were analyzed for the water samples collected from the Osun River. The samples were taken from three different sites during different months of the year. The results of the physiochemical and bacteriological analyses of the water sample obtained from River Osun were presented in Tables 2 to 4. Table 2 presents the results of analyses obtained from November 2022 sampling in the study area which represents the dry season sampling. Both Tables 3 and 4 present the results of the analyses in the months of April and July 2023 respectively. These represent the rainy season sampling. Each table will show different periods of sample collection and will be categorized under the dry season and wet season.

Table 2: Water Quality Analyses for November 2022

S/ID	°C	Ph	EC µS/cm	TA mg/l	TH mg/l	Ca mg/l	Mg mg/l	Cl mg/l	COD mg/l	BOD mg/l	PO4 mg/l	NO3 mg/l	HCO3 mg/l	Fe mg/l	Mn mg/l
A1	32.3	6.89	121	40	52	14.29	3.98	7.84	6.65	4.2	0.16	3.55	18.04	2.33	0.58
A2	32.8	6.75	117	56	56	10.93	7.00	7.36	6.80	4.6	0.22	3.38	26.29	2.52	0.62
A3	32.9	6.86	118	50	54	12.61	5.49	7.44	6.62	4.0	0.16	3.62	23.20	2.38	0.55
B 1	33.2	6.55	123	46	64	11.78	8.44	9.28	7.45	3.5	0.12	3.84	21.13	2.74	0.38
B 2	33.2	6.61	118	42	70	11.77	9.91	9.56	6.91	3.8	0.08	3.40	19.07	2.69	0.41
B 3	32.9	6.58	139	40	62	13.46	6.92	9.32	7.70	3.6	0.08	3.93	18.04	2.46	0.36
C1	31.3	7.44	116	52	56	12.61	5.98	9.18	6.38	4.4	0.11	3.35	26.28	1.88	0.64
C2	31.6	7.28	115	42	62	11.77	7.95	9.24	6.41	4.6	0.13	3.26	19.07	1.92	0.61
C3	32.0	7.46	116	40	58	10.93	7.49	8.96	6.35	4.4	0.15	3.22	18.04	1.84	0.66

From Table 2, the pH values of the sample collected in November, during the dry spell range from 6.5 to 7.46. The highest electrical conductivity EC, recorded during this period was 139 µS/cm which is far below the permissible. The same goes with all other parameters in the collected river water samples.

Table 3: Water Quality Analyses for April 2023

S/ID	°C	pH	EC µS/cm	TA mg/l	TH mg/l	Ca mg/l	Mg mg/l	Cl mg/l	COD mg/l	BOD mg/l	PO_4 mg/l	NO_3 mg/l	HCO_3 mg/l	Fe mg/l	Mn mg/l
A1	27	6.95	164	48	68	15.14	7.37	21.56	9.72	3.50	0.19	5.22	22.16	2.22	0.54
A2	27	6.42	188	54	56	14.30	4.95	22.54	8.80	4.80	0.18	5.22	25.26	2.38	0.51
A3	27	6.45	182	52	54	15.98	3.44	19.60	8.35	4.00	0.15	5.20	24.22	2.54	0.54
B1	26	6.71	204	42	60	15.14	5.42	32.34	9.13	3.00	0.13	3.19	19.07	2.78	0.46
B2	26	6.64	232	36	70	16.82	6.83	39.20	9.25	3.00	0.12	3.17	15.98	3.16	0.52
B3	27	6.70	224	44	62	11.77	7.95	33.32	9.56	3.40	0.16	3.20	20.10	2.74	0.48
C1	26	6.30	176	48	66	12.61	8.42	22.54	11.74	5.60	0.21	5.62	22.16	3.38	0.52
C2	26	6.20	178	40	72	15.14	8.35	27.44	11.36	5.60	0.22	5.48	18.04	2.92	0.48
C3	26	6.35	185	54	72	16.82	7.27	42.14	13.20	5.80	0.27	5.61	25.26	3.26	0.48

Table 3 represents the results of the sampling at the onset of the rainy season. The pH values of the sample collected in April, 2023, range from 6.20 to 6.95, which is more of acidic in nature. The highest electrical conductivity recorded during this period was 232 µS/cm which is higher than that obtained in the previous sampling, yet far below the permissible of 400 µS/cm. The higher value of electrical conductivity recorded could be attributed to more pollutants washed into the river by runoff. Almost all the parameters experienced an increase in the concentration of the parameter, particularly COD and the phosphates and nitrates. These are attributed to more pollutants in the river due to the rainy period.

Table 4: Water Quality Analyses for July 2023

S/ID	°C	pH	EC µS/cm	TA mg/l	TH mg/l	Ca mg/l	Mg mg/l	Cl mg/l	COD mg/l	BOD mg/l	PO4 mg/l	NO3 mg/l	HCO3 mg/l	Fe mg/l	Mn mg/l
A1	30	6.72	236	44	62	23.10	9.49	56.62	15.38	4.80	0.44	3.98	20.10	5.11	0.38
A2	30	6.87	259	42	54	29.42	6.80	67.54	13.72	5.30	0.36	3.56	19.07	3.68	0.42
A3	28	6.84	248	42	62	31.50	7.26	68.53	15.68	5.00	0.28	4.18	19.05	4.92	0.45
B1	29	6.73	311	42	52	35.76	3.87	25.80	12.26	6.20	0.32	3.33	19.22	6.72	1.22
B2	29	6.35	367	54	48	42.00	2.46	34.77	12.77	5.80	0.26	3.62	25.13	6.48	1.19
B3	29	6.38	344	46	54	37.86	3.95	28.86	13.42	5.80	0.30	3.18	21.93	6.65	1.36
C1	31	6.78	228	42	58	39.94	4.40	65.50	17.38	6.00	0.42	3.35	19.07	5.19	0.62
C2	30	6.73	253	42	62	39.96	5.46	99.38	18.05	6.70	0.45	3.61	19.07	6.49	0.69
C3	31	5.97	288	40	92	46.20	11.20	129.12	17.88	6.30	0.42	3.48	13.04	6.22	0.65

Table 4 presents the results of the sampling obtained during the rainy season in July 2023. The pH values of the sample collected in April 2023, range from 5.97 to 6.87, which is more of acidic in nature compared to the previous sampling. The highest electrical conductivity recorded during this period was 367 µS/cm which is higher than those obtained in the two previous samplings of November 2022 and April 2023, yet far below the permissible of 400 µS/cm. The influence of precipitation is being felt in the results as an increase in the values of electrical conductivity could be as a result of more pollutants washed into the river by runoff. Almost all the parameters experienced an increase in the concentration of the parameter, particularly COD. Figure 2 presents the graphical illustration of variation of WQI values for different sampling periods and locations (Points). The figure revealed that the highest WQI values were obtained in the month of July 2023 at all sampling points A, B, and C which represented the rainy session.

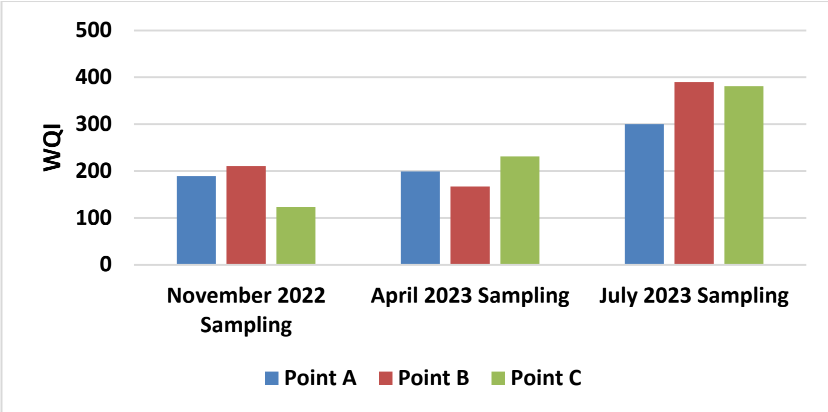

Figure 2: Comparison of WQI Values for the Sampling Periods of November 2022, April 2023 and July 2023

pH generally signifies the degree of acidity or alkalinity of a water sample. Although the average pH value of 6.69 was within the prescribed limits, however, the minimum pH value of 5.97 was below the prescribed limit, i.e., 6.5–8.5. Electrical conductivity measures the electric current carrying capacity of a water sample and is directly related to the dissolved ions present in the water. The EC, which indirectly signifies the concentration of salt content in water, is an important parameter for evaluating the suitability of water for irrigation purposes. Generally, water of EC less than 2250 µS/cm is considered suitable for all irrigation purposes, with a few exceptions, e.g. very sensitive crops and highly clayey soil according to Haritash *et al*. (2016). Water is classified into three categories based on the electrical conductivity (EC) values: (1) no problems (< 700 µS/cm); (2) gradual increasing problems from the continuous use of water (700–3000 µS/cm) and (3) immediate development of severe problems (> 3000 µS/cm) (FAO 2008). The ideal value of EC considered by Richards is less than 750 µS/cm (Shil *et al*., 2019). In this study, EC (in µS/cm) values varied from 115 to 232µS/cm with a mean value of 156.44 µS/cm in the dry season and varied from 228 to 367µS/cm with a mean value of 281.5556 µS/cm in the wet season. EC values of all the water samples recorded are below 750 µS/cm, which is in compliance with both WHO value and FAO regulation and thus indicate good quality of irrigation water.

Chloride is a significant WQ parameter that is commonly dispersed in nature as sodium (NaCl), potassium (KCl), and calcium ($CaCl_2$) salts. Various sources of chloride in water include weathering of various rocks, surface run-off from inorganic fertilizer-dependent agricultural areas, irrigation discharge, animal feeds, and so on. During the dry season, the average chloride concentration in the water samples tested ranged from 7.36 to 42.17 mg/L. During the wet season, the chloride concentration fluctuated from 25.8 to 129.12 mg/L. The detected chloride values for river water were well within the acceptable limit of 155 mg/L.

Phosphorus in rivers and lakes is generally caused by sewage effluent (mostly from water industry sewage treatment works) and agricultural land losses. Food waste, food and drink additives, and P dosing of drinking water all contribute to phosphorus loadings in sewage. Human and animal waste, phosphorus-rich bedrock, laundry and cleaning wastewater, industrial effluents, and fertilizer runoff all contribute to phosphorus contamination in streams. Phosphorus is a nutrient that is required by both plants and animals. Excess phosphorus in surface water, on the other hand, can stimulate accelerated development of aquatic plants and algae. This can result in a range of water-quality issues, such as low dissolved oxygen concentrations, which can kill fish and injure other aquatic life. A river should not exceed 0.1 mg/L phosphates. Phosphates exceeding these levels can be very harmful. The phosphate level according to this study (0.23 mg/L) for the entire study period exceeded the limit (0.1 mg/L). This has been attributed to excessive human and animal waste, and domestic activities like laundry and cleaning wastewater, industrial effluents, and fertilizer runoff.

Total alkalinity is an aqueous solution's ability to neutralize an acid. Water's alkalinity is caused by the presence of carbonate, bicarbonate, and hydroxide ions. Throughout the sampling period, the mean concentration of alkalinity in water samples was 45.19 mg/L across both seasons. In all seasons, the mean alkalinity value was well under the WHO-recommended range of 200 mg/L.
The box and whisker plots of the water parameters have also been drawn representing the entire sampling period to show the variations of studied parameter values. The plots are shown in Figure 3. Box and whisker plots show that pH, acidity, EC, TA, Ca, Cl, carbonates, phosphates and nitrates have almost the same trend. These parameters do not vary significantly along the sampling stations at different sampling locations within the study area. The rest parameters vary with the sampling stations. The conspicuous observation in this study was the observed higher concentrations of these parameters during the wet (rainy) season. This is probably because of heavy runoff of water during rainy season that had homogenized the water of the river (Zhang *et al*. 2017; Kumarasamy *et al*. 2014) thereby washing pollutants within the city into the river.

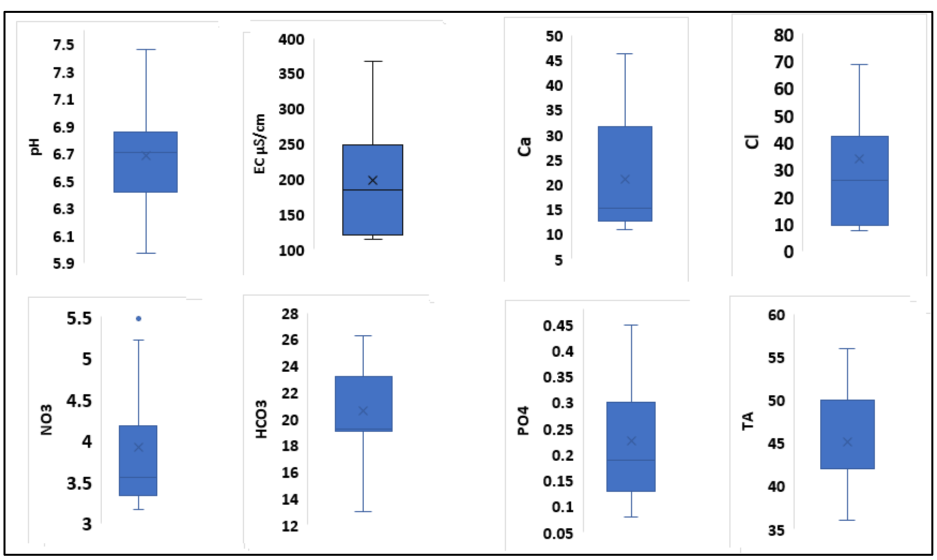

Figure 3: The box and whisker plots of the water parameters for the entire study period

Estimation of Water Quality Index of water sample

To ascertain the suitability of River Osun for municipal and agricultural purposes using the water quality index WQI, the WQI for each sampling period were as presented in Tables 5 to 13. Three different values of WQI were obtained for each sampling period. The WQI were obtained for different sampling points A, B, and C for each sampling periods of November 2022, April 2023, and July 2023.

Table 5: WQI for November 2022 at Sampling Point A

S/ID	pH	EC µS/cm	TA mg/l	TH mg/l	Cl mg/l	Ca mg/l	Mg mg/l	NO3 mg/l	PO4 mg/l	BOD mg/l	Mn mg/l	∑
A1	7.44	116	52	56	9.18	12.61	5.98	3.35	0.11	4.4	0.64	
A2	7.28	115	42	62	9.24	11.77	7.95	3.26	0.13	4.6	0.61	
A3	7.46	116	40	58	8.96	10.93	7.49	3.22	0.15	4.4	0.66	
Obs. V.	**7.393**	**115.667**	**44.667**	**58.667**	**9.127**	**11.770**	**7.140**	**3.277**	**0.130**	**4.467**	**0.637**	
St. V.	7.4	400	200	100	155	75	50	3	0.1	8	0.2	
1/S.V	0.135	0.003	0.005	0.010	0.006	0.013	0.020	0.333	10.000	0.125	5.000	**15.651**
K	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	
Wi	0.00863	0.00016	0.00032	0.00064	0.00041	0.00085	0.00128	0.02130	0.63895	0.00799	0.31947	**1.00000**
Qi	98.333	28.917	22.333	58.667	5.888	15.693	14.280	109.222	130.000	55.833	318.333	
WiQi	0.84905	0.00462	0.00713	0.03748	0.00243	0.01337	0.01825	2.32624	83.06309	0.44593	101.69904	**188.46664**

$$WQI = \sum_{i=1}^{n} q_i w_i \Big/ \sum_{i=1}^{n} w_i .$$

$$WQI = 188.47 / 1.00$$

$$WQI = 188.47$$

Table 6: WQI for November 2022 at Sampling Point B

S/ID	pH	EC µS/cm	TA mg/l	TH mg/l	Cl mg/l	Ca mg/l	Mg mg/l	NO3 mg/l	PO4 mg/l	BOD mg/l	Mn mg/l	Σ
B1	6.89	121	40	52	7.84	14.29	3.98	3.55	0.16	4.2	0.58	
B2	6.75	117	56	56	7.36	10.93	7	3.38	0.22	4.6	0.62	
B3	6.86	118	50	54	7.44	12.61	5.49	3.62	0.16	4	0.55	
Obs. V.	**6.833**	**118.667**	**48.667**	**54.000**	**7.547**	**12.610**	**5.490**	**3.517**	**0.180**	**4.267**	**0.583**	
St. V.	7.4	400	200	100	155	75	50	3	0.1	8	0.2	
1/S.V	0.135	0.003	0.005	0.010	0.006	0.013	0.020	0.333	10.000	0.125	5.000	**15.651**
K	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	
Wi	0.00863	0.00016	0.00032	0.00064	0.00041	0.00085	0.00128	0.02130	0.63895	0.00799	0.31947	**1.00000**
Qi	-41.667	29.667	24.333	54.000	4.869	16.813	10.980	117.222	180.000	53.333	291.667	
WiQi	-0.3598	0.00474	0.00777	0.03450	0.00201	0.01432	0.01403	2.49663	115.01044	0.42596	93.17975	**210.83039**

$$WQI = \sum_{i=1}^{n} q_i w_i \Big/ \sum_{i=1}^{n} w_i.$$

$$WQI = 210.83/1.00$$

$$WQI = 210.83$$

Table 7: WQI for November 2022 at Sampling Point C

S/ID	pH	EC µS/cm	TA mg/l	TH mg/l	Cl mg/l	Ca mg/l	Mg mg/l	NO3 mg/l	PO4 mg/l	BOD mg/l	Mn mg/l	Σ
C1	6.55	123	46	64	9.28	11.78	8.44	3.84	0.12	3.5	0.38	
C2	6.61	118	42	70	9.56	11.77	9.91	3.4	0.08	3.8	0.41	
C3	6.58	139	40	62	9.32	13.46	6.92	3.93	0.08	3.6	0.36	
Obs. V.	**6.580**	**126.667**	**42.667**	**65.333**	**9.387**	**12.337**	**8.423**	**3.723**	**0.093**	**3.633**	**0.383**	
St. V.	7.4	400	200	100	155	75	50	3	0.1	8	0.2	
1/S.V	0.135	0.003	0.005	0.010	0.006	0.013	0.020	0.333	10.000	0.125	5.000	**15.651**
K	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	
Wi	0.00863	0.00016	0.00032	0.00064	0.00041	0.00085	0.00128	0.02130	0.63895	0.00799	0.31947	**1.00000**
Qi	-105.000	31.667	21.333	65.333	6.056	16.449	16.847	124.111	93.333	45.417	191.667	
WiQi	-0.90661	0.00506	0.00682	0.04174	0.00250	0.01401	0.02153	2.64335	59.63504	0.36274	61.23241	**123.058575**

$$WQI = \sum_{i=1}^{n} q_i w_i / \sum_{i=1}^{n} w_i.$$

$$WQI = 123.06/1.00$$

$$WQI = 123.06$$

Table 8: WQI for April 2023 at Sampling Point A

S/ID	pH	EC µS/cm	TA mg/l	TH mg/l	Cl mg/l	Ca mg/l	Mg mg/l	NO3 mg/l	PO4 mg/l	BOD mg/l	Mn mg/l	∑
A1	**6.95**	**164**	**48**	**68**	**21.56**	**15.14**	**7.37**	**5.22**	**0.19**	**3.5**	**0.54**	
A2	**6.42**	**188**	**54**	**56**	**22.54**	**14.3**	**4.95**	**5.22**	**0.18**	**4.8**	**0.51**	
A3	**6.45**	**182**	**52**	**54**	**19.6**	**15.98**	**3.44**	**5.2**	**0.15**	**4**	**0.54**	
Obs. V.	**6.607**	**178.000**	**51.333**	**59.333**	**21.233**	**15.140**	**5.253**	**5.213**	**0.173**	**4.100**	**0.530**	
St. V.	7.4	400	200	100	155	75	50	3	0.1	8	0.2	
1/S.V	0.135	0.003	0.005	0.010	0.006	0.013	0.020	0.333	10.000	0.125	5.000	**15.651**
K	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	
Wi	0.00863	0.00016	0.00032	0.00064	0.00041	0.00085	0.00128	0.02130	0.63895	0.00799	0.31947	**1.00000**
Qi	-98.3	44.500	25.667	59.333	13.699	20.187	10.507	173.778	173.333	51.250	265.000	
WiQi	-0.85	0.00711	0.00820	0.03791	0.00565	0.01720	0.01343	3.70116	110.75079	0.40933	84.66046	**198.7621**

$$WQI = \sum_{i=1}^{n} q_i w_i / \sum_{i=1}^{n} w_i.$$

$$WQI = 198.76/1.00$$

$$WQI = 198.76$$

Table 9: WQI for April 2023 at Sampling Point B

S/ID	pH	EC µS/cm	TA mg/l	TH mg/l	Cl mg/l	Ca mg/l	Mg mg/l	NO3 mg/l	PO4 mg/l	BOD mg/l	Mn mg/l	∑
B1	**6.71**	**204**	**42**	**60**	**32.34**	**15.14**	**5.42**	**3.19**	**0.13**	**3**	**0.46**	
B2	**6.64**	**232**	**36**	**70**	**39.2**	**16.82**	**6.83**	**3.17**	**0.12**	**3**	**0.52**	
B3	**6.7**	**224**	**44**	**62**	**33.32**	**11.77**	**7.95**	**3.2**	**0.16**	**3.4**	**0.48**	
Obs. V.	**6.683**	**220.000**	**40.667**	**64.000**	**34.953**	**14.577**	**6.733**	**3.187**	**0.137**	**3.133**	**0.487**	
St. V.	7.4	400	200	100	155	75	50	3	0.1	8	0.2	
1/S.V	0.135	0.003	0.005	0.010	0.006	0.013	0.020	0.333	10.000	0.125	5.000	**15.651**
K	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	
Wi	0.00863	0.00016	0.00032	0.00064	0.00041	0.00085	0.00128	0.02130	0.63895	0.00799	0.31947	**1.00000**
Qi	-79.167	55.000	20.333	64.000	22.551	19.436	13.467	106.222	136.667	39.167	243.333	
WiQi	-0.68356	0.00879	0.00650	0.04089	0.00930	0.01656	0.01721	2.26235	87.32274	0.31282	77.73854	**167.05212**

$$WQI = \sum_{i=1}^{n} q_i w_i \Big/ \sum_{i=1}^{n} w_i .$$

$$WQI = 167.05 / 1.00$$

$$WQI = 167.05$$

Table 10: WQI for April 2023 at Sampling Point C

S/ID	pH	EC µS/cm	TA mg/l	TH mg/l	Cl mg/l	Ca mg/l	Mg mg/l	NO3 mg/l	PO4 mg/l	BOD mg/l	Mn mg/l	Σ
C1	**6.3**	**176**	**48**	**66**	**22.54**	**12.61**	**8.42**	**5.62**	**0.21**	**5.6**	**0.52**	
C2	**6.2**	**178**	**40**	**72**	**27.44**	**15.14**	**8.35**	**5.48**	**0.22**	**5.6**	**0.48**	
C3	**6.35**	**185**	**54**	**72**	**42.14**	**16.82**	**7.27**	**5.61**	**0.27**	**5.8**	**0.48**	
Obs. V.	**6.283**	**179.667**	**47.333**	**70.000**	**30.707**	**14.857**	**8.013**	**5.570**	**0.233**	**5.667**	**0.493**	
St. V.	7.4	400	200	100	155	75	50	3	0.1	8	0.2	
1/S.V	0.135	0.003	0.005	0.010	0.006	0.013	0.020	0.333	10.000	0.125	5.000	**15.651**
K	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	
Wi	0.00863	0.00016	0.00032	0.00064	0.00041	0.00085	0.00128	0.02130	0.63895	0.00799	0.31947	**1.00000**
Qi	-179.167	44.917	23.667	70.000	19.811	19.809	16.027	185.667	233.333	70.833	246.667	
WiQi	-1.547	0.00717	0.00756	0.04473	0.00817	0.01688	0.02048	3.95437	149.08760	0.56573	78.80345	**230.969143**

$$WQI = \sum_{i=1}^{n} q_i w_i \Big/ \sum_{i=1}^{n} w_i .$$

$$WQI = 230.97 / 1.00$$

$$WQI = 230.97$$

Table 11: WQI for July 2023 at Sampling Point A

S/ID	pH	EC µS/cm	TA mg/l	TH mg/l	Cl mg/l	Ca mg/l	Mg mg/l	NO3 mg/l	PO4 mg/l	BOD mg/l	Mn mg/l	Σ
A1	6.72	236	44	62	56.62	23.1	9.49	3.98	0.44	4.8	0.38	
A2	6.87	259	42	54	67.54	29.42	6.8	3.56	0.36	5.3	0.42	
A3	6.84	248	42	62	68.53	31.5	7.26	4.18	0.28	5	0.45	
Obs. V.	**6.810**	**247.667**	**42.667**	**59.333**	**64.230**	**28.007**	**7.850**	**3.907**	**0.360**	**5.033**	**0.417**	
St. V.	7.4	400	200	100	155	75	50	3	0.1	8	0.2	
1/S.V	0.135	0.003	0.005	0.010	0.006	0.013	0.020	0.333	10.000	0.125	5.000	**15.651**
K	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	
Wi	0.00863	0.00016	0.00032	0.00064	0.00041	0.00085	0.00128	0.02130	0.63895	0.00799	0.31947	**1.00000**
Qi	-47.500	61.917	21.333	59.333	41.439	37.342	15.700	130.222	360.000	62.917	208.333	
WiQi	-0.41013	0.00989	0.00682	0.03791	0.01708	0.03181	0.02006	2.77350	230.02088	0.50251	66.55697	**299.56729**

$$WQI = \sum_{i=1}^{n} q_i w_i \Big/ \sum_{i=1}^{n} w_i.$$

$$\text{WQI} = 299.57/1.00$$

$$WQI = 299.57$$

Table 12: WQI for July 2023 at Sampling Point B

S/ID	pH	EC µS/cm	TA mg/l	TH mg/l	Cl mg/l	Ca mg/l	Mg mg/l	NO3 mg/l	PO4 mg/l	BOD mg/l	Mn mg/l	Σ
B1	6.73	311	42	52	25.8	35.76	3.87	3.33	0.32	6.2	1.22	
B2	6.35	367	54	48	34.77	42	2.46	3.62	0.26	5.8	1.19	
B3	6.38	344	46	54	28.86	37.86	3.95	3.18	0.3	5.8	1.36	
Obs. V.	**6.487**	**340.667**	**47.333**	**51.333**	**29.810**	**38.540**	**3.427**	**3.377**	**0.293**	**5.933**	**1.257**	
St. V.	7.4	400	200	100	155	75	50	3	0.1	8	0.2	
1/S.V	0.135	0.003	0.005	0.010	0.006	0.013	0.020	0.333	10.000	0.125	5.000	**15.651**
K	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	
Wi	0.00863	0.00016	0.00032	0.00064	0.00041	0.00085	0.00128	0.02130	0.63895	0.00799	0.31947	**1.00000**
Qi	- 128.333	85.167	23.667	51.333	19.232	51.387	6.853	112.556	293.333	74.167	628.333	
WiQi	-1.1081	0.01360	0.00756	0.03280	0.00793	0.04378	0.00876	2.39723	187.42442	0.59236	200.73581	**390.15616**

$$WQI = \sum_{i=1}^{n} q_i w_i \Big/ \sum_{i=1}^{n} w_i.$$

$$\text{WQI} = 390.16/1.00$$

$$WQI = 390.16$$

Table 13: WQI for July 2023 at Sampling Point C

S/ID	Ph	EC µS/cm	TA mg/l	TH mg/l	Cl mg/l	Ca mg/l	Mg mg/l	NO3 mg/l	PO4 mg/l	BOD mg/l	Mn mg/l	Σ
C1	6.78	228	42	58	65.5	39.94	4.4	3.35	0.42	6	0.62	
C2	6.73	253	42	62	99.38	39.96	5.46	3.61	0.45	6.7	0.69	
C3	5.97	288	40	92	129.12	46.2	11.2	3.48	0.42	6.3	0.65	
Obs. V.	**6.493**	**256.333**	**41.333**	**70.667**	**98.000**	**42.033**	**7.020**	**3.480**	**0.430**	**6.333**	**0.653**	
St. V.	7.4	400	200	100	155	75	50	3	0.1	8	0.2	
1/S.V	0.135	0.003	0.005	0.010	0.006	0.013	0.020	0.333	10.000	0.125	5.000	**15.651**
K	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	**0.064**	
Wi	0.00863	0.00016	0.00032	0.00064	0.00041	0.00085	0.00128	0.02130	0.63895	0.00799	0.31947	**1.00000**
Qi	- 126.667	64.083	20.667	70.667	63.226	56.044	14.040	116.000	430.000	79.167	326.667	
WiQi	- 1.09369	0.01024	0.00660	0.04515	0.02606	0.04775	0.01794	2.47059	274.74716	0.63229	104.36132	**381.2714**

$$WQI = \sum_{i=1}^{n} q_i w_i \Big/ \sum_{i=1}^{n} w_i.$$

$$\text{WQI} = 381.27 / 1.00$$

$$WQI = 381.27$$

Table 14: Summary of WQI Values for the sampling periods and locations

Month	Point	WQI	Average WQI	Remark
NOVEMBER, 2022	A B C	188.47 210.83 123.06	174.12	Unsuitable
APRIL, 2023	A B C	198.76 167.05 230.97	198.93	Unsuitable
JULY, 2023	A B C	299.57 390.16 381.27	357	Unsuitable

Table 14 shows the summary of the WQI estimation for the sampling locations and sampling points. The values of the WQI are observed to increase with sampling period. This, in other words, means rainfall played major roles in the Osun River pollution. According to the summary of the results in Table 4.13, the obtained values of WQI from the three sampling stations varied from 123.06 to 390.16, with an average value of WQI of 243.35, which was much over 100. The greatest WQI values were reported during the rainy season, ranging from 299.57 to 390.16, indicating that the river will be unfit for use during this period, as opposed to the dry season. During the rainy season, river water is unsuitable due to increased surface run-off from neighboring urban accumulations and direct discharge from storm water drains along roads adjacent to the river. This is consistent with similar results observed by Sebastian and Yamakanamardi (2013) in case of Cauvery River.

Discussion of results

The pH of the aquatic systems is an important indicator of the water quality and the extent pollution in the watershed areas. Results obtained for pH from the three sampling points throughout the study period varied between 5.97 and 7.46 as shown in the previous Tables. The mean pH value was 6.69. Analytical observation of the pH values shows that metals like Cadmium and Zinc are most likely to have increased detrimental environmental effect as a result of lower pH 6.5 (Davies *et al.*, 2005). However, the pH concentration in the study locations is within allowable limits of 7.4 for surface water (World Health Organization, 1998). The mean total alkalinity value in the study area is below the permissible limits of 200 mg/L. And also, the total hardness values obtained from all the sampling points at different sampling periods are all within the tolerable limits of (Nigerian Industrial Standards, 2003). Hardness of water causes chocking and clogging troubles of pipelines, causes formation of scales in boilers leading to wastage of fuel and the danger of overheating of boilers (Egereonu, 2004). The hardness of natural waters depends mainly on the presence of dissolved calcium and magnesium salts (Ikomi and Emuh, 2000). The total hardness varies from 48-92 mg/L and the values for the study area were found to be within the tolerable limit of WHO specification (World Health Organization, 1998) of 100 mg/L. Water containing high solids may cause laxative or constipation effects (Egereonu, 2004). Nitrate and Nitrite are natural ions that are part of nitrogen cycle. Nitrate ion in water is undesirable. This is because it can cause methaemoglobinaemia in infants less than 6 months old (Egereonu and Nwachukwu, 2005), however, the nitrate value varies from 3.19 - 5.62 mg/L. All the samples were observed to exceed the permissible limit of 3.0 mg/L and this could be attributed to leachates from waste disposal, sanitary landfills, over-application of inorganic nitrate fertilizer or improper manure management practice (Yisa and Jimoh, 2010). High nitrate levels also leads to eutrophication (World Health Organization, 2004).

Conclusion

In this study, WQI method was applied to investigate the water quality status of Osun River. The investigation was conducted during both dry and wet seasons. The water quality of the river is generally poor with exception at a few sampling stations during the dry season. The average pH values were found to be within the permissible limit and fall within the standard expected. In this study, EC (in µS/cm) values varied from 115 to 232 µS/cm with a mean value of 156.44 µS/cm in the dry season and varied from 228 to 367µS/cm with a mean value of 281.5556 µS/cm in the wet season. EC values of all the water samples recorded are below 750 µS/cm, which is in compliance with both WHO value and FAO regulation and thus indicate good quality of irrigation water. Increase in the values of electrical conductivity was attributed to more pollutants being washed into the river by runoff. During the dry season, the average chloride concentration in the water samples tested ranged from 7.36 to 42.17 mg/L. During the wet season, the chloride concentration fluctuated from 25.8 to 129.12 mg/L. The detected chloride values for river water were well within the acceptable limit of 155 mg/L. With respect to the nitrate value varies from 3.19 - 5.62 mg/L. All the samples were observed to exceed the permissible limit of 3.0 mg/L and this could be attributed to leachates from waste disposal, sanitary landfills, over-application of inorganic nitrate fertilizer or improper manure management practice.

The box and whisker plots of the water revealed that pH, acidity, EC, TA, Ca, Mg, Cl, carbonates, phosphates and nitrates have almost the same trend. These parameters do not vary significantly along the sampling stations at different sampling locations within the study area. The magnesium hazard values of all the samples during the sampling periods have values below the permissible limit and, therefore, considered suitable for irrigation purpose. Overall, the water of Osun River is good for industrial and agricultural purposes.

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