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Use of Water Quality Index to Assess the Impact of Flooding on Water Quality of River Kaduna, Nigeria

*[1]ONOYIMA, CC; [2]OKIBE, FG; [2]OGAH, E; [3]DALLATU, YA

*[1]*Department of Chemistry, Nigeria Police Academy, Wudil, Nigeria*
[2]*Department of Chemistry, Federal University of Health Sciences, Otukpo, Nigeria*
[3]*Department of Chemistry, Ahmadu Bello University, Zaria, Nigeria*
**Corresponding Author Email: krissonoss@yahoo.co.uk; Tel: 08035982690*

ABSTRACT: Flooding is increasingly becoming a yearly occurrence in Nigeria and many parts of the world and is linked to climate change. It comes with a wide range of consequences including the destruction of life and property and surface water pollution. This study used water quality index (WQI) to assess the impact of 2019 and 2020 flood events on the water quality of River Kaduna. Nine water quality parameters were selected based on Nigeria standards, while the weighted arithmetic method was applied in calculating the WQI. The result shows that electrical conductivity, TDS, Cl^-, Na, sulphate, and nitrate were all below the maximum standard limits throughout the study period, while Fe and turbidity were above the limits. While other parameters showed varied responses before and after the two flood events, Fe and turbidity were consistently higher after the flood events. The water quality of the river is generally in the extremely poor class, both before and after the 2019 and 2020 floods (WQI > 100). There was a pronounced decrease in water quality at all the sampling stations after both the 2019 and 2020 flood events. The decreasing water quality should be of a public health concern as a large number of people depends on this river for domestic use.

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Flooding occurs when water accumulates in places that are not normally submerged, due to heavy rainfall, melting snow, glacial outbursts, and dam break (MICRODIS, 2010). Annual flooding is increasingly affecting a majority of Nigerian states due to increased precipitations linked to climate change (Echendu, 2020). Climate change processes could alter the hydrological cycle leading to increased precipitations and consequently flooding (Ching *et al.,* 2015). The rainfall pattern in the past three decades indicates that the intensity of rainfall will increase and flooding incidences will subsequently continue to rise with attendant consequences (Echendu, 2020). Since 2012, flood in Nigeria has become a perennial environmental crisis. Flooding puts life and properties at risk and may cause surface water pollution, thereby reducing access to potable water and destruction of wildlife habitats (Gautam and van-der-Hoek, 2003; Ching *et al*., 2015; Olanrewaju *et al*., 2019; Li *et al*., 2020;). There are many possible sources of contamination during and after flood events, including dumping ground, graveyard, chemical works, pesticides and fertilizers in warehouses, oil spillage, septic tanks, household, and industrial hazardous chemicals, etc. (Gautam and van-der-Hoek, 2003). Flood will either increase contaminants and decrease water quality or dilute contaminants and improve water quality (Merolla, 2011). When floodwater reaches places where the contaminants are, they are slowly dissolved resulting in the formation of diluted solution, afterward, when part of floodwater evaporates, the concentration of the contaminants may increase (Gautam and van-der-Hoek, 2003). The increase or decrease in water quality of receiving surface water depends on the type of the contaminant, the concentration of the contaminant in the receiving surface water, the floodwater, and the dilution rate (Pinto *et al*., 2013). However, when point source of pollution is present, water quality generally deteriorates due to less dilution (Mosley, 2015). Although various researchers have reported adverse effects of flooding on surface water quality (Okoye *et al*., 2014; Sun *et al*., 2016; Wu *et al*., 2017; Li *et al*., 2020), flooding results in complex and varied water quality effects, which operates at various temporal and spatial scale (Sun *et al*., 2016). It's therefore critical to assess the impact of a flood on the surface water quality of each river to prevent/manage the adverse effect. However, Nigeria is listed, alongside

**Corresponding Author Email: krissonoss@yahoo.co.uk; Tel: 08035982690*

Bangladesh, Vietnam, Sudan, Thailand, and Indonesia, as a country prone to flooding but with a dearth of floodwater quality study (Rui *et al*., 2018). Various methods have been used to assess water quality including multivariate statistical methods (Ladipo *et al*., 2012, Okibe *et al*, 2019), modelling techniques (Huang et al., 2016), multi-metric indices (Wu *et al*., 2012), pollution indices (Son *et al*., 2020), etc. However, WQI is a very effective and simple method that combines several environmental parameters and converts them into a single value that reflects the water quality condition (Wu *et al*., 2017). It has been widely used to assess both surface and groundwater quality of different areas (Alobaidy *et al*., 2010; Bharathi *et al*., 2016; Awachat. and Salkar, 2017; Otene and Nnadi, 2019). The concept is based on the comparison of the water quality parameters with respective regulatory standards (Khan *et al*., 2003). The aim of the present study is to use water quality index to assess the impact of flooding on the water quality of River Kaduna, Nigeria.

MATERIALS AND METHODS

Study Area: River Kaduna which rises from Jos Plateau and flows through Kaduna town adopts a south-westerly course before completing its 340 miles (550 km) flow to Niger State at Muregi (opposite Pategi). The River is used for domestic, fishing, and agricultural purposes as the people of the community are predominantly farmers and fishermen, though, some livestock farming is also practiced in the study area.

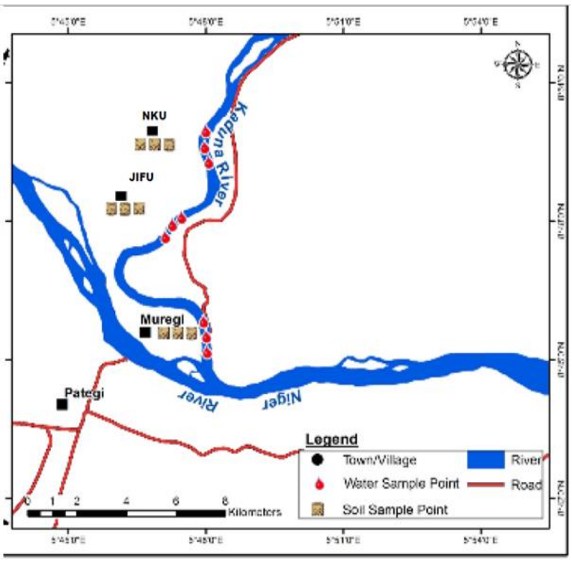

Fig 1: Map of the study area

The nature and magnitude of floods in the study area are distinctive and always occur on an unimaginable scale owing to the fact that despite its low-lying area, it is also located at the terminal end of the Kaduna River before adjoining the Niger River (River Niger-Kaduna confluence). In addition, the three earlier known Dams in Nigeria can be located upstream of the study area which further contributes and exacerbate flooding that greatly affects these communities (downstream) and their farming activities.

Sample Collection: The sampling was carried out in nine sampling points which were identified with the use of GPS at a distance of 50 m apart from each other within a sampling station. Three sites were selected for sampling namely; Nku (NK), Jifu (JI), and Muregi (MU) with an approximate distance of 500 m away from each other. Samples were collected manually using recommended apparatus for each of the parameters of interest. The sampling was done before flooding in the month of March, and after flooding in September. The sites were observed during seasonal sampling for changes and types of activities. Conductivity and temperature were measured on-site while other parameters were determined in the laboratory immediately following sampling. A litre of water sample each was collected in triplicate from each of the nine locations of the sites. Grab samples were collected at 20 cm below the water sampler. Samples for major ions were collected in cleaned plastic bottles. The samples were immediately transported to the laboratory under low-temperature conditions in ice-boxes and stored in the laboratory at 4 °C until analysis.

Sample Analysis: The determination of physicochemical parameters such as pH, Sulphates, Nitrates, Total Dissolved Solids, Turbidity were carried out in accordance with the method described by AOAC, (1990), while the metal concentration was determined using atomic absorption spectroscopy (AAS).

Calculation of Water Quality Index (WQI): The water quality index was calculated using the weighted arithmetic index method as reported by Douglas *et al.*, (2015). Nigeria reference standard (Table 2) was adopted for assigning weights to the water quality parameters. Only routinely monitored parameters with available Nigeria standard reference values were selected.

$$WQI = \frac{\sum_{i=1}^{n} W_i Q_i}{\sum_{i=1}^{n} W_i} \quad (1)$$

$$W_1 = \frac{K}{S_i} \quad (2)$$

$$k = \frac{1}{\sum_{i=1}^{n} \frac{1}{S_i}} \quad (3)$$

$$Q_t = \frac{C_n - C_i}{S_i - C_i}\ x\ 100 \quad (4)$$

Where: W_i is the assigned weight, K is a proportionality constant, Q_i is the quality rating for the ith water quality parameter, n is the total number of the water quality parameters, C_n is the concentration of ith water quality parameter, S_i is the standard value of the ith water quality parameter, C_i is the ideal value of the ith water quality parameter (C_i for pH = 7, for other parameters, C_i = 0) (Alobaidy *et al*., 2010; Otene and Nnadi, 2019). WQI rating according to this method is shown in Table 1

Table 1: Water Quality Index Scale

WQI	Water Quality
< 25	Excellent
26 - 50	Good
51 - 75	Poor
76 - 100	Very poor
> 100	Extremely Poor

Table 2: Reference standards and relative weights of water quality parameters

Parameter	Unit	standard	relative weight
pH	-	6.5 - 8.5	0.03186
Conductivity	S/cm	1000	0.000271
Turbidity	NTU	5	0.05416
Na	mg/L	200	0.001354
Sulphate	mg/L	100	0.002708
TDS	mg/L	500	0.0005416
chloride	mg/L	250	0.00108
Nitrate	mg/L	50	0.005416
Fe	mg/L	0.3	0.9027

RESULTS AND DISCUSSION

Water Quality Parameters: The mean values of the analysed water quality parameters for all the three sampling stations are presented in Table 3, Table 4, and Table 5. The results indicate that the pH values fall within the standard range of 6.5 – 8.5 at all the sampling sites, within the study period, both before and after the flood. There was no noticeable trend before and after the flood. This is in line with the report by Mosley, (2015) that pH shows mixed response during drought (and flooding). pH is one of the key indicators of water quality and its value shows the extent of pollution (Amadi *et al*., 2010). It affects the solubility of metals and nutritive chemicals in water (Ching, *et al*., 2015). Electrical conductivity depends on the presence of ions, their total and relative concentrations, mobility, and temperature of measurement (Saxena and Sharma, 2017). Mean conductivity values for all the sites fall below the standard limit of 1000 s/cm (Nigeria standard) throughout the study period. There was only a slight increase in conductivity after the flood, except at site Nk in 2019. Ions responsible for conductivity may be harmful or beneficial to the body (Amadi *et al*., 2010). Turbidity, on the other hand, exceeded the maximum limit (5 NTU) at all the stations before and after flood. The mean turbidity values also increased after the flood at all the sites both in 2019 and 2020. Turbidity values reported for most rivers in Nigeria were far greater than the 5.0 NTU limit (Ajibade, 2004; Adefemi *et al*., 2007; Wakawa *et al*., 2008). The results also show that Na, TDS, Cl^-, SO_4^{2-} and NO_3^- are all below the maximum standard limit at all the study sites throughout the study period. There was an increase in mean values of TDS, Cl^-, SO_4^{2-} and NO_3^- after the flood with the exception of NO_3^- and Cl^- at Mu in 2019. Na level on the other hand increased after the 2019 flood but decreased after the 2020 flood. The increase in pollutant level after a flood event is either due to a point source or less dilution effect, while a decrease in pollutant level means dilution supersedes the pollutant input effect (Mosley, 2015; Wu *et al*., 2017). The mean values of Fe exceeded the maximum standard limit of 0.3 mg/L at all the sampling stations both in 2019 (before and after the flood) and 2020 (before and after the flood). The mean value increased after each flood event at all the stations.

Table 3: Mean values of water quality parameters at Muregi sampling station

	2019		2020	
	BF	AF	BF	AF
pH	6.76±0.33	7.58±0.17	7.52±0.03	7.23±0.01
Conductivity	71.34±1.43	88.67±0.61	56.54±0.02	64.00±0.24
Turbidity	21.59±1.15	24.36±0.38	76.69±1.30	82.78±2.22
Na	0.40±0.00	0.44±0.01	2.77±0.05	0.46±0.02
TDS	44.00±1.00	58.35±2.17	37.87±0.04	42.63±0.32
Cl^-	10.44±0.47	10.10±0.53	9.31±0.02	13.29±0.30
SO_4^{2-}	0.67±0.23	2.33±0.33	2.78±0.15	4.22±0.22
NO_3^-	13.00±0.55	11.27±0.21	7.80±0.21	9.50±0.02
Fe	0.32±0.01	2.59±0.18	6.76±0.15	28.16±0.52

BF = Before Flood; AF = After Flood

Table 4: Mean values of water quality parameters at Jifu sampling station

	2019		2020	
	BF	AF	BF	AF
pH	7.45±0.09	7.27±0.07	7.56±0.06	7.24±0.01
Conductivity	66.67±0.52	74.96±0.78	56.63±0.02	64.44±0.18
Turbidity	22.74±0.68	22.88±0.39	73.71±0.11	92.33±0.11
Na	0.34±0.00	0.37±0.01	2.86±0.02	0.42±0.04
TDS	43.71±0.21	56.91±1.46	37.93±0.02	42.54±0.33
Cl^-	9.44±0.24	9.60±0.56	9.28±0.01	12.20±0.15
SO_4^{2-}	0.33±0.17	2.33±0.29	3.11±0.11	4.00±0.29
NO_3^-	10.62±0.81	10.67±0.54	8.27±0.06	9.47±0.01
Fe	0.55±0.03	1.74±0.19	7.23±0.19	22.66±0.18

BF = Before Flood; AF = After Flood

Table 5: Mean values of water quality parameters at Nku sampling station

	2019		2020	

	BF	AF	BF	AF
pH	7.33±0.01	7.40±0.02	7.62±0.04	7.25±0.00
Conductivity	68.89±2.38	68.81±0.58	56.54±0.03	63.67±0.17
Turbidity	25.30±0.35	32.03±0.43	78.53±0.64	93.92±0.26
Na	0.38±0.00	0.38±0.01	2.73±0.11	0.50±0.02
TDS	46.95±1.81	48.63±0.61	37.71±0.10	43.13±0.15
Cl^-	10.44±0.24	11.21±0.23	9.34±0.02	14.80±0.04
SO_4^{2-}	0.78±0.15	2.11±0.20	3.22±0.15	3.67±0.17
NO_3^-	12.97±0.67	13.10±0.35	8.28±0.04	9.47±0.01
Fe	0.42±0.02	1.66±0.04	6.74±0.09	34.50±1.04

BF = Before Flood; AF = After Flood

However, the increase in the mean value of Fe after the 2020 flood is so dramatic that it is suggestive of a point source of pollution. The trend of the contaminant level in surface water after a flood is a function of many factors including the type of the contaminant, concentrations of the contaminant in the receiving surface water and floodwater, and the dilution rate (Nabelkova, *et al*., 2012). Floods will either increase contaminants leading to a decrease in water quality or dilute contaminants and improve water quality (Merolla, 2011). The net result will depend on the integration of a number of water quality parameters, which can be easily accomplished using water quality index (WQI).

Water Quality Index: WQI combines several environmental parameters and effectively converts them into a single value that reflects the water quality condition (Wu *et al.,* 2017). The results of the WQI are summarized in Figure 2. The water quality of the river is generally in the extremely poor class, both before and after the 2019 and 2020 floods (WQI > 100). Only site MU was in a very poor class before the 2019 flood (76 < WQI < 100). There was a pronounced decrease in water quality of all the sampling stations after both the 2019 and 2020 flood events. The average values of the WQI for all the sampling stations show that there was a threefold decrease in water quality after both the 2019 flood (333.68 %) and that of the 2020 flood (300.12 %). The decreasing water quality indicates that there was significant input of pollutants after each flood event. The result also indicates a deteriorating trend in water quality of the river within the study period as the water quality can be arranged in the decreasing order: 2019 (BF) > 2019 (AF) > 2020 (BF) > 2020 (AF). The decreasing water quality should be a public health concern as a large number of people depend on this river for domestic use. Although there was spatial variation of water quality, there was no noticeable trend among the sampling stations within the study periods. The major contributors to the extremely poor water quality of the river are Fe and turbidity. These parameters far exceeded the standard limits in the river, especially after the two flood events.

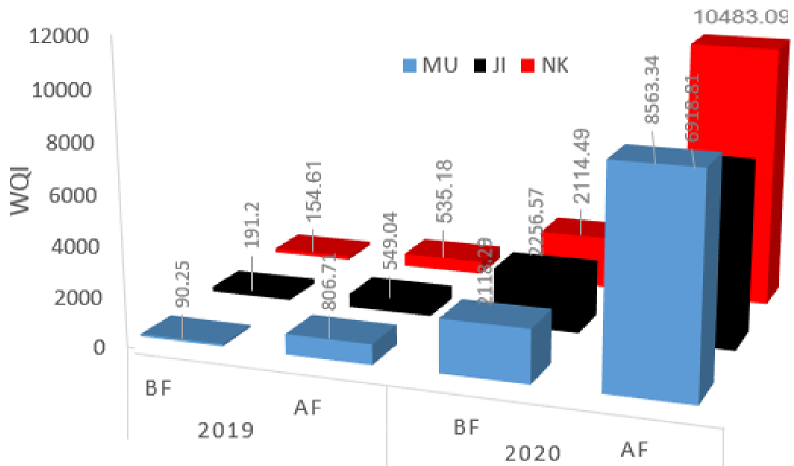

Fig 2: WQI of sampling sites before flooding (BF) and after flooding (AF)

*Conclusion***:** The water quality of the Kaduna River was already in a very poor state even before the two studied flood events. However, the impact of the floods was enormous as shown by a pronounced decrease in water quality at all the sampling stations after both the 2019 and 2020 flood events. The water quality can be arranged in decreasing temporal order as follows: 2019 (BF) > 2019 (AF) > 2020 (BF) > 2020 (AF). The deteriorating trend in water quality of the river within the study period should be of a public health concern as a large number of people depend on this river for domestic use.

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