Assessment of heavy metal and physico-chemical pollution loadings of River Benue water at Makurdi using water quality index (WQI) and multivariate statistics

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Received: 14 May 2020 / Accepted: 15 June 2021 / Published online: 25 June 2021
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Abstract

In this work, the quality of River Benue water at Makurdi was assessed for its heavy metal load alongside seven other physico-chemical parameters using water quality index (WQI) and multivariate statistical tools. A total of 45 samples from three (3) different points along the River course were collected for five months (October 2018–May, 2019) spanning the dry and wet seasons. Samples were analysed in accordance with standard methods. Most of the parameters evaluated were found to fall in the allowable limits of the World Health Organization (WHO) among others, except for colour, turbidity, total suspended solids, nickel, lead and cadmium. WQI analysis using the BISWQI, OWQI and CCMEWQI indicated that all indexing methods were suitable for estimating the WQI of River Benue as they all showed that the water corresponded to the classification as “poor water”. Heavy metal index of the river ranged from 13.40–6080.00 and from 47.07–7240.00 for the dry and wet seasons, respectively, and was majorly influenced by high cadmium and lead pollution levels. Principal component analysis (PCA) revealed three rotated factor with respective communality levels for both the dry and wet seasons. Factor 1 was positively loaded with nine parameters which accounted for 32.3% of the total variance during the dry season, while it was positively loaded with 10 parameters in the wet season accounting for 25.9% of total variance. Hierarchical cluster analysis (HCA) revealed that the river was zoned into four clusters each for both dry and wet seasons. Sampling points 2 and 3 were the most polluted during the dry season, while sampling point 1 was found to be the most polluted in the wet season. It was concluded that the increasing and diverse nature of anthropogenic activities on the river course was responsible for the deteriorating quality of the water. The study recommended continuous pollution monitoring and local regulations to reduce the entrance of both diffuse and point source pollution into the river.

Keywords Heavy Metal Index · River Benue · Water Quality Index · Multivariate Statistics · Pollution

Introduction

Water is a universal solvent and is one of the most commonly available natural resources of man which makes up about 70% of man’s body (Talabi et al., 2020). Heavy metals on the other hand can be defined as “metals with densities that are five times heavier than water and are formed naturally from the terrestrial environments, and they are found

in rocks, plants, soils and sediments” (Talabi et al., 2020; Oroborator et al., 2020).

The works of man and his industries have tendencies to increase the quantity of heavy metals in the environment, which favours environmental degradation (Ubwa et al., 2013). But high levels of heavy metals in water can be deleterious and injurious to man’s health and his environment (Li et al., 2007). In Nigeria, the onset of river water pollution with respect to heavy metals (Pb) was first reported by Monbreshola et al., (1983) in their studies on Nigerian rivers in Ibadan, South-West, Nigeria.

River Benue is one of the most important river, both in Benue State and Nigeria due to its location within the state capital city (Makurdi) and its favourable potentials for diverse beneficial purposes (recreation, agriculture, commerce and industry). In recent times, the River Benue has

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been subjected to tremendous changes in its quality as a result of increased human, industrial and commercial activities on the river banks (Akaahan et al., 2015; Eneji et al., 2017).

Over time, a few studies have been done to elucidate on the quality of River Benue water, moreover, as it traverses several communities and villages along its course. Eneji (2011) reported high concentrations of heavy metal in River Benue water around the Makurdi transect of the river. Their results indicated that the levels of trace contaminants in the water were above the maximum permissible levels allowed for drinking water as per the World Health Organization (WHO) standards. Similarly, Ejembi et al. (2018) carried out a bill of heavy metal loads in coastline deposits of River Benue and found out that heavy metal concentrations were above the allowable limits of WHO and NESREA. Deterioration in the features of water may be owed to the rapidly increasing urbanization trend, population pressure, industrial development, poor public health facilities and pollution of water assets by a diversity of dangerous substances and powerful pathogens (Ogedengbe and Akinbile, 2004).

These pollutions are mainly linked to raw anthropological and visceral litters, rubbish and manufacturing wastes. In Nigeria, the pollution of rivers in terms of heavy metals can be ascribed to indiscriminate release of raw effluents from industries, oxidization of steel provisions in buildings, leachates from waste dumps and automobiles, etc. (Jaji et al. 2007). According to FFTC (2008) as cited by Akinbile and Omoniyi (2018), raw human waste and junks are purposely and or unknowingly released into uncluttered channels, tributaries and rivers, leading to the contamination of freshwater reservoirs, watercourses and ponds. The panacea to such problems of environmental degradation remains frequent observations and supervision to preserve the quality features of the water and also the improvement of expertise for its handling and reuse (FFTC 2008).

According to Ogedengbe and Akinbile (2010), “In man’s quest to increase his food supplies, obtain uncontaminated and clean water to drink and limit deterioration of his health and damage to his possessions, the products of his technological exploits that would have been used to his advantage have turned out to be the silent conqueror and threat to his existence”.

The features of superficial and ground water assets can meaningfully alter water use in most parts of the world, particularly in the arid and semi-arid regions. In such areas where water contaminants from anthropological and manufacturing activities have extremely tainted the quality of water, it is advanced that the focus in water quality administration should be to periodically assess the contamination levels of aquatic bodies, regulate pollution sources and disseminate appropriate enlightenment campaigns (Akinbile and Omoniyi, 2018).

NBS (2009) posited that about 30% of Nigerians relied solely on rivers, tributaries, natural reservoirs and precipitation for their drinking water needs. They further projected that by the year 2030, many countries especially in Africa and Asia will face severe water scarcity as a result of climate change and generation of excessive wastewater from domestic, industrial and commercial undertakings.

Man, terrestrial animals/organisms, plants and water-based creatures may be negatively influenced by reduced water quality which could be responsible for increased incidences of deaths, sicknesses, poor yields and retarded growths (Briace and De-Farrati, 2008). Thus, it has become imperative to constantly assess the water quality parameters of major sources (oceans, rivers, lakes, etc.) in order to maintain a balanced ecosystem and explore effective and sustainable management strategies for our water bodies (Yilmaz, 2007).

Water quality index (WQI), multivariate statistics and heavy metal index (HMI) have been utilized and found to be reliable tools for providing useful insights towards sustainable decision-making for water management. For instance, Rana et al. (2018), Sharma et al. (2020), Vasistha and Ganguly (2020), Kondom et al. (2021) have demonstrated in their various studies that the foregoing approaches are suitable tools for assessing water pollution status of rivers, groundwater and leachate in different climes.

The obligation of frequent water quality monitoring must not be overemphasized. It is vital and supreme if public health and major water resources must be preserved in Nigeria and elsewhere. Therefore, the focus of the current research was to assess the quality of River Benue water at Makurdi with emphasis on heavy metals contamination which was elucidated using the HMI and the contributions of each heavy metal to the river pollution load during the wet and dry seasons. Furthermore, the instantaneous pollution status of the river was comparatively assessed using the BIS 10500 WQI (BISWQI), the Oregon WQI (OWQI) and the Canadian Council of Ministers of the Environment WQI (CCMEWQI) approaches. Similarly, principal component analysis (PCA) and hierarchical cluster analysis (HCA) were used to understand the interrelationships among the pollutants and also to infer pollution sources in the river.

The foregoing is important if proper harnessing and utilization of water from the river for various purposes (home, manufacturing and farming) so as to upsurge fibre and food production in the area are to be achieved.

Most importantly, it has been recently observed that diverse land use practices and anthropogenic impacts (sand mining, industrial effluent discharge, irrigation and herbicides application, flooding, indiscriminate solid waste dumping, etc.) have been associated with the river in the study location, thus increasing suspicion of its increased pollution loads, especially with regards to toxic, non-biodegradable

and carcinogenic pollutants such as heavy metals and herbicides (Eneji et al., 2011).

Therefore, since most of the communities situated along the course of the river depend heavily on it for their day to day portable, recreational and agricultural needs, it is pertinent to ascertain the level of pollution of the river and recommend the right purification and management measures to be adopted.

The thrust of the study was thus to assess the pollution levels of River Benue water at Makurdi at three selected locations along the river course. These locations are associated with various anthropogenic impacts and may be a reason for great variations in the quality of the water at the different points.

Materials and methods

The area of study

The study area in the current work was River Benue located in Makurdi town (capital city of Benue state-Nigeria). Its earthly coordinates are 8°21'0" North, 8°30'0" East. This river flows and passes through different locations and villages in the town. It is one of the two main rivers in Nigeria. Its origin is traced to the Cameroonian mountains as it traverses westwards through Makurdi to meet the other major river (River Niger) at Lokoja in Kogi State. Some of its tributaries are Rivers Katsina-Ala, Donga, Mu, Bantaji and Taraba among others. Around the New Bridge area in Makurdi, the river has an average depth and cross-sectional area of 7.82 m and 4608.42 m², respectively, with an average width of 1.194 km. The basin of the river which is concealed with meta-sediments is made up of land area below 300 m above sea level. The overflow plain dominated with large spans of swamps is ideal for irrigation-based dry spell cultivation. The river is a known and utilized source of natural water, alluvial and sand deposits in commercial quantities to the environs. Benue Roof Tiles Company Ltd., the building and brick-making industries are the major beneficiaries of these natural endowments. The river is used for agricultural, commercial, industrial, recreational and domestic purposes, e.g. fishing, washing of plates, drinking and abattoir (meat market) with uncontrolled waste disposal on the river banks and course. The people around this river locations deposit a lot of their waste products into the river or immediate environs. It is therefore important that these sources be analysed in order to elucidate on the quality of the water at these locations.

Makurdi lies between latitude 7.733°N and longitude 8.5391°E of Greenwich meridian as shown in Fig. 3. It is located in the Southern guinea savanna area of Nigeria and consists of two different (dry and wet) seasons. The highest

rainfalls in the area are annually experienced between the months of April and October with a mean value of 1137 mm (Isikwue and Onyilo, 2010).

In 2007, Makurdi population was estimated at 500,797 people (The World Gazetteer, 2013). The topographic map of the area shows that the land form is slightly irregular. Most parts of the land have been deprived of its original land cover comprising mostly of tall trees, tall grasses and shrubs. The yearly potential evapotranspiration is pegged at about 2602 mm, with mean yearly relative humidity of about 40.7% (Isikwue and Onyilo, 2010).

Average monthly temperature of the area falls within 17–36 °C. The high temperatures experienced in Makurdi are credited chiefly to the proximity of the town to the River Benue as a result of the reflection of solar radiation from the river back to its environs. Figure 1 is the map of the town displaying the River Benue and its tributaries.

Sampling and analytical procedures

Three (3) sampling points were chosen along the course of the river (Fig. 2). Samples were collected by the grab method in triplicate at each sampling point for a period of five months encompassing both the dry and wet periods. Specifically, a total of 45 samples were collected between the months of October, 2018, and May, 2019.

Some of the anthropogenic activities observed at the selected sampling points along the river course included indiscriminate municipal solid and liquid waste releases and large-scale fishing (Sampling point 2), small-scale farming, laundry and large-scale fishing and recreation (Sampling point 1) and effluent discharge, abattoir, fishing,

sand mining, ferrying, recreation and municipal solid waste disposal (sampling point 3). Detailed narrative of the sampling settings is given in Table 1. Preservation of samples and analysis was done at the Chemistry laboratory of the Benue State University following the standard methods (APHA, 2005; CPCB, 2007). The concentration of twelve (12) physico-chemical parameters in the water samples was measured viz. colour, temperature, turbidity, total dissolved solids (TDS), pH, electrical conductivity (EC), total suspended solids (TSS), lead (Pb), zinc (Zn), cadmium (Cd), copper (Cu) and nickel (Ni) using standard laboratory procedures and equipment (APHA, 2015; Radojovic and Bashkin, 1999).

Temperature was determined in situ with a mercury thermometer, pH was measured using a digital pH meter, colour was determined using a portable data logging spectrophotometer (HACH DR 2010 equipment), TDS was determined by a HM Digital TDS-4 pocket size meter, EC was determined with the aid of a Suntext SC-120 conductivity meter,

Fig. 1 Map of Makurdi town revealing the River Benue and its tributaries *Source* Benue State Ministry for Lands and Survey, (2011)

turbidity was determined using a HACH 2100P turbidity meter.

TSS was determined using a HACH DR 2010 TSS meter. The presence of Cu, Pb, Zn, Cd and Ni was determined by the methods described by Akinbile et al., (2013) using an atomic absorption spectrophotometer (PG 990 AAS).

Descriptive statistics, spatio-temporal variations and water quality index

Descriptive statistics such as minimum, maximum, mean, standard deviation, skewness and kurtosis for all water quality parameters studied at the chosen locations and times were done using the Statistical Package for Social Sciences (SPSS) software, version 21. Furthermore, the spatio-temporal variations in the water quality were expressed in graphical illustrations using the Microsoft Excel package Version 10.

Upon obtaining the essential physico-chemical features of the water samples, the quality index was evaluated with

the use of WQI tool. WQI was used for approximating the level of pollution of the river by showing the combined consequences of the physico-chemical features at a glance. It is a simplified way of expressing the extent of pollution or otherwise of a water body irrespective of the huge number of variables involved. It gives information about the quality class of the water at a glance.

WQI calculations for the current study were determined based on the BIS 10500 WQI (BISWQI) with slight modifications in which the Nigerian Standard for Drinking Water Quality (NSDWQ) was used as the maximum permissible limit for each parameter. BISWQI determination involved three successive steps. “The first step was ‘assigning weights’. Each of the 12 parameters was assigned a weight (w_i), according to its relative importance in the overall drinking water quality analysis. The most significant parameters were given a weight of 5 and the least significant a weight of 1” (Al-Omran et al., 2015). Currently, the highest weight of ‘5’ was allocated to Cd, while Ni, Pb, Zn, Cu and TDS were given a weight of ‘4’ each. The less harmful

Fig. 2 Map of Makurdi showing River Benue and the sampling points

Table 1 Location of sampling points

Sampling station	Description	Land use and anthropogenic activities	Latitude	Longitude
ST 1	Angbaye	Crop production, brick laying, recreation, fishing, and hunting	7° N 73' 28"	8° E 54' 79"
ST2	Brewery/BSUTH	Crop production, commercial activities brick laying, fishing, industrial effluent discharge and solid waste dumping	7° N 72' 55"	8° E 57' 47"
ST3	Wurukum Abattoir	Mild crop production, commercial activities (Wurukum Market, Abattoir), sand mining, fishing, solid waste dumping, ferrying and recreation	7° N 73' 78"	8° E 70' 22"

parameters (temperature, pH, turbidity, TSS, electrical conductivity and colour) were given a value of '3' each.

The next step was the 'relative weight calculation'. "The relative weight (W_i) was computed using Eq. 1

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

where W_i is the relative weight w_i is the weight of each parameter and n is the number of parameters" ((Al-Omran et al., 2015).

"The third step is 'quality rating scale calculation'. The quality rating scale (q_i) for each parameter is calculated using Eq. 2.

$$q_i = \frac{C_i}{S_i} \times 100 \quad (2)$$

where q_i is the quality rating, C_i is the concentration of each chemical parameter in each water sample in mg /L, except Temperature, pH, electrical conductivity and turbidity, while S_i is the WHO (2011) standard for each chemical parameter.

Finally, the W_i and q_i were used to calculate the SI_i for each chemical parameter (Eq. 3), and then the BISWQI is calculated using Eq. 4.

$$SI_i = W_i \times q_i \quad (3)$$

$$BISWQI = \sum_{i=1}^n SI_i \quad (4)$$

where SI_i is the sub-index of each parameter, q_i is the rating based on concentration of each parameter and n is the number of parameters" (Al-Omran et al., 2015). The computed WQI values were then classified into five categories

(Table 4) in accordance with the methods of Rana et al. (2018), Asit and Surajit (2015), Al-Omran et al. (2015), Ramakrishnalath et al. (2009); Hameed (2012) and Ketata-Rokbani et al. (2011). A general BISWQI was computed for the river water based on the grand means of chemical parameters considered in comparison with the OWQI and CCMEWQI which are well-known standard WQI classification methods (Rana et al., 2018). This was done to enable the authors to draw a holistic conclusion on the quality of the River Benue water in the two seasons.

The OWQI and CCMEWQI are computed using Eqs. 5–6, respectively, Calmuc et al. (2018); Rana et al. (2018).

$$OWQI = \sqrt{\frac{n}{\sum_{i=1}^n \frac{1}{S_i^2}}} \quad (5)$$

where n is the number of parameters, S_i is the sub-index of the sub-index i th parameter.

$$CCMEWQI = 100 - \left(\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732} \right) \quad (6)$$

where

$$F_1 = \left(\frac{\text{Number of variables whose objectives are not met}}{\text{Total number of variables}} \right) \times 100 \quad (6a)$$

$$F_2 = \left(\frac{\text{Number of tests whose objectives are not met}}{\text{Total number of tests}} \right) \times 100 \quad (6b)$$

F_3 = Amplitude – the range to which the failed tests are above the guidelines

Determination of heavy metal index (HMI)

The HMI in this study was estimated following the procedure outlined by Zakhem and Hafez (2015) and utilized again by Sharma et al. (2020). HMI was used to rate the combined influence of different heavy metals on the integral quality of water. Usually, weights between 0 and 1 are assigned to the individual heavy metals depending on the relative importance of the metals. The techniques for determination of HMI are well documented in Zakhem and Hafez (2015) and were adopted for use in this study with slight modifications based on the NSDWQ. The mean value of each heavy metal was used for calculating the HMI for the two seasons (dry and wet). HMI below 19 was taken as low, those from

19–38 were taken as moderate and those > 38 were considered high. A threshold value for HMI of 100 is considered unsuitable for drinking water (Zakhem and Hafez, 2015). The contributions from Ni and Cu were neglected as the mean values were each found to be 0 mg/L in the dry and wet seasons, respectively. Therefore, in this study, only, contributions from Pb, Cu, Cd and Zn were considered for the estimation of the HMI in dry season and those from Pb, Ni, Cd and Zn in the wet season.

Multivariate statistical analysis

According to Fatai (2011) as cited by Akinbile and Omoniyi (2018) “principal component analysis (PCA) otherwise called factor analysis is based on a varimax rotation technique from Statistical Package for the Social Sciences (SPSS Version 15.0) which is used to investigate whether a number of variables of interest $Y_1, Y_2, Y_3, \dots, Y_i$ are linearly related to a smaller number of unobservable factors $F_1, F_2, F_3, \dots, F_k$. It is assumed that each Y variable is linearly related to two factors, according to Sharma (1996) as follows (Eqs. 7–9):

$$Y_1 = \beta_{10} + \beta_{11}F_1 + \beta_{12}F_2 + \beta_{13}F_2 + e_1, \quad (7)$$

$$Y_2 = \beta_{20} + \beta_{21}F_1 + \beta_{22}F_2 + \beta_{23}F_2 + e_2, \quad (8)$$

$$Y_3 = \beta_{30} + \beta_{31}F_1 + \beta_{32}F_2 + \beta_{33}F_2 + e_3. \quad (9)$$

The error terms e_1, e_2 and e_3 , indicate that the hypothesized relationships are not exact. In the special vocabulary of factor analysis, the parameter β_{ij} represents the loadings. For

$$(6c)$$

example, β_{12} is called the loading of variable Y_1 on factor F_2 . Each observation variable is a linear function of independent factors and error terms and can be written as in Eq. 10:

$$Y_i = \beta_{i0} + \beta_{i1}F_1 + \beta_{i2}F_2 + (1)e_i. \quad (10)$$

This can be written in terms of variance as in Eqs. 11 and 12:

$$\begin{aligned} Var(Y_i) &= \beta_{i1}^2 Var(F_1) + \beta_{i2}^2 Var(F_2) + \beta_{i3}^2 Var(F_3) + (1)^2 Var(e_i) \\ &= \beta_{i1}^2 + \beta_{i2}^2 + \beta_{i3}^2 + \sigma_i^2, \end{aligned} \quad (11)$$

$$Var(Y_i) = \beta_{i1}^2 + \beta_{i2}^2 + \beta_{i3}^2 + \sigma_i^2, \quad (12)$$

where $\beta_{i1}^2 + \beta_{i2}^2 + \beta_{i3}^2 = \text{communality}$, and $\sigma_i^2 = \text{specific variance}$. From Eq. 6, the variance of Y_i has three parts: first, the communality of the variable is the part that is explained by the common factors F_1 , F_2 and F_3 . Second, the specific variance is the part of the variance of Y_i that is not accounted for by the common factors. If the three factors were perfect predictors of the variables, then Eq. 13 suffices as follows:

$$e_i = e_2 = e_3 = 0 \text{ always, and } \sigma_{i1}^2 = \sigma_{i2}^2 = \sigma_{i3}^2 = \sigma_{i4}^2 = 0. \quad (13)$$

After identifying the major hidden pollutant sources in the water samples, the next step was to examine the similarity among considered stations for possible zonings according to the level of existing pollution. For this purpose, the hierarchical cluster analysis (HCA) was used to decide which of the sampling points (stations) are most similar to each other, considering all of the pollution properties simultaneously. HCA employs the familiar concept of distance, considering two points, I and j, with coordinates $(X_{1i}; X_{2i}; X_{3i})$ and $(X_{1j}; X_{2j}; X_{3j})$, respectively; the Euclidian distance between the two points is hypotenuse of the triangle ABC expressed as in Eq. 14”.

$$D(I, j) = (A^2 + B^2 + C^2)^{1/2} = \{(X_{1i} - X_{1j})^2 + (X_{2i} - X_{2j})^2 + (X_{3i} - X_{3j})^2\}^{1/2}. \quad (14)$$

These methods have been previously used by other researchers to elucidate on features of surface water resources in several regions of the world (Rana et al., 2018; Akinbile and Omoniyi, 2018; Al-Omran et al., 2015; Park et al., 2014).

Results and discussion

Descriptive statistics and spatio-temporal variation in River Benue water quality

Physical parameters

Results of descriptive statistics revealing the quality features of the Benue River during the dry and wet spells considering the spatial difference of the sampling stations as compared with the World Health Organization (WHO 2015), standards for drinking water, the Food and Agricultural Organization (FAO 2015) standards and the Nigerian Standards for Drinking Water Quality (NSDWQ 2015) are as shown in Table 2.

From Table 2, it was observed that the colour varied from 95 to 250 pt.co and from 160 to 425 pt.co with mean values of 172.5 ± 50.848 and 292.5 ± 146.856 for the dry and wet seasons, correspondingly. The slim variance noticed in the colour of the water in the two seasons may be as a result of the point that colour tends to change in wet season due to rain drops, which disturbs bottom sediments that rise and

dissolve in the water. Colour concentrations in the water were far above the NSDWQ value of 15 for drinking water quality.

The results for temperature as obtained changed from 22 to 30.7°C and from 26 to 30.1°C with mean values of $26.35 \pm 3.077^\circ\text{C}$ and $28.05 \pm 1.633^\circ\text{C}$ for the dry and wet seasons accordingly.

Table 2 Descriptive statistics of physico-chemical parameters of River Benue water

Parameters	Dry season			Wet season			Standards			Remark
	Min	Max	Mean $\pm$ SD	Min	Max	Mean $\pm$ SD	WHO	FAO	NSDWQ	
TDS (mg/l)	125	570	347.5 ± 173.012	150	600	375 ± 158.745	1000	2000	500	**
EC ($\mu\text{S}/\text{cm}$)	50	304	177 ± 128.051	19	315	167 ± 92.791	4000	3000	5000	**
Temp ($^\circ\text{C}$)	22	30.7	26.35 ± 3.077	26	30.1	28.05 ± 1.633	30	25	30	*
pH	7.8	8.7	8.25 ± 0.267	7.0	8.4	7.7 ± 0.133	6.50–8.50	6.50–8.50	6.50–8.50	*
TSS (mg/l)	33	377	205 ± 111.891	37	385	211 ± 133.164	–	–	0.100	***
Colour (pt.co)	95	250	172.5 ± 50.848	160	425	292.5 ± 146.856	–	–	15	***
Turbidity (NTU)	20	531	275.5 ± 158.602	30.1	455	242.55 ± 163.110	1.5	35.0	5	***
Lead (mg/l)	0.025	0.592	0.309 ± 0.171	0.141	0.592	0.367 ± 57.381	0.01	0.01	0.01	***
Zinc (mg/l)	0.097	3.628	1.863 ± 1.445	0.595	0.993	0.794 ± 0.302	5	5	3	**
Copper (mg/l)	0	1.134	0.567 ± 0.370	0	0	0 ± 0.017	2	2	1	**
Cadmium (mg/l)	0.058	0.199	0.129 ± 0.400	0	0.150	0.075 ± 0.072	0.003	0.003	0.003	***
Nickel (mg/l)	0	0	0 ± 0.144	0.201	0.232	0.217 ± 0.012	0.07	0.02	0.02	***

*Within limits

**Below limits

***Above limits

The observed differences in temperature for the two spells can be ascribed to the point that temperature tends to be higher in the dry spell as reported by NIMET (2009). The dry spell had the mean temperature of 26.35 ± 3.077 °C, while the wet spell had a mean value of 28.05 ± 1.633 °C (Table 1). This could be ascribed to weather changes caused by the uniqueness of the two main spells in Nigeria. Except for the FAO value of 25 °C, the average temperatures in the study area were within the acceptable limits of WHO and NSDWQ Fig. 3. These findings are in close alignment with those of Igbiosa et al. (2012).

Turbidity varied from 20 to 531 NTU during the dry spell and from 30.1 to 455 NTU in the wet spell with average values of 275.5 ± 158.602 and 242.55 ± 163.110 , respectively, for the dry and wet spells which were in tandem with the observations of Eloskay and Abukila (2014). Mean values of turbidity were higher than the WHO, FAO and NSDWQ Standards for drinking water (Table 2) (Figs. 3,4,5). Advanced figures recorded for turbidity all through the wet spell in the current study may be associated with the surge in water level ensuing from amplified rainfall amounts, improved soil removal rates and increased carriage of separated soil units. Also, at this level, aquatic resources may give away their capabilities to aid in the abundance of water-based ecosystems, as the most apparent consequence

is a decrease in the light offered for photosynthesis. The foregoing phenomenon tends to diminish the aquatic plant development rates and in turn restricts the quantity of water-based creatures that nourish on these floras and lastly fish population that depend on water-based creatures for their nourishment are affected.

Total dissolved solid (TDS) varied from 125 to 570 mg/L with average figures of 347.5 ± 173.012 mg/L for the dry season and also varied from 150 to 600 mg/L during the wet spell with an average worth of 375 ± 158.745 mg/L. For both spells, TDS values were found to be lower than the WHO limit of 1000 mg/L (WHO 2010), the FAO limit of 2000 mg/L but higher than the NSDWQ limit of 500 mg/L for drinking water. The findings of this work are closely aligned to those of Raman et al. (2009).

Total suspended solids (TSS) varied from 33 to 377 mg/L during the dry spell with an average of 205 ± 111.891 mg/L and from 37 to 385 mg/L during the wet spell with an average of 211 ± 133.164 mg/L. These figures were found to be higher than the NSDWQ allowable limits for drinking water. This can be attributed to the presence in high concentrations of animal matter, industrial waste, decaying plant and sewage in most of the studied locations. High concentrations of suspended solids can cause many problems for streams,

Fig. 3 Spatio-temporal variation in temperature, pH, lead and turbidity

Fig. 4 Spatio-temporal variation in cadmium, nickel, TDS and electrical conductivity

ivers and aquatic life; a similar trend was reported by Anwar et al. (2011).

Chemical parameters

The pH of River Benue water showed relative variations (7.8–8.7) with an average of 8.25 ± 0.267 during the dry spell. It may be inferred that the water was slightly alkaline and might be unwholesome for portable uses during this period. Conversely, the pH values during the wet spell ranged from 7.0–8.4 with an average of 7.7 ± 0.133 . This is attributable to the numerous anthropogenic engagements along the course of the river during the year. These figures were observed to fall within the acceptable limits for drinking water (Figs. 3,4,5). Charkhabi and Sakizadeh (2006) also reported a similar trend for pH in their study on water quality changes in the most polluted reach of the Anzali wetland in northern Iran.

Electrical conductivity (EC) varied from 50 to 304 $\mu\text{S}/\text{cm}$ with an average of $177 \pm 128.051 \mu\text{S}/\text{cm}$ during the dry period and from 19 to 315 $\mu\text{S}/\text{cm}$ during the wet period with an average of $167 \pm 92.791 \mu\text{S}/\text{cm}$. Average figures for conductivity

were found to fall below the WHO, FAO and NSDWQ standard value. The low level of EC during the wet spell may be as a result of the increased volume of the river and decreased temperature in such seasons which does not favour speciation that tend to alter or increase conductivity in water (Chikogo et., al 2012).

Spatio-Temporal variations in heavy metals in River Benue

Heavy metal like Pb, Zn, Cu, Cd and Ni were tested and detected in the water samples during both (dry and wet) seasons (Table 2). Copper (Cu) and nickel (Ni) were not detected at some time during the dry and wet seasons (Table 2). Presence of lead, zinc, copper, cadmium and nickel varied from 0.025 to 0.592, 0.097 to 3.628, 0 to 1.134, 0.058 to 0.199, 0 to 0 mg/L, with averages of 0.309 ± 0.171 , 1.863 ± 1.445 , 0.568 ± 0.370 , 0.129 ± 0.400 and 0 ± 0.144 mg/L, respectively, in dry season. Similarly, they were found to vary from 0.141 to 0.592, 0.595 to 0.099, 0 to 0, 0 to 0.150 and 0.201 to 0.232 mg/L with

Fig. 5 Spatio-temporal variations in colour, TSS, copper and zinc

averages of 0.367 ± 57.381 , 0.794 ± 0.302 , 0 ± 0.017 , 0.072 ± 0.031 and 0.217 ± 0.012 mg/L, respectively, during the wet spell. The presence of lead was quite high and found to be above the WHO, FAO and NSDWQ standards in the both seasons. Similarly, Cd was found to be above the recommended limits by WHO, FAO and NSDWQ in both periods. Conversely, the concentration of nickel was observed to fall below the WHO, FAO and NSDWQ limits in both seasons. Elevated levels of Cd and Ni can be injurious to human health (mainly by the high potency to contract gastro-intestinal ailments like diarrhoea and gastro-intestinal diseases) to man, domestic creatures and wildlife that utilize these aquatic resources for portable reasons (Ayenimo et al. 2010). Zinc and copper were found to be below recommended values of WHO and FAO but were above the NSDWQ in the dry season. Similar findings have been documented in the literature (Olatunji et al., 2012; Olubumi et al., 2010). These elements were however observed to be below all standards during the wet season (Figs. 3, 4, 5). The high levels of these metals in the

Table 3 Heavy metal index for River Benue

S/No	Heavy metals	Heavy metal index (HMI)	
		Dry season	Wet season
1	Pb	6080.00	7240.00
2	Cd	8500.00	4900.00
3	Ni	ND	2070.00
4	Cu	13.40	ND
5	Zn	35.50	47.07
6	Mean/overall	7920.00	5088.56

ND: Not detected

dry season can be associated with leaching of industry-based effluents and clarification of water through nearby iron-containing land forms before moving into the river. Similar observations were posited by Akinbile et al. (2013), as well as Ayodele and Percy (2011) in their separate studies.

Heavy metal index and relative contributions

The HMI and relative contributions from each heavy metal for the studied river in both seasons are as presented in Table 3. It was observed that the HMI ranged from 13.4 to 8500 in the dry season with a mean of 7920.2. The highest and lowest contributions were observed to emanate from Cd and Zn, respectively. In the wet season, HMI varied from 47.07 to 7240 (mean = 5088.6). The highest contributions to the mean HMI in the wet season was observed to be as a result of the high concentration of Pb, while the lowest contribution emanated from Zn pollution.

It was generally observed that the HMI values of River Benue for both the dry and wet spells were extremely above the threshold value (100) recommended for drinking water. These high values of HMI in the river can be attributed to diffuse and point source pollutions from agricultural and industrial activities on the river bank. The River Benue is the major sink for all pollution sources in the area, thus such high values of toxic pollutants in the river are expected as a result of expanding population and increased human/industrial activity with the Makurdi reach where the present study was conducted. These findings collaborate perfectly with the results shown for WQI, which proved that the River Benue water was of the type that could be classified as “Very Poor”.

The HMI values reported for this study are expectedly found to be higher than those reported previously for groundwater (Zakhem and Hafez, 2015; Sharma et al., 2020). This was because surface water is expected to be more polluted as compared to groundwater as a result of contributions from both diffuse and point source pollutions to surface water bodies. Furthermore, high values of Pb and Cd in the river can be linked to the dumping of refuse in the vicinity of the river bank which is a constant practice in the area. Other possible sources of this metals include the effluents from a large meat processing units (abattoir) situated close to the bank of the river. The meat processors utilize waste tyres as source of energy for the roasting of slaughtered animals which deposit heavy metals into the effluents that are discharged directly to the river. Use of pesticides and fertilizers, effluents from a brewery and that from a teaching hospital all located close to the river may be the likely sources of heavy metal pollution.

Principal component/factor analysis and pollutants' relationship

Factor loadings for the dry spell are as shown in Table 4. From Table 4, it can be seen that three rotated factors were unravelled alongside the communality level during the dry

Table 4 Factor analysis for the dry spell

Parameters	Factor 1	Factor 2	Factor 3	Communalities
TDS	0.135	0.189	−0.256	0.789
Electrical conductivity	0.229	0.036	−0.062	0.866
Colour	−0.177	0.038	0.283	0.891
TSS	0.012	−0.259	−0.081	0.825
PH	0.176	0.191	−0.016	0.563
Temperature	−0.012	0.271	0.074	0.897
Turbidity	0.011	0.070	0.353	0.919
Cadmium	0.185	−0.050	0.061	0.971
Zinc	0.055	0.303	−0.049	0.967
Lead	0.151	−0.039	0.166	0.984
Copper	0.088	0.044	0.259	0.764
Nickel	−0.223	−0.028	0.020	0.881

Table 5 Factor analysis for the wet spell

Parameters	Factor 1	Factor 2	Factor 3	Communalities
TDS	−0.486	0.034	−0.024	0.238
Electrical conductivity	0.878	0.307	−0.185	0.900
Colour	−0.279	0.794	0.086	0.716
TSS	0.480	−0.116	−0.235	0.300
PH	0.643	0.158	0.375	0.579
Temperature	0.040	0.659	−0.672	0.888
Turbidity	0.692	0.405	0.270	0.716
Cadmium	0.181	−0.570	−0.563	0.675
Zinc	0.653	0.211	0.250	0.533
Lead	0.855	0.033	−0.214	0.777
Copper	0.187	−0.490	0.719	0.792
Nickel	−0.449	0.793	0.279	0.909

period. Factor 1 was found to be positively laden with nine parameters TDS, EC, TSS, pH, turbidity, Cd, Pb, Zn and Cu as opposed to temperature, colour and Ni (negative stocking), which accounted for 32.3% of the rotated variance. Cd, Pb, pH and EC were found to have the highest positive loadings in factor one and could be said to be responsible for the pollution loads of the studied river water during the dry season.

Akinbile and Omoniyi (2018) also observed a negative loading of temperature in factor 1 in their studies on the Ogbese River, South-western Nigeria. Temperature, colour and nickel reduction are advantageous to the river pollution, however, lead, cadmium, zinc and turbidity were found to have the highest explainable communality in the pollution structure of the river. Conversely, factors two and three were observed to be positively loaded with 8 (Zn, temperature, pH, TDS, colour, turbidity, Cu and Zn) and 7

(colour, turbidity, Cu, Pb, Ni, Cd and temperature) parameters, respectively. Generally, Cd, Pb, Zn and turbidity had the highest extractable communalities and were termed as the main attributes for contamination of the river water in the dry spell. As stated earlier, the pollution of the river with heavy metals could be associated with various anthropogenic activities at the studied locations especially those involving industrial and commercial discharge, as well as indiscriminate dumping of unsegregated solid waste around the shores of the River Benue.

The contamination of Warri River as a result of indiscriminate industrial effluent releases has been reported by Ayenimo et al. (2005). According to the authors, the river was examined for metals like Fe, Cu, Ba, Pb, Cd, Cr, Ni and Co. Findings revealed high levels of the metals at sampling locations that had close proximity to an industry. Relationship investigation of the metals also indicated mutual basis for the river pollution. Other water quality parameters also indicated raised levels in concentration, further signifying contamination of the river by the closely sited industry. A similar trend was also reported by Hatje et al., (2003) in their studies on trace metal dissolution in sediments of an estuary in Australia.

Table 5 shows three rotated factors and communalities for the wet spell, which revealed ten contaminants (TDS, EC, TSS, pH temperature, turbidity, cadmium, zinc, lead and copper) with the uppermost positive loadings in the first factor and accounting for 25.9% of the total rotated variance.

TDS, colour and Ni just as with the case in the dry season were negatively loaded in factor 1 during the wet season. This shows that they were likely not released from the same source with the pollutants that are positively loaded in factor 1. Thus, the prevalence of Pb, Zn, Cu and Cd in River Benue water can be linked to a common source which is likely from waste disposed into the river, while Ni presence in the river may be as a result of seepage from industrial effluents or dissolution of basement rocks.

Research works done in several Nigerian cities had revealed that industry-based discharges are one of the foremost causes of surface water contamination in Nigeria (Ekiye and Luo, 2010). Industrial effluents when released untreated or partially treated into the rivers have potentials of aggregating water quality indices. Dada (1997) reported that “less than 10% of industries in Nigeria treat their effluents before being discharged into the rivers”. This has globally paved way for high loadings of inorganic metals such as Pb, Cd, Cr and Fe in several aquatic entities (Wakawa et al., 2008).

Factors 2 and 3 were observed to be positively loaded with EC, colour, pH, temperature, turbidity, Zn, Pb, Ni, TDS and colour, pH, turbidity, Zn, Cu and Ni, respectively, with Pb, Cu, EC, temperature and Ni having the highest extractable communalities. This suggests that in the wet season, Pb, Cu and Ni appear to be the main heavy metals responsible for the deteriorating quality of River Benue water. As earlier mentioned, Pb and Cu are likely released into the river as

Fig. 6 Dendrogram of hierarchical cluster analysis for all the stations in dry season

a result of anthropogenic influence, while Ni may be contributed from other sources including basement dissolutions (Wakawa et al., 2008; Ezomoh et al., 2019).

Hierarchical cluster analysis and zoning of pollutions in the river

Cluster analysis was accomplished using average values of the studied parameters for every sampling station both for the dry and wet spells. Figure 6 shows the results of four separated clusters along the river in the river shore during the dry season. From Fig. 6, it could be seen that the pollution levels of River Benue were in the order of cluster 4 > 1 > 3 > 2. Clusters 2 and 3 were the least polluted stations and were of the same pollution levels. It can also be seen from Fig. 6 that clusters 2, 3 and 4 were associated to sampling point 1 (Angbaye), while clusters 1 and 3 were associated with sampling point 2 (Brewery and BSUTH) and clusters 2 and 4 were linked to sampling point 3 (Wurukum abattoir). Based on the foregoing, the River Benue water was zoned in terms of increasing pollution load in the order of Wurukum abattoir > Brewery/BSUTH > Angbaye. This trend was linkable to the numerous anthropogenic engagements at the Wurukum and brewery sampling point as compared to Angbaye which is just known for river bank agriculture and mild fishing and recreational activities. Several researchers have attributed an increase in river

water pollution with increasing or diverse human activities (Akimbile and Omoniyi, 2018; Anyanwu et al., 2020; Oluyori et al., 2020).

Figure 7 again shows four (4) separated clusters for River Benue water during the wet season. Just as was observed during the dry season Fig. 6, the contamination ranks of River Benue during the wet season was in the order of cluster 4 > 2 > 3 > 1. Clusters 1 and 3 were the least polluted and had similar pollution levels. It can also be seen from Fig. 6 that clusters 1 and 4 were associated with sampling point 1 (Angbaye), while cluster 3 was associated with sampling point 2 (Brewery and BSUTH). Cluster 2 was linked to sampling point 3 (Wurukum abattoir). Based on the foregoing, the River Benue water was zoned in terms of increasing pollution load for the wet season to be in the order of Angbaye > Brewery/

Table 6 Water quality index (WQI) classifications

BISWQI	OWQI	CCMEWQI	Water quality category
≤ 50	90 – 100	95 – 100	Excellent
50 – 100	85 – 89	80 – 94	Good
100 – 200	80 – 84	65 – 79	Fair
200 – 300	60 – 79	45 – 64	Poor
≥ 300	0 – 59	0 – 44	Very Poor

Fig. 7 Dendrogram of hierarchical cluster analysis for all the stations in wet season

BSUTH > Wurukum. This trend could majorly be attributed to the increased agricultural runoff entering the river at these sampling points, as well as intensive fishing activities especially in the month of October at these locations (Angbaye and Brewery/BSUTH). These findings are in tandem with those of (Hooda et al., 2000; Ayranci and Hooda, 2005; 2011; Talabi et al., 2020).

Assessment of River Benue water using WQI

The WQI of River Benue was estimated using three different indexes viz. the BISWQI, the OWQI and CCMEWQI using the appropriate water quality parameters. Results for the BISWQI during the dry spell were found to be 259.04 and those during the wet season were 236.51 which corresponded to the WQI classification class of “poor water” (Table 6). Similarly, results based on the OWQI gave values of 68.19 and 61.03 for the dry and wet seasons, respectively, which again corresponded to the classification as “poor water”. Furthermore, estimates based on the CCMEWQI were found to be 53.11 and 46.63 for the dry and wet season, respectively, which again correspond to the classification as “poor water”. Thus, it was found that all three WQI approaches adopted in the current study were suitable for estimating the WQI of River Benue. Kondom et al. (2021) made such observations in their study on the suitability of several water quality indexes for estimating River Benue water quality.

The foregoing suggest that potable and other industrial and commercial uses of water obtained from the River Benue at the studied location must be subjected to treatment before such uses as consuming it in its present form, both during the dry and wet seasons poses a great threat to human health and livelihood. Akimbile and Omoniyi (2018) reported similar values of 44.61 and 44.91, based on the classification scale as reported by Elizabeth et al. (2010) and Pradyusa et al. (2009) for the quality of river Ogbese, respectively, for the dry and wet spells, which indicated that the water was bad and could be likened to the River Benue water at Makurdi as considered in the current study. This was another indication that Nigerian rivers are increasing in their pollution levels as a result of diverse factors including anthropogenic activities and urbanization. There is therefore an urgent need to promote continuous monitoring of surface water bodies in order to avert the inherent dangers associated with the consumption of heavily polluted water. Table 5 shows the WQI scale used in the current study.

Conclusions and recommendations

In this study, assessment of heavy metal pollution loads in River Benue water at Makurdi was carried out by employing

the water quality index (WQI) and multivariate statistical tools. WQI based on the BIs standard was found to be 259.04% and 236.51%, respectively, for the dry and wet spells and thus the water was classified as “poor water” in terms of its portable use potentials. The OWQI gave values of 68.19 and 61.03 for the dry and wet seasons, respectively, while the values obtained based on the CCMEWQI were 53.11 and 46.63 for the respective seasons. Comparatively, all WQI methods used revealed that the River Benue water could be classified as “poor water” and as such any of the approaches could reliably estimate the WQI of the studied river.

Factor analysis revealed three rotated factors. Factor one which revealed the highest level of pollution was positively loaded with TDS, electrical conductivity, TSS, pH, turbidity, cadmium, lead, zinc and copper as opposed to temperature, colour and nickel which were negatively loaded in factor 1. Lead, cadmium, zinc and turbidity had the highest communality in the dry season. On the other hand, factor 1 was positively loaded with TDS, electrical conductivity, TSS, pH, temperature, turbidity, cadmium, zinc, lead and copper as opposed to colour and nickel in the wet season. Cluster analysis revealed that sampling points 3 (Wurukum Abattoir) and 2 (Brewery/BSUTH) were the most polluted in the dry season to the release of undiluted effluents into the river, while sampling point 1 was the most polluted during the wet season as a results of increased agricultural runoff into the river. It was experiential that the pollution levels of the water were associated more with increasing and diverse anthropogenic activities within and around the river course in the studied locations.

HMI analysis showed that cadmium and lead were responsible for the high mean HMI values (7920–5088) recorded for both the dry and wet seasons. This suggests that the River Benue water was grossly unfit for domestic and recreational uses.

Specifically, the study showed that there was an objectionable influence on the physico-chemical features of River Benue water, which can be attributed to nearby dumpsites that drain its leachates into the river, as well as from the activities of the Benue breweries, teaching hospital which discharges its untreated waste into the river and increased use of pesticides and fertilizers for agricultural production on the river banks which generate highly polluted runoff into the water body during the wet season.

The implications of the current findings is that domestic, recreational and agricultural consumption of River Benue water at the studied points without prior treatment might negatively disturb the health of man, water-based animals and plants in the vicinity of the polluted water. Apart from the above-mentioned findings, there is also a need to assess the health risk related with the portable consumption of

untreated River Benue water at Makurdi by the residents in order to avert the suspected danger associated with the act.

Limitations of the study

Some limitations of the current include the following:

1. The River Benue water was not monitored throughout the year, only a few months were covered to span the two seasons. There could be some changes if the river was monitored throughout the year for 12 consecutive months.
2. Heavy metals in the samples were determined using the atomic adsorption spectrophotometer (AAS). More accuracies and sensitivity could be gotten if higher equipment like ICP-OES was used.
3. Not all standard water quality indexes were compared in the current study; there could be some discrepancies if other WQI methods are also considered.
4. HCA was used principally for zoning the river course based on the monitored points into various pollution levels. Then, the land use practices and anthropogenic activities within the monitored points were used to infer the likely sources of pollution to the river especially with regards to heavy metals. HCA was not directly used to infer pollution sources and pollutant relationships as is with most study. Although this approach may look new, it also served to be a good method for inferring pollution sources to rivers.

Acknowledgements The authors wish to acknowledge the support received from the Environmental Chemistry Laboratory of the Benue State University, thank you for providing your laboratory space and instrumentation for this research work.

Author's Contribution J.T.U supervised the research and edited the manuscript. R.T.I and M.H participated in data collection, experimental designs and analysis, as well as writing the first draft of the manuscript.

Funding No funding was received for this research.

Data availability All data in this article are fully available without restriction.

Declaration

Conflict of interest The authors have declared that they have no conflict of interests regarding this paper.

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