A Comparison of Water Quality Indexes for an Inland River

F. A. Kondum¹*, R. T. Iwar¹ and E. T. Kon¹

¹Department of Agricultural and Environmental Engineering, University of Agriculture, Makurdi, Nigeria.

ABSTRACT

The present study assessed water quality parameters and attempts to compare four different Water Quality Indexes (WQIs) for consistency, similarity and reliability in assessing the water quality of river Benue - an inland river - under wet and dry seasons. The results demonstrate that River Benue is continually being polluted in both dry and wet seasons by different sources, particularly domestic sewage and storm runoffs from farmlands. The quality of the water generally exceeded physiochemical and microbiological infection risk limits recommended in water quality guidelines concerning their use for domestic, recreational and irrigational purposes. Proper sewage treatment and river quality monitoring are needed to guard against hazards to public health and vulnerable river water resources. The WQIs applied were: CCME WQI, BC WQI, Dinius' WQI and Weighted Arithmetic WQI. To evaluate the differences between these indexes, data on ten water quality parameters (Temperature, pH, total dissolved solids, electrical conductivity, Nitrates, Phosphates, biochemical oxygen demand, dissolved oxygen and faecal coliform count) for two distinct seasons from 6 river monitoring sites along the river Benue at Makurdi reach, were used. Significant discrepancies were observed in classification results between the Dinius' WQI and the other three...
WQIs. Similarly, the WA and BC WQIs showed an over-optimistic rating due to their eclipsing limitation. Among others, it was concluded that any of the four indexes except Dinius’ index can be adopted but the CCME water quality index would be best suited for assessing water quality in River Benue.

Keywords: Water quality indexes; comparison; river benue; water quality parameters.

1. INTRODUCTION

Water is an essential natural resource that sustains human and plant life, and maintains ecological balance for economic and developmental activities of all kinds. Besides the need for drinking, it plays a vital role in the various sectors of the economy such as agriculture, livestock production, forestry, industrial activities, hydropower generation, fisheries and recreational activities [12,18]. The availability and quality of surface waters has been deteriorating due to increasing population, industrialization and urbanization, thereby threatening human and ecological health, drinking water availability and economic development [5,6,7,8]. Rivers are the largest source of fresh surface water; a vital source for maintaining groundwater levels, and have a significant impact on the climate of surroundings where they are found [4].

Water quality impairment results from both anthropogenic inputs (such as municipal and industrial wastewater discharges, agricultural runoff) and natural processes such as chemical weathering and soil erosion. Therefore, it is all the more crucial to monitor and predict surface water quality accurately and timely [9,10,11,12].

Water quality is the chemical, physical, biological and radiological characteristics of water and its necessity to be assessed, because it is required for sustainable water resource use, ecosystem health, social development and more importantly, laying a foundation for the prevention and control of water pollution [13,14]. To efficiently address water quality issues, it is necessary to carry out a critical assessment to evaluate water quality deterioration and pollutant sources. This can be assessed using different water quality indices [15,16,1,17]. A water quality index can be assessed based on various physical, chemical and bacteriological parameters of a water source; this method provides information to the concerned policy makers in reference to the water quality of status of region [12,18].

The task of converting a large amount of very complex water quality data into very simple information which is easily interpretable by non-scientist policy makers is an overwhelming one. The use of numerical indexing systems to integrate a large pool of data into a single value is a great innovation that has helped water quality scientists in surmounting this daunting task. Horton [19] was the first scientist to create a grading method for interpreting water quality data. This innovation paved the way for several types of research which have developed more innovative rating systems, otherwise known as Water Quality Indexes (WQI).

Generally, all WQI is developed following three step procedures. Firstly, there is parameter selection based on the professional judgement of experts. This is usually done using the Delphi approach. Secondly, there is the formation of sub-indices. At this stage, all selected parameters are transformed into dimensionless scaled values, a process which involves creating a quality function (curve) for each selected parameter. Finally, there is the use of arithmetic, geometric or harmonic averages to create a mathematical expression—a process known as Sub-indices Aggregation. The mathematical expression so created is called a Water Quality Index and given a name based on the discretion of the developers. Some examples include, National Sanitation Foundation Water Quality Index (NSFWQI), Canadian Council of Ministers of the Environment Water Quality Index (CCMEWQI), British Columbia Water Quality Index (BCWQI), Dinius Water Quality Index (DWQI) and Oregon Water Quality Index (OWQI).

Numerous water quality indices have been developed all over the world which is used to judge out the general water quality within a particular area promptly and efficiently [20,15,21,22,16,23]. These indices give water quality in a single value by comparing different parameters as per the standards to classify the quality of water of a particular region.

According to Vasistha and Ganguly [18], the available water quality indexes have some
limitations; there are problems of eclipsing and ambiguity which gives rise to issues of opacity and misinterpretation. Also, there is the problem of rigidity of parameters which does not permit additional parameters other than the existing ones; therefore, the water quality index aggregation used for one area might be unsuitable for other areas [1].

Given these limitations, there is a growing awareness to critically assess and choose an optimal water quality assessment index for a particular purpose and specific water use and also for a specific region. Therefore, a comparison of the performance of different water quality indexes (WQI) is necessary to better understand the efficacy of each water quality index and to present a guideline for their use. This guideline will assist in selecting an appropriate water quality index that provides a practical and accurate characterization of the water quality status. However, until now, no attempt has been made to examine and compare the efficacy of numerous water quality indices and to propose the best applications of these indices for accurate and meaningful assessment of water quality in Nigeria and Benue state in particular. Therefore, this work aims to compare different water quality indices for the River Benue water quality assessment.

2. METHODOLOGY

2.1 Weighted Arithmetic Water Quality Index Method (WA)

Weighted arithmetic water quality index method categorized the water quality based on the degree of purity by using the most commonly measured water quality parameters [1]. The method has been widely used by the various scientists and the calculation of WQI is made by using the following equation:

\[ \text{WQI} = \sum_{i=1}^{n} \frac{Q_i}{W_i} \]  

(1)

Where: \( Q_i \) is the quality rating of the ith parameter; \( W_i \) is the relative weight of the ith parameter; and \( n \) is the number of water quality parameters applied.

2.2 Canadian Council of Ministers of the Environment Water Quality Index (CCME)

The CCME WQI was developed as a tool to assess and report water quality information to both management institutions and the public. Several studies in the literature have applied this index for various purposes. In Canada, it was used to evaluate the water quality status of several river basins [24,21], to evaluate drinking water quality [24,25] and to assess water quality in metal mines [26]. In addition to the above-mentioned applications of CCME WQI in Canada, this index also has been adopted in several other countries. The calculation of index scores in CCME WQI method can be obtained by using the following relations:

\[ \text{WQI} = 100 - \left( \frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732} \right) \]  

(2a)

Where:

\[ F_1 = \left( \frac{\text{Number of variables whose objectives are not met}}{\text{Total number of variables}} \right) \times 100 \]  

(2b)

\[ F_2 = \left( \frac{\text{No of tests whose objectives are not met}}{\text{Total number of tests}} \right) \times 100 \]  

(2c)

\[ F_3 = \text{Amplitude-the range to which the failed tests are above the guideline} \]

2.3 British Columbia Water quality Index (BC)

British Columbia water quality index was developed by the Canadian Ministry of Environment in 1995 to evaluate water quality, where water quality parameters are measured and their violation is determined by comparison with a predefined limit. To calculate final index value the following equation is used:

\[ \text{BCWQI} = 100 - \left( \frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.453} \right) \]  

(3)

The number 1.453 was selected to give assurance to the scale index number from zero to 100. It is important to note that repeated samplings and increasing stations increase the accuracy of British Columbia index.

2.4 Dinius Water Quality Index (D)

It is a multiplicative water quality index developed by Dinius for six categories of water uses: public water supply, recreation, fish, shellfish, agriculture and industry [27].
\[ \text{IWQ} = \sum_{i=1}^{n} l_i w_i \] (4)

Where,
\( \text{IWQ} \) = Dinius water quality index whose value ranges from 0–100,
\( l_i \) = sub index function of the pollutant parameter,
\( w_i \) = unit weight of the pollutant parameter whose value ranges from, 0–1 and
\( n \) = number of pollutant parameters.

2.5 Estimation of sub-indices (S_i) and weighting factors (W_i) for parameters

The estimation of sub-indices (S_i) and weighting factors (W_i) for each water quality parameter used in this study was done according to the methods described by Lumb et al. [28]. The water quality ratings and corresponding index values for each of the four indices is shown in Table 1.

2.6 Study Area

The study was conducted on River Benue at Makurdi reach. Makurdi (latitude 7° 41’ N; longitude 8° 28’ E) has an elevation of about 104 meters above sea level. It has a humid tropical climate characterized by two distinct wet and dry seasons. The wet season starts in April and ends in October, while the dry season starts in November and ends in March. The mean annual rainfall is between 1200 and 2000 mm [29,30,31] while the mean annual temperature ranges between 28°C and 33°C and has relative humidity ranges of between 75% and 85%. Makurdi has an area of about 34,059 km² and a population of over 400,000 as at the year 2011 by the National Population Council of Nigeria [32,33]. The River Benue is a major driver of economic, agricultural, and environmental significance in the city as it supplies the bulk of water used by the people of Makurdi and its environs for different activities depending on its point of contact.

The river flows through densely populated areas of humid savannahs and occupies a very wide valley and divides Makurdi into two parts namely, the Northern and the Southern part. It is an important tributary to the River Niger and is the second largest river in Nigeria. The course of the river enters the North Eastern end of the state and runs southwards through, agro-processing industries, and farm-lands, residential and commercial areas in Makurdi. Apart from the industrial effluents that are being released into the river from manufacturing plants within the town, it also serves as a recipient of domestic waste, sewage, abattoir effluents, and agricultural land runoffs. Fig. 1. shows the map of the study area.

2.7 Sample Collection

Sampling was done in both dry (December, January and March) and wet (July, August and September) seasons in 2018 and 2019. Surface water samples were collected from six (6) sampling stations along River Benue at its Makurdi reach between 8:00 to 10:00am in polyethylene bottles of 2 litres capacity at a depth of 1 metre below water surface. The samples were stored in an ice chest containing ice cubes and transported to the laboratory for analysis within 6 hours. The choice of the locations was to reflect virtually all the activities going on in the river.

Samples were analysed for some physical, chemical and biological parameters. The pH, Dissolved Oxygen (DO), Temperature (T), Electrical Conductivity (EC) and Turbidity(Turb) were measured in-situ at 1metre depths using a spectrophotometer (Model 7100, Wagtech Company) in accordance with the procedures given in the user's manual, while total dissolved solid (TDS), Nitrate (N), Biological Oxygen Demand (BOD), Faecal Coliform (FC), Sulphate, Total hardness, Na⁺, Mg²⁺, Ca²⁺, Cl⁻, K⁺, and Total Suspended Solids(TSS) concentrations were analysed using standard equipment and procedures in accordance with the standard methods of water and wastewater guidelines by APHA [35] at the Benue Rural Water Supply and Sanitation Agency (BENWASSA) laboratory in Makurdi.

| Ratings  | CCME   | D    | BC  | WA   |
|----------|--------|------|-----|------|
| Excellent| A 95-100| 91-100| 0-3 | 0-25 |
| Good     | B 80-94 | 81-90| 4-17| 26-50|
| Fair     | C 65-79 | 60-80| 18-43| 51-75|
| Poor     | D 45-64 | 50-59| 44-59| 76-100|
2.8 Data Analysis

Calculations of means and standard deviations (SD), correlations (paired t test) and two-way analysis of variance (ANOVA) were performed using Sigmaplot 14.0 version (Systat Software Inc.). All tests of significance and correlations were considered statistically significant at P values of <0.01. Mean values of water quality parameters were compared with standard values recommended by the World Health Organization (WHO) and Nigeria Standard for Drinking Water Quality (NSDWQ).

3. RESULTS AND DISCUSSION

3.1 Concentrations of Water Quality Parameters in River Benue

The average values and standard deviations (SD) of water quality parameters for river Benue in both wet and dry seasons in relation with the recommended values given by the World Health Organization (WHO, 2008), and the Nigeria Standard for Drinking Water Quality [36] are presented in Table 2.

3.2 Temperature

The mean and standard deviation of Temperature for the wet season (WS) was 26.86±0.98 and 27.60±0.62ºC in the dry season (DS). This difference in temperature is as result of the usually hot weather conditions experienced in last two and half months (February to April) of the dry season, ambient temperatures reach 40ºC. Water Temperature has great influence on both biological activities and the chemistry of surface waters. The raise in temperature results to a decrease in the amount of dissolved oxygen and other gases due to reduction in molecular forces of attraction between gas molecules [18]. A particular Temperature range determines the kinds of organisms that can live in rivers and lakes. Once temperatures exceed these thresholds, rivers and lakes begin to experience aquatic drift. With regards to water chemistry, temperature influences the rate of chemical reactions in water...
bodies. Higher temperatures result in increased chemical reactions. Also, higher temperatures can increase the solubility and thus toxicity of certain compounds [37,18]. For example, minerals in surrounding rocks and debris can dissolve, thereby increasing the electrical conductivity of the water body. Also, high water temperatures result in low dissolved oxygen and pH levels, than cool water temperatures. In addition, according to WHO [38], water temperature affects the palatability and impacts on the acceptability of some organic and inorganic water constituents. For instance, high water temperature is positively correlated with growth of microorganisms and enhances taste, odour, colour and corrosion problems.

For this present study, water temperature values were lower compared to the water temperature values obtained in previous studies by Soom et al. [39] and Akaahan et al. [6] who reported average water temperatures of 29.63±0.53ºC and 28.09±1.97ºC, respectively. However, the results are within the standard range of 25-30°C given by the WHO [37] and NSDWQ [35].

3.3 Hydrogen ion concentration (pH)

This is a measure of the relative amount of free hydrogen and hydroxyl ions in water. The pH of water affects the biological and chemical constituents of a water body as well as its usage [2,40,18]. The solubility of chemicals such as nutrients and heavy metals present in a water body determines whether aquatic life can use it. Toxicity of metals present in water increases with decrease in pH values [41] (Nambatingar et al. 2017). Also, high pH ranges causes a bitter taste, encrusts water pipes with deposits and it reduces the effectiveness of chlorine as a disinfectant in water treatment processes. Conversely, low water pH corrodes metals and other substances in contact with it.

In this study, pH values showed different values between the WS and DS in which the WS values were higher (8.73±0.49), while DS recorded 7.69±0.19. This difference is due to the negative correlation between water temperature and pH. During the DS water temperatures are higher resulting in lower pH levels. These values were high compared to 7.01±0.03 and 6.95±0.86 reported by Eneji et al. [32] and Akaahaan et al. [6], respectively. Similarly, Okenyi et al. [42] reported average values of 6.43 for WS and 6.45 for DS, while Soom et al. [39] gave 6.64±0.26 for the same basin. Although, the DS results are within the standard range recommended by the WHO and NSDWQ, those of the WS exceeded the upper threshold value of 8.50. This increase in pH during the WS is apparently due to an increase in photosynthetic algae activities resulting from high nutrient run-off in agricultural fields, household and agro-allied activities on the river banks. However, according to Albadaii et al. (2013), an overall pH range of 6.5 to 9 is adequate for aquatic life. Therefore, it is very important to maintain this pH range for sustainable aquatic ecosystem functioning.

3.4 Turbidity

It is an optical property of water that measures the amount of light that is scattered by materials present in the water when light passes through the water sample. Excessive turbidity in water is aesthetically unappealing and poses a health concern. This is because turbidity results from the presence of suspended particles such as silt, clay, organic matter, and microscopic organisms. Turbidity provides shelter to pathogens. By attaching themselves to particulate matter, pathogens reduce their exposure to disinfectants. Studies have shown a strong relationship between removal of turbidity and removal of protozoa [43,44]. In this study, average turbidity values varied between 195.49±65.62 and 94.03±14.74 NTU for the WS and DS, respectively. This high variation is attributable to the high volume of sediment packed runoffs from agricultural fields and residential areas during the WS. In the DS, the sediments settle at the bottom of the river, making it less turbid. Both WS and DS turbidity values exceeded the recommended limits (5 NTU) set by WHO and NSDWQ. The implications of this is that, water treatment costs will increase since it would take more time and treatment chemicals to achieve desired results. Furthermore, such high concentrations of particulate matter affect light penetration and ecological productivity, recreational values, and habitat quality, and causes sedimentation. With increased sedimentation, siltation can occur, which can result in harm to habitat areas for fish and less stream capacity for impoundment of runoff, leading to flooding.

3.5 Total Dissolved Solids

This water quality parameter measures the concentrations of ions present in the water body. The average concentration of total dissolved solids (TDS) in the DS and WS are 24.87±4.09
and 45.48±6.29 mg/L, respectively. In this study, the concentrations of TDS were less than those reported for the same basin (35.5 for DS and 77.5 for WS) by Okenyi et al. [42]. Moreover, it was observed that the WS has higher TDS values compared to the DS. This can be attributed to the presence of extreme anthropogenic activities along the river course and runoff with high suspended matter, during the WS, which is non-existent in the DS.

However, the average values are within the recommended limits of 250 mg/L and 500 mg/L given by the WHO and NSDWQ, respectively. Despite being within acceptable limits, it is important to note that: TDS in water originates from natural sources (rock minerals), sewage, agricultural and urban run-off, industrial wastewater, and chemicals used in the water treatment processes. High TDS may affect the aesthetic quality of the water, corrode plumbing fixtures, impact a bitter or salty taste, waste soap, result in incrustations, films, or precipitates on fixtures, and reduce the efficiency of water filters and boiler equipment. The palatability of drinking water with a TDS level of smaller than 600 mg/L is always considered to be good for human health, while if it is larger than 1000 mg/L considered to be unpalatable [45,3]. Therefore, proper wastewater treatment and runoff management practices should be employed to maintain low concentrations of TDS in River Benue.

3.6 Electrical Conductivity

Considers how well electricity can pass through the substances that are present in the water. It looks at the concentration of dissolve ionic nutrients that are in the water. EC can be related to TDS of the water, but the relationship is function of the type and nature of the dissolved ions and possibly the nature of any suspended materials. TDS accounts for both EC generating particles as well as particles that don’t conduct electricity which is where the main difference lies. In this study, average EC concentrations for WS were 535.78±13.65 and DS was 574.11±9.10 μs/cm. These concentrations are far above the acceptable limit of 250 μs/cm given by the WHO; conversely, the NSDWQ considers concentrations ≤1000 μs/cm to be acceptable. The EC values for this study were considerably higher, compared to the values obtained in previous studies [32,46,42] within the same water body. Generally, EC in river Benue was affected by the inorganic dissolved solids majorly calcium from limestone which is an abundant rock within the basemen complex. Also, nitrate, sulphate, magnesium, and sodium are common mineral constituents found in tributaries of the River Benue, therefore these could have also influenced high EC concentrations. Also, Higher variations in the EC could be attributed to anthropogenic activity and geochemical processes prevailing in the study area [47,3]

3.7 Nitrate

The nitrate (NO$_3^-$) concentrations in WS and DS were 14.69±1.35mg/l and 8.34±0.30 mg/l respectively. In addition, the nitrate values in this study were within the maximum permissible limit set by WHO [38] and NSDWQ [36] which is 50mg/L. Similarly, approximate concentrations of 2.0mg/l (DS) and 2.7mg/l (WS) were reported in the same basin by Okenyi et al. [42]. This drastic increase may likely have been influenced by the increase in farming activities within the catchment area, where use of inorganic fertilizer is common. The discharge of sewage water, runoff from agricultural fields sprayed with fertilizers and pesticides can lead to input of inorganic nutrients into the soil which washes off into the river [18]. According to Maila et al. [48] the occurrence of nitrate in water is mainly of anthropogenic sources due to the contact of soil with nitrate fertilizers, animal wastes, domestic effluents, human and septic tank leakage. Elevated levels of nitrates in water can cause: overstimulation of growth of aquatic plants and algae, restriction of oxygen transport in the bloodstream of animals drinking such waters. Furthermore, the reduction of nitrate to nitrite increases toxicity of nitrate to humans. Nitrite in human blood oxidises normal haemoglobin to methaemoglobin which inhibits transport of oxygen to the tissues [49].

3.8 Phosphates

The average concentrations of phosphate (PO$_4^{3-}$) ranged from 1.89±0.26mg/L in the WS and 1.91±0.50mg/L during DS. These values exceed the acceptable levels set by WHO and NSDWQ which is 0.7mg/L. In addition, results were low compared to the results from the same basin recorded by Eneji et al. [32] which ranged from 5.65 to 6.63mg/L in the WS and 3.73 mg/L in DS. Overall, high concentrations of phosphates are an indication of the pollution associated with a reduction in dissolved oxygen in water bodies caused by an increase of mineral and organic nutrients (eutrophication) conditions. Moreover,
domestic effluents particularly those rich in detergents, fertilizer runoff, and industrial wastewater are the main reasons of high phosphate levels in surface waters such as rivers and lakes. Given the indiscriminate discharge of untreated municipal wastewater into the river Benue, and prevalent soil erosion, these high phosphate concentrations are expected. From the average levels of phosphate for the period under study, it is apparent that municipal effluents are a major source of phosphates in river Benue. There is an urgent need for setting up a wastewater treatment plant to reduce phosphate levels in effluents before discharge into the river Benue.

3.9 Biochemical oxygen demand (BOD)

This represents the amount of oxygen required to remove waste organic matter from water under aerobic conditions at a given temperature. It is used as an index of the degree of organic pollution in water. The average BOD of the river Benue was 61.81±4.35 in the WS and 28.81±4.04 in the DS. The higher values of BOD recorded in WS is as a result of natural plant decaying processes and other contributors that increase the total nutrient in water bodies such as runoff rich in fertilizer, abattoir wastewater being directly discharged into river without any form of treatment, and sewage from the urban areas. Additionally, the BOD values of the river Benue in both seasons were not within the recommended permissible limit (10 mg/L) by WHO and NSDWQ. Considering reports from previous works [32,33,38], the concentrations of BOD in river Benue has increased considerably over the last 8 years. BOD concentration is directly associated with DO concentrations. High values of BOD imply a decline in DO, but the presence of a sufficient concentration of dissolved oxygen is critical to maintaining the aquatic life and aesthetic quality of streams and lakes. This further underscores the urgent need for a wastewater treatment plant in Makurdi town and provision of measures to control runoff from farm lands draining into the river Benue.

3.10 Dissolved Oxygen

The dissolved oxygen (DO) of the water samples analysed ranged from 6.22±1.02mg/L during WS, and from 11.42±3.81mg/L during DS. The lowest DO was recorded in the WS, while the higher values were recorded in the DS. Furthermore, the DS results are within the standard acceptable levels (≥10mg/L) for Nigerian rivers, however the WS levels were lower than the permissible levels. Additionally, values of DO found by Eneji et al. [32] in their study of the same basin were below what was obtained in this present study. A possible reason for DO peaking in DS and declining in the wetter months could be that the WS, make the waters murky, requiring more aerobic activities, thereby reducing DO whereas in the DS, the waters are less turbid, hence, high DO [40].

3.11 Faecal Coliforms Count

The faecal coliform bacteria are introduced into the surface waters from the release of domestic waste and sewage into water bodies; Sewage can serve as a substrate for microorganisms to survive hence such polluted waters usually possess a high microbial load [50,18] thereby reducing the portability of water by introduction of various fatal diseases. Faecal coliforms were present in all the water samples, and none of the water samples met international standards for human consumption. The mean FCC values of 4.2×10^3±1.8×10^3 and 1.62×10^3±7.0×10^2 were recorded both dry and wet seasons, respectively. These values were much higher than the WHO [38] and NSDWQ [36] values which should be zero (per 100 ml) of sample in all drinking water supplies, piped or unpiped, treated or untreated, and <1,000 faecal coliforms/100ml for unrestricted irrigation [38,51]. Implication is that none of the water samples in both seasons met recommended standards. With these high values of FCC present in the river Benue, there are serious concerns over the health of the consumers of such crops irrigated and washed with River Benue water, and that of fishermen and river goers along the river course who use the water, at sections considered clean, for drinking, domestic and recreational purposes. Apparently, this might explain the prevalence of waterborne and food-borne diseases, such as typhoid fever, cholera and diarrhoea prevalent in the area. Therefore, river Benue water poses a health risk and is not suitable for human consumption and irrigation purposes. These findings are consistent with that of Owuna [52].

3.12 Seasonal Variations and water quality status

The river water quality experienced slight changes with respect to the two distinct seasonal variations (wet and dry seasons). The dry season is characterised by low flow conditions with less turbidity, making the water clear. Conversely, the
wet season has high flow conditions and with high turbidity and debris, making the river murky. Overall, in dry season water quality was slightly better than wet season which is not surprising. Two scenarios influence the slight difference in water quality between the DS and WS. Firstly, since wastewater inputs from Makurdi town are not subject to seasonal variations, the amount of pollutants remained relatively stable throughout the year. So, during high flow conditions of the WS, concentrations of pollutants in the river water decreased due to dilution, but, runoff rich in agricultural pollutants and silts cancels out the dilution effect. Secondly, in the DS there is no dilution of pollutants by rainfall; however, there is no addition of pollutants from runoff. Thus, the difference in water quality between the two seasons is not substantial. Nevertheless, some quality parameters, particularly turbidity experience considerable variations between both seasons. In Table 2, the average Turbidity concentration for WS is more than twice that for DS.

Along the river course, as expected, the upstream water quality was better than downstream. S6 and S5 were highly polluted downstream due to the presence of dense human population of the area. In addition, low water flow volumes in the DS prevented much dilution effect, since effluents from hospitals, markets and residential areas were continuously discharged into the river. In the upstream section of the river, particularly S1, the sparsely populated areas, characterized by irrigated farmlands does not contribute runoff to the river in DS. Apparently, the water quality appeared to be good or fair. Nevertheless, there is need for improvement in the quality of water through better management measures such as establishment of waste water treatment plants.

The BC and D WQIs rated the river water quality as highly polluted at all the sampled locations (See Table 3). Conversely, the situation at sampling sites was more contrasted and varied with the CCME and WA WQIs. Generally, the BC and D indexes were more pessimistic than the CCME and WA WQIs in all seasons of the year. Exceptionally, the D water quality index remained alarmist by rating water quality in as extremely poor all year round. It was unable to distinguish water quality status at the sampling sites with varying hydrological conditions because the water quality is determined using the worst evaluation of the overall parameters and appeared systematically as very poor. In general the 3 remaining indexes reveal a slight quality increase by at least a gain of one quality class from WS to DS conditions (again, see Table 3).

The product moment correlation coefficients are shown in Table 4. All five indices are meaningfully correlated with each other. The CCME and BC indices are highly correlated having a correlation coefficient of 0.937. Also, the CCME water quality index is highly correlated with D water quality index and also closely related with WA water quality index, although negatively. However, the D water quality index has the least negative correlation of -0.541 with WA.

The graphical presentation of various water quality indices is given in Fig. 2. Although, the monthly variation of water quality indices shows a regular trend for CCME, BC and D, it can be observed that results of WA index show no regular trend except that lower values of water quality index has been observed in the months of December and January. Also, mathematical analysis has been carried out to determine the correlation among the indices.

The WA water quality index rated the river water quality higher than the other three index methods. The CCME and BC WQIs have a similar pattern for the change of water quality over the six months period.

| Parameters | Wet season (mean±SD) | Dry season (mean±SD) | WHO | NSDWQ |
|------------|----------------------|----------------------|-----|-------|
| T(ºC)      | 26.86±0.98           | 27.60±0.62           | 30  | 30    |
| pH         | 8.73±0.49            | 7.69±0.19            | 6.50-8.50 | 6.50-8.50 |
| Turb (NTU) | 195.49±65.62         | 94.03±14.74          | 5   | 5     |
| TDS(mg/l)  | 24.87±4.09           | 45.48±6.29           | -   | 500   |
| EC( μs/cm) | 535.78±13.65         | 574.11±9.10          | 250 | 1000  |
| NO₃⁻(mg/l) | 14.69±4.35           | 1.89±0.26            | 8.34±0.30 | 50    |
| PO₄³⁻(mg/l)| 1.91±0.50            | 1.89±0.26            | 0.70 | 0.70  |
| BOD(mg/l)  | 61.81±4.35           | 28.81±4.04           | 10  | 10    |
Table 3. Water quality status according to the four water quality indexes

| Months  | WQI/Location | S₁ | S₂ | S₃  | S₄  | S₅ | S₆ |
|---------|--------------|----|----|-----|-----|----|----|
| January | CCME         | 6.22±1.02 | 11.42±3.81 | 10  | 10  |
|         | BC           | 4.2×10³±1.8×10³ | 1.0 | 10  | 10  |
|         | sWA          | 21.17±E | 20.84±E | 20.57±E | 21.3±E | 21.94±E | 20.92±E |
|         | D            | 4.2×10³±1.8×10³ | 1.0 | 10  | 10  |

Table 4. Product moment correlation coefficients among four indices

|         | CCME   | BC    | WA    | D     |
|---------|--------|-------|-------|-------|
| CCME    | 1      | .937**| -.797**| .872**|
| BC      | .937**| 1     | -.726**| .541**|
| sWA     | -.797**| -.726**| 1     |       |
| D       | .872**| .541**| 1     |       |

**Correlation is significant at 0.01 level (2-tailed)
The D has the problem of ambiguity, while the WA has the problem of eclipsing. According to Gupta et al. [17], the problem of eclipsing is the underestimation rather than exaggeration of pollution. Eclipsing occurs when extremely poor environmental quality exists for at least one pollutant variable, but the overall index does not indicate this fact. This explains the high optimism of the WA WQI in rating the river Benue water quality above the other three index methods. The BC index also has the problem of eclipsing. It does not account for a zero value of any one sub-index if the overall index is greater than zero. The Danius water quality index is a multiplicative index which rated all water samples as being very poor, regardless of considerable changes in some quality parameters. The DWQI value is also lower than the rest three indices. It could be characterized as strictest, given that its application leads to the classification of the river with the lowest quality category of E. Finally, CCMEWQI could be characterized as modest given that its application gave the classification of the river mostly between the middle classes of the quality ranking, ranging between classes B and D.

4. CONCLUSION

The results presented here demonstrate that River Benue is continually being polluted in both dry and wet seasons by different sources, particularly domestic sewage and storm runoffs from farmlands. The quality of the water generally exceeded physiochemical and microbiological infection risk limits recommended in water quality guidelines with respect to their use for domestic purposes, recreation and irrigation. Proper sewage treatment and river quality monitoring are needed to guard against hazards to public health and vulnerable river water resources.

WQIs are useful tools, particularly for water management stakeholders who need to know whether the quality of water bodies is good enough for specified activities. Water quality indexes make it possible to sum up complex water quality parameters into a single digit in understandable classes (excellent, good, fair, poor and very poor). Several WQIs have been developed and used for specific management purposes in site specific hydrological conditions. Despite the large number of studies carried out using different WQIs for quality assessment of inland water bodies, there is hardly any reported study that compares these diverse WQIs. Considering the lack of information in this area of water quality indices, the present study compared four WQIs, namely: CCME, BC, WA and D for consistency, similarity and reliability in assessing the water quality of an inland river.

To evaluate the differences between these indices, data on ten water quality parameters (Temperature, pH, total dissolved solids, electrical conductivity, Nitrates, Phosphates, biochemical oxygen demand, dissolved oxygen and faecal coliform count) available for two distinct seasons (wet season and dry season) for 6 river monitoring sites across the river Benue at Makurdi reach, were used. Although all the four indexes showed significant correlation with each other, Dinius’ index was the lowest of the four. Correspondingly, The WA and BC WQIs showed an over optimistic rating due to their eclipsing limitation. Apparently, one should prefer any of the three indices to Dinius’ index, and the best choice would be the CCME water quality index. Therefore, any of the four indexes except Dinius’ index can be adopted but the CCME water quality index would be obviously the best suited for assessing water quality in river Benue. In conclusion, deviations in results of the various indices was observed, nevertheless, the application of the above methodologies in an adequate number of water bodies and sampling period is needed in order to arrive at more reliable conclusions regarding their comparative performance for inland water bodies.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Tyagi S, Sharma B, Singh P, Dobhal R. Water quality assessment in terms of water quality index. American Journal of Water Resources. 2013;1(3):34-38. DOI: 10.12691/ajwr-1-3-3.

2. Khatri N, Tyagi S. Influences of natural and anthropogenic factors on surface and groundwater quality in rural areas. Frontiers in life science. 2014;8(1):23-29.
3. Adimalla N, Qian H. Groundwater quality evaluation using water quality index (WQI) for drinking purposes and human health risk (HHR) assessment in an agricultural region of Nanganur, south India. Ecotoxicology and Environmental Safety. 2019;176:153-161.

4. Deo RC, Samui P, Kisi O, Yaseen ZM. Intelligent data analytics for decision-support systems in hazard mitigation: Theory and practice of hazard mitigation. Springer Transactions in Civil and Environmental Engineering. Ebook; 2021. DOI: https://doi.org/10.1007/978-981-15-5772-9

5. Houser JN, Richardson WB. Nitrogen and phosphorus in the upper Mississippi river: Transport, processing and effects on the river ecosystem. Hydrobiologia. 2010;640: 71-88. DOI: https://doi.org/10.1007/s10750-009-0067-4.

6. Li S, Zhang Q. Spatial Characterization of Dissolved Trace Elements and Heavy Metals in the Upper Han River (China) Using Multivariate statistical Techniques. 2009;176(1-3):579-588. DOI: 10.1016/j.jhazmat.2009.11.069.

7. Morse NB, Wollheim WM. Climate Variability Masks the Impacts of Land Use Change on Nutrient Export in a Suburbanizing Watershed. Biogeochemistry. 2014;121:45-59. DOI: https://doi.org/10.1007/s10533-014-9998-6.

8. Wu Z, Wang X, Chen Y et al. Assessing river water quality using water quality index in Lake Taihu Basin, China. Science of the Total Environment. 2018;612:914–922

9. Holloway JM, Dahlgren RA, Hansen B, Casey WH. Contribution of Bedrock Nitrogen to High Nitrate Concentrations in Stream Water. Nature. 1998;395(6704):785-788. DOI: https://doi.org/10.1038/27410

10. Singh KP, Basant N, Gupta S. Support vector machines in water quality management. Anal. Chim. Acta. 2011;703:67-68. DOI: 10.1016/j.aca.2011.07.027.

11. Ji X, Dahlgren RA, Zhang M. Comparison of seven water quality assessment methods for the characterization and management of highly impaired river systems. Environ. Monit. Assess. 2015;188(15):1-16. DOI: https://doi.org/10.1007/s10661-015-5016-2.

12. Chen K, Chen H, Zhou C et al. Comparative analysis of surface water quality prediction performance and identification of key water parameters using different machine learning models based on big data. Water Research. 2020;171:115454.

13. Onyegeme Okerenta BN, Obia C, Wegwu MO. Physiochemical properties of water quality of Imeh, Edgelem and Chokocho communities located along Otamiri-Oche river in Etche Ethnic Nationality of Rivers State, Nigeria. J. Appl. Sci. Environ. Manag. 2016;20(1):113-119.

14. Shrestha S, Kazama F. Assessment of surface water quality using multivariate statistical techniques: A case study of the Fuji River Basin, Japan. Environmental Modelling and Software. 2007; 22(4):464-475. DOI: 10.1016/j.envsoft.2006.02.001.

15. Gupta AK, Gupta SK, Patil RS. A comparison of water quality indices for coastal water. Journal of Environ. Sci. and Health, Part A: Toxic/Hardous Substances and Environ. Engineering. 2003;38(11):2711-2725. DOI: https://doi.org/10.1081/ESE-120024458.

16. Turkey P, Bhattacharya T, Chakraborty S. Water quality indices-important tools for water quality assessment: A review. International Journal of Advances in Chemistry. 2013;1(1):15-28. DOI: 10.5121/ijac.2015.1102.

17. Shin JY, Artigas F, Hobble C et al. Assessment of anthropogenic influences on surface water quality in urban estuary, Northern New Jersey: Multivariate approach. Environ. Monit. Assess. 2013;185:2777-2794. DOI: 10.1007/s10661-012-2748-0.

18. Vasistha P, Ganguly R. Water quality assessment of natural lakes and its importance: An overview. Materials Today: Proceedings. 2020;30(30):1-9. DOI: https://doi.org/10.1016/j.matpr.2020.02.092

19. Horton RK. An index number system for rating water quality. Journal of Water Pollution Control. 1965;37(3):300-306.
20. Abbasi SA. Water quality indices. State-of-art report, National Institute of Hydrology, Scientific Contribution; 2002. No. INCOH/SAR-25/200562, Roorkee: INCOH, 73.

21. Lumb A, Halliwell D, Sharma T. Application of CCME water quality index to monitor water quality: A case study of the Mackenzie River Basin, Canada. Environ. Monit. Assess. 2006; 113:411-429. DOI: https://doi.org/10.1007/s10661-005-9092-6.

22. Kannel PR, Lee S, Lee YS, Kannel SR, Khan SP. Application of water quality indices and dissolved oxygen as indicators for River water classification and urban impact assessment. Environ. Monit. Assess. 2007;132(1-3):93-110. DOI: 10.1007/s10661-006-9505-1.

23. Mukate S, Whag V, Panaskar D, et al. Development of New Integrated Water Quality Index (IWQI) model to evaluate the drinking suitability of water. Ecological Indicators. 2019;101:348-354.

24. Khan F, Husain T, Lumb A. Water quality evaluation and trend analysis in selected watersheds of the Atlantic region of Canada. Environ Monit Asses. 2003;88:221-242. DOI: 10.1023/a:1025573108513.

25. Hurley T, Sadiq R, Mazumder A. Adaptation and evaluation of the Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI) for Use as an effective tool to characterize drinking source water quality. Water Res. 2012;46(11):3544-52. DOI: 10.1016/j.watres.2012.03.061.

26. De Rosemond S, Duro DC, Dube M. Comparative analysis of regional water quality in Canada Using the Water Quality Index. Environ Monit Assess. 2009;156(1-4):223-40. DOI: 10.1007/s10661-008-0480-6.

27. Dinius SH. Design of an index of water quality. Water Resou. Bull. 1987;23(5):833-843. DOI: 10.12691/ajwr-1-3-3.

28. Lumb A, Sharma T, Bibeault JF, Klawunn P. A comparative study of USA and Canadian water quality index models. Water Qual. Expo. Health. 2011;3:203-216. DOI: https://doi.org/10.1007/s12403-011-0056-5

29. Akpen GD, Eze RAM. Water pollution modelling of the river benue in the reach of Makurdi Town. Journal of Nigerian Society of Engineers, NSE Technical Transaction. 2006;41(2):45-46.

30. Isikwue MO, Iorver D, Onoja SB. Effect of depth on microbial pollution of shallow wells in Makurdi Metropolis, Benue State, Nigeria. British J. Environ. Climate Change. 2011;1(3):66-73. DOI: https://doi.org/10.9734/BJECC/2011/354

31. Aho IM, Utsev JT, Isikwue MO. Trend analysis of raw water parameters in River Benue at the Reach of Makurdi, Nigeria. Global Journal of Engineering Research. 2014;13:1-9 DOI: 10.4314/gjer.v13i1.1.

32. Eneji IS, Onuche AP, Sha’ato R. Spatial and temporal variation in water quality of River Benue, Nigeria. Journal of Environmental Protection. 2012;3: 915-921. DOI: 10.4236/jep.2012.328106.

33. Akaahan TJ, Araoye PA, Olabanji FM. Macro invertebrates fauna group and their relationship with environmental variables in River Benue at Makurdi, Benue State, Nigeria. Journal of Ecology and the Natural Environment. 2014;6(8):271-279. DOI: https://doi.org/10.5897/JENE2014.0460.

34. Agyo RA, Ofukwu RA, Okoh AEJ, Agada CA. Bacteriological quality of water in private wells and boreholes in Makurdi Metropolis, Benue State, Nigeria. Int. J. One Health. 2020;6(1):76-82. DOI: www.doi.org/10.14202/IJOH.2020.76-82.

35. APHA, AWWA, WEF. Standard methods for the examination of water and wastewater, 21st ed. Washington, DC, American Public Health Association, American Water Works Association and Water Environment Federation; 2005.

36. Nigerian Standard for Drinking Water Quality (NSDWQ). Nigerian Industrial Standard NIS 554, Standard Organization of Nigeria; 2007.

37. Bhateria R, Jain D. Water quality assessment of lake: A review. Sustainable Water Resources Managemen. 2016;2:161-173.

38. World Health Organization (WHO). Guidelines for drinking-water quality: 3rd Edition Incorporating the first and second addenda volume 1 recommendations. Geneva: World Health Organization; 2008.
39. Soom JW, Solomon SG, Ayuba VO. Assessment of some physico-chemical parameters of River Katsina-Ala at Buruku, Benue State, Nigeria. International Journal of Fisheries and Aquatic Studies. 2018;6(2):556-561.

40. David DL, Barau BW, Hammanjoda SA, et al. Water quality of the upper Benue River of Taraba State, Nigeria. Ethiopian Journal of Environmental Studies & Management. 2020;13(2):261-273.

41. Li H, Shi A, Li M, Zhang X. Effect of pH, temperature, dissolved oxygen, and flow rate of overlying water on heavy metals release from Storm Sewer Sediments. Journal of Chemistry. 2013;2013. DOI: https://doi.org/10.1155/2013/434012

42. Okenyi BE, Ngozi Olehi C, Ibe CO. Physico-chemical index of River Benue and its implications. IOSR Journal of Applied Chemistry. 2016;9(4):53-55. DOI: 10.9790/5736-0904015355.

43. Heller L, Martins Vieira MBC, Alves de Brito LL, Salvador DP. Association between the concentration of protozoa and surrogates in effluents of the slow sand filtration for water treatment. Brazil Journal of Microbiology. 2007;38(2). DOI: https://doi.org/10.1590/S1517-83822007000200029

44. Omarova A, Tussupova K, Berndtsson R, et al. Protozoan parasites in drinking water: A system approach for improved water, sanitation and hygiene in developing countries. International Journal of Environ. Res. Public Health. 2018;15(3):495. DOI: 10.3390/ijerph15030495.

45. World Health Organisation (WHO). Guidelines for Drinking water quality, 4rd ed. incorporating the first and second addenda. Recommendation, Geneva. 2011;1.

46. Akaahan TJ, Anaga SO, Akogwu SA. Studies on aesthetics of water quality of River Benue, Makurdi, Nigeria. Asian Journal of Environment and Ecology. 2016;1(1):1-10 DOI: https://doi.org/10.9734/AJEE/2016/31544.

47. Subbarao N, Marghade D, Dinakar A, et al. Geochemical characteristics and controlling factors of chemical composition of groundwater in a part of Guntur District, Andhra Pradesh, India. Environ. Earth Sci. 2017;76:747. DOI: https://doi.org/10.1007/s12665-017-7093-8.

48. Maila YA, El Nahal I, Al Agha MR. Seasonal variations and mechanisms of groundwater nitrate pollution in the Gaza Strip. Environ. Geol. 2004;47:8-90.

49. World Health Organization (WHO). Nitrate and nitrite in drinking water. Background document for development of WHO guidelines for drinking-water quality. Geneva: World Health Organization; 2007.

50. Ighalo JO, Adeniyi AG. A comprehensive review of water quality monitoring and assessment in Nigeria. Chemosphere 2020;260(127569):1-27.

51. Chigor VN, Okuofu CA, Igbinosa EO, et al. Water quality assessment : Surface water sources used for drinking and irrigation in Zaria are a Public Health Hazard. Environ Monit Assess. 2012;184: 3389-3400. DOI: 10.1007/s10661-011-2396-9.

52. Owuna AE. Quality assessment of hand-dug wells water in Otukpo Town and its Environs, Benue State, Nigeria [M.Sc. thesis] Ahmadu Bello University, Zaria, Nigeria; 2012.

© 2021 Kondum et al.; This is an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sdiarticle4.com/review-history/66219