Chapter

Application of Water Quality Index for the Assessment of Water from Different Sources in Nigeria

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Abstract

Water quality index (WQI) provides a single number that expresses the overall water quality, at a certain location and time, based on several water quality parameters. The objective of WQI is to turn complex water quality data into information that is understandable and usable by the public. A number of indices have been developed to summarize water quality data in an easily expressible and easily understood format. The WQI is basically a mathematical means of calculating a single value from multiple test results. This chapter discusses, in detail, the application of a water quality index for the assessment of water quality to different several water sources in Nigeria.

Keywords: Water Quality Index, Water Quality Indicators, Surface Water, Underground Water, Environmental Health

1. Introduction

Clean, safe and adequate freshwater is of utmost importance to human existence and the survival of all living components in the ecosystem. Water quality issues are complex and diverse, deserving urgent global attention and action [1]. The decline in water quality has become a global issue of concern because of its inherent ability to cause major alterations to the hydrological cycle. The past decade has seen remarkable impact of man on the environment due to unprecedented increase in population and rapid rate of urbanization as well as the intensification and expansion in agricultural practices. This has led to progressive and continual degradation of resources especially surface water. Polluted water is an important vehicle for the spread of diseases. In developing countries about 1.8 million people, mostly children, die every year as a result of water-borne diseases [2]. According to Bullard, [3] inferred that impaired surface water quality always result in an unhealthy socio-economic environment.

The characteristics of water are defined by its composition and are commonly referred to as water quality. Water quality is generally defined as "the chemical, physical and biological characteristic of water usually in respect to its suitability for a designated use" [4]. The assessment of water quality, usually carried out by determining its physico-chemical and biological properties or parameters against a set of standards, is used to determine whether the water is suitable for consumption or safe for the environment. Water quality assessment can be defined "as the evaluation of physical, chemical and biological state of the water in relation with the natural state, anthropogenic effects and future uses" [5]. The water quality parameters are then used as a reference to a set of standards based on the intended usage of the water broadly classified into industrial/domestic use, human consumption (portability) and restoration (in the environment/ecosystem, generally for health of human/aquatic life). Water quality standards are used to protect different designated uses of water. The standards of each one of these designated uses are very different from each others. For example, the water used for drinking requires a higher standard compared to the standard used for agricultural and industrial use (water for domestic purposes should therefore be free from toxic substances and organisms in order to prevent waterborne diseases).

2. Importance of water quality assessment and monitoring

The assessment of water quality is very pertinent to both public health and aquatic life. Water quality has a significant impact on water supply and oftentimes determines supply options [6, 7]. The understanding and monitoring of sources and quality of water used for water supply is of societal, economic and conservational importance since per capita water demand is increasing while accessibility to freshwater availability is continuing to decline. Local water quality can be used to identify the sources and fates of toxic contaminants and pollutants either from ecology, geology, and anthropogenic activities (industrial processes, runoff from agricultural farms etc) in the area [5]. Identifying the source (s) of contamination and developing appropriate management strategies are essential to minimizing potential public health risks [8]. Moreover, data obtained via assessment and monitoring water quality provides empirical evidence to assist health and environmental decision making. In water management practices, water quality values serve as useful and sensitive indicators of changes in the physical, chemical or biological composition of the overall water status [9].

2.1 Water quality indicators

To determine the quality of a water body, the chemical, biological and physical conditions of a water body must be measured. Chemical measurements, biological surveys, and visual observations (physical) provide a "big picture" of what's happening in a water body. The following is a list of indicators (physical, chemical and biological) that are often measured to assess the quality of water.

a. Physical indicators

   Some physical indicators of the quality of a water sample from any source include,

   - Temperature - Electrical Conductivity - Taste - Total Suspended Solids (TSS)
   - Turbidity - Odor - Color - Total Dissolved Solids (TDS)

b. Chemical indicators

   Some chemical indicators of the quality of a water sample from any source include,

- pH – Biochemical Oxygen Demand (BOD) – Chemical Oxygen Demand (COD)

- Dissolved Oxygen (DO) – Total Hardness – Phosphates – Pesticides – Nitrates

- Surfactants – Heavy metals

c. Biological indicators

Some biological indicators of the quality of a water sample includes,

- Bacteria (fecal coliform, *Escherichia coli*, Cryptosporidium, *Giardia lamblia*), — Viruses - Fungi protozoa - Parasitic worms - *Pimephales promelas* (fathead minnow) -*Americamysis bahia* (Mysid shrimp) - Benth ic macroinvertebrates (Ephemeroptera or mayfly, Plecoptera or stonefly and Trichoptera or caddisfly – Sea Urchin – Mollusca (Bivalve mollusks – *Americamysis bahia* (Mysid shrimp)

2.2 Water quality standards

Water quality standards imply statements and numeric values that describe water quality and fall within the following three components:

i. Designated uses of the water body as related to water supply, aquatic life, agriculture, or recreation.

ii. Water quality criteria and general statements that describe good water quality and specific numerical concentrations for various parameters.

iii. Anti-degradation policy designed to maintain and protect the existing water uses for each water body.

The standard used for particular water is a function of the expected use of the water. **Table 1** presents some of the established standards of some water quality parameters. What this means is that the established standard used for drinking water is used only in determining the Drinking Water Quality Index while the Aquatic Water Quality Index standards are used to protect aquatic life. Basically, the index can be calculated for three different uses:

a. Drinking Water Quality Index which includes drinking, recreation, irrigation, and livestock watering use.

b. Aquatic Water Quality Index which includes aquatic life protection and use.

c. Overall Water Quality Index which includes the protection of human health, aquatic ecosystems and wildlife.

2.3 Water quality index

The general norm for reporting water quality parameters by comparing the different analyzed parameters with their respective permissible limits and standards set by regulating bodies at local, regional, national or international levels has

Parameters	WHO	CCME
pH (mg/l)	6.5–8.5	8.5
DO (mg/l)	—	5
Temperature (°C)	25	15
Turbidity (NTU)	5	5
TDS (mg/l)	500	500
Ammonia (mg/l)	0.2	1.37
Nitrate (mg/l)	50	48.2
Lead (mg/l)	0.01	0.01
Iron (mg/l)	0.3	0.3
Chromium (mg/l)	0.05	0.05

Sources: [10, 11].

Table 1.
Sets of some established standards.

been deduced to be ineffective in environmental monitoring program by both managers and the general public [12]. Carlos and Alejandra [13] argued that providing statements that summarize the water quality data in a simple expressible format that describes the general health or status of a water body is more preferable to environmental managers and the general public rather than been asked to give a rather biased interpretation to complex and technical environmental data. The Water Quality Index (WQI) was first developed by Horton [14] and presents a mathematical method of calculating a single value to represent water quality from multiple water quality parameters. The index represents the level of quality of a water body such as lake, river or stream by using some of the regularly used water parameters (BOD, temperature, turbidity, conductivity etc.) [15]. The WQI is based on the measurement of different water quality parameters thus providing a mechanism for presenting a cumulatively derived numerical expression for defining water quality [16]. The water quality index reduces water quality data to common scale and combines them into a single number in accordance with a chosen method or model of computation. WQI reflects the composite influence of different water quality parameters and is calculated from the point of view of the suitability of both surface and groundwater for intended usage.

The method follows three steps namely:

i. Selection of parameters

ii. Determination of quality function for each parameter and

iii. Aggregation through mathematical equation.

In order to rank the overall water quality, the Canadian Council of Ministers of Environment CCME [17] established the use of an index that mathematically combines all water quality measures and provides a general and readily understood description of the quality of water. Over the years, many countries have accepted the CCME scheme representing the water quality index for water quality monitoring and assessment of surface and underground water in terms of their chemical, biological and nutrient constituents and overall esthetic condition. The Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI) is preferred as a tool for the work due to its simplicity and ability to combine complex water quality data without compromising its technical integrity [16]. The CCME Water Quality Index is considered the most effective method of measuring water quality to determine its suitability for an intended use [18].

In the United States, the US National Foundation uses a weighted linear system of the WQI as a guideline for defining water quality [19]. Many other countries have used the same concepts to define their water quality status including Malaysia [20], Spain [21], Bangladesh [22], and China [23]. The water quality index reduces the bulk number of water parameters used in an assessment and provides a single value. This value is a simplified and logical form that expresses the average quality of water at a specific time based on the analytical values of physico-chemical parameters. This procedure facilitates a simpler and easier interpretation of the data rather than assessing each parameter and allows easy public access and understanding of the water quality data [12, 24, 25].

2.4 Merits of the water quality index

Several advantages and benefits accrue from the use of the water quality index [22] include:

1. Reduction in the number of parameters required to compare water quality for a definite use
2. Provision of a single number that represents overall water quality at a certain location and time
3. Identification of space and time dynamics in the quality of water.
4. Provision of assurance on the safety of a water body to users such as habitat for aquatic life, irrigation water for agriculture and livestock, recreation and esthetics, and drinking water supplies.
5. It is very effective for water quality monitoring.
6. Provides means of comparisons between different rivers and sampling sites.
7. The indices is one of the most simplified methods of communicating water quality classification to the general public or those in authority.
8. It simplifies a complex dataset into easily understandable and usable information.
9. The single-value output of the index, derived from several parameters, provides important information about water quality that is easily interpretable by the general and non-technical populace.
10. The index is a useful tool for communicating water quality information to the large public and to legislative decision makers.

2.5 Limitations of the water quality index

Despite the benefits attributed to the WQI, it is however besieged with some challenges [26, 27], some of which are stated below,

1. WQI is not an absolute measure of degree of pollution or the actual water quality.
2. Lack of precision and accuracy in classification technique of importance of evaluation of parameters.
3. Inefficiency in dealing with uncertainty and subjectivity in a complex environmental issue such as the incompatibility of observations, uncertainty, imprecision in criteria.
4. Lack of a uniform method for measuring water pollution involving biological parameter.
5. Inadequate to transfer complex environmental data into information.

3. Water quality determinant

The selection of significant water quality parameters is vital and key to having good representation of all indicators of water quality [28, 29]. Water quality parameters commonly used by various researchers include dissolved oxygen, total phosphates, temperature, pH, turbidity, chemical oxygen demand, fecal coliform, total solids, biochemical oxygen demand and nitrates [30–32]. The weight associated with each parameter is based on its respective standards and the magnitude of the assigned weight indicates the parameter's significance and impact on the index. Below is the weighting factors assigned to some of the water quality parameters (**Table 2**).

Water quality parameters	Weight factors
Dissolved Oxygen	0.22
Biological Oxygen Demand	0.19
Chemical Oxygen Demand	0.16
Ammoniacal nitrogen	0.15
Suspended solid	0.16
pH	0.12

Table 2.
Water quality parameters and weight factors.

4. Water quality index calculation

Though, a lot of water quality parameters are used for water assessment, some of the parameters seem to have a common similarity as they have their basis of comparing water quality parameters with their respective regulatory standards with interpretation of the results as good or bad [33].The parameters involved in the weighted arithmetic water index method water quality uses:

i. Degree of purity which is obtained from the most commonly measured water quality variables: temperature, biochemical oxygen demand, fecal coliform, pH, dissolved oxygen, total phosphates, turbidity, nitrates and total solids.

ii. Water quality rating scale, (qi)

iii. Relative weight and (wi)

iv. Overall WQI (Qi)

The WQI is calculated by averaging the individual index values of some or all of the parameters within five water quality parameter categories that depicts the pollution level or status of the water:

i. Water clarity: turbidity (NTU) and/or Secchi disk depth (meters or feet);

ii. Dissolved oxygen: Dissolved oxygen concentration (mg/l);

iii. Oxygen demand: biochemical oxygen demand (mg/l), chemical oxygen demand (mg/l) and/or total organic carbon (mg/l);

iv. Nutrients: total nitrogen (mg/l), and/or total phosphorus (mg/l); and

v. Bacteria: total coliform (per mg/l) and/or fecal coliform (per mg/l)

The numerical value of the quality rating (q_i) is obtained from the water quality data then multiplied by a weighting factor that is relative to the significance of the test to water quality. The formula below is used to obtain q_i:

$$q_i = \frac{c_i}{s_i}\ x\ 100 \tag{1}$$

where,
q_i, = quality rating scale.
c_i, = concentration of i parameter.
s_i = WHO standard value of i parameter.
Relative weight (w_i) is calculated by

$$w = \frac{1}{s_i} \tag{2}$$

The standard value of the i parameter is inversely proportional to the relative weight. The relative weight (w_i) is calculated by

$$w_i = \frac{w_i}{\sum_1^n w_i} \tag{3}$$

Finally, overall WQI was calculated according to the following expression:

$$WQI = \frac{\sum_i^n Q_{iW_i}}{\sum W_i} \tag{4}$$

The sub-index Si and WQI are computed using the relationship in Eqs. (3) and (4), respectively

$$SIi = w_i\ \ x\ \ q_i \tag{5}$$

$$WQI = \sum SIi \tag{6}$$

where SI_i is the sub-index of the *ith* parameter and q_i is the rating based on the concentration of the *ith* parameter.

Ranking of WQI Values.

The Global Environmental Monitoring Systems [34] adopted the Water Quality Index (WQI) developed by the Canadian Council of Ministers of Environment (CCME) and based its development on the combination of three factors into one index. The detailed formulation of the WQI, as documented by CCME [17] and Amir *et al.*, [35] comprises three factors which include:

Scope, **F1** - the number of variables whose objectives are not met and calculated as

$$F_1 = \frac{Number\ of\ failed\ Variables}{Total\ Number\ of\ Variables}\ \text{x}\ 100 \tag{7}$$

Frequency, **F2,** – the frequency with which the objectives are not met.

$$F_2 = \frac{Number\ of\ failed\ Tests}{Total\ Number\ of\ Tests}\ \text{x}\ 100 \tag{8}$$

Amplitude, **F3,** – the amount by which the objectives are not met.

F3 is calculated in three steps:

a. The number of times by which an individual concentration is greater than (or less than, when the objective is a minimum) the objective is termed an “excursion” and is estimated as follows;

b.

$$Excursions_i = \frac{Failed\ test\ values_i}{Objestive_i} - 1 \tag{9}$$

For cases in which the test value must not exceed the objective:

$$Excursions_i = \frac{Objestive_i}{Excursions_i Objestive_i} - 1 \tag{10}$$

c. The collective amount by which individual tests is out of compliance is calculated by summing the excursions of individual tests from their objectives and dividing by the total number of tests (both those meeting objectives and those not meeting objectives). This variable, referred to as the normalized sum of excursions (*nse*), is calculated as:

$$nse = \sum_{i=1}^{n} \frac{excursions_i}{Number\ of\ tests} \tag{11}$$

d. F3 was thereafter calculated by an asymptotic function that scales the normalized sum of the excursions from objectives (*nse*) to yield a range between 0 and 100 as given in Equation

$$F_3 = \frac{nse}{0.01nse + 0.01} \tag{12}$$

The CCME WQI is determined using equation below:

$$\mathrm{WQI} = 100 - \frac{\sqrt{F_{1+}^{2}F_{2+}^{2}\,F_{3}^{2}}}{1.732} \tag{13}$$

The calculation produces a score value that ranges between 0 and100. The higher the score the better the quality of water. The CCME WQI values ranges between 0 which depicts a worst water quality and 100, the best water quality [36]. The interpretation is that a water body with WQI scores that range between 71 and 100 are very suitable for the expected use, meet the required expectations for water quality and are of lowest concern, scores that ranges between 51 and 70 indicate marginal concern while a water body with WQI values with scores below 50 do not meet expectation and are of highest concern.

The CCME places the WQI values into five categories with the following interpretations [22]:

- *Excellent*: (CCME WQI Value 95–100) – Water quality is protected with a virtual absence of threat or impairment; conditions very close to natural or pristine levels.

- *Good:* (CCME WQI Value 80–94) – Water quality is protected with only a minor degree of threat or impairment; conditions rarely depart from natural or desirable levels.

- *Fair*: (CCME WQI Value 65–79) – Water quality is usually protected but occasionally threatened or impaired; conditions sometimes depart from natural or desirable levels.

- *Marginal*: (CCME WQI Value 45–64) – Water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels.

- *Poor:* (CCME WQI Value 0–44) – Water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels.

A number of indices have been developed to summarize water quality data in an easily expressible and easily understood format. The scores are then ranked into one of the five categories described below (**Table 3**) [34, 37]:

WQI value	Ratings of water quality
91–100	Excellent
71–90	Good
51–70	Medium
26–50	Bad
0–25	Very Bad

Table 3.
Ratings of water quality indices.

5. Sources of water in Nigeria

Globally, the provision and supply of adequate water to the populace is one of the core responsibilities and duties of the government. This is because water is among the first requirements in the hierarchy of citizens' needs and a failure to guarantee water supplies to those that need it most can lead to serious political setbacks [38]. A good knowledge of the source(s) of water is necessary to improve on the provision and supply of water to the populace. Nigeria is divided into six geological zones, namely, North-east, North-west, North-central, South–south, South-east, and South-west (**Figure 1**). The country has six hydrological basins covering the swampy forest in the south, the dense rainforest in the east, hilly shrub lands in the middle belt, savannah grasslands in the north, and semi-arid areas in the far north [38]. There are two major river systems in the country: the River Niger and River Benue both meet at Lokoja. River Niger enters the country from the northwest and River Benue enters from the northeast [39].

The most available sources of water for most urban–rural communities in developing countries, including Nigeria, are surface waters (rivers, streams, ponds and lakes) and groundwater (in form of boreholes and hand-dug wells). Surface waters in Nigeria are usually contaminated with domestic, agricultural, and industrial wastes and cause many water-related diseases and ill health to living organisms [40, 41] while Nigerian groundwater quality is generally good but these waters are often laden with high contents of heavy metals (e.g., Fe, Mn, Cd, As Hg), nitrates, fluorides or cyanides and can be contaminated with a wide variety of pathogenic organisms (often above recommended WHO levels).

A larger part of the Nigerian populace are self -dependent in meeting their daily water provision from natural sources: rivers, streams, ponds, rain and hand-dug wells or modern supply sources which include public sector supplies or private and commercial borehole businesses [42]. Access to adequate water supply in Nigeria is hampered by geographical, socio-economic and institutional factors. Reports from the WHO/UNICEF [43–45] indicate that 72% of urban dwellers have access to

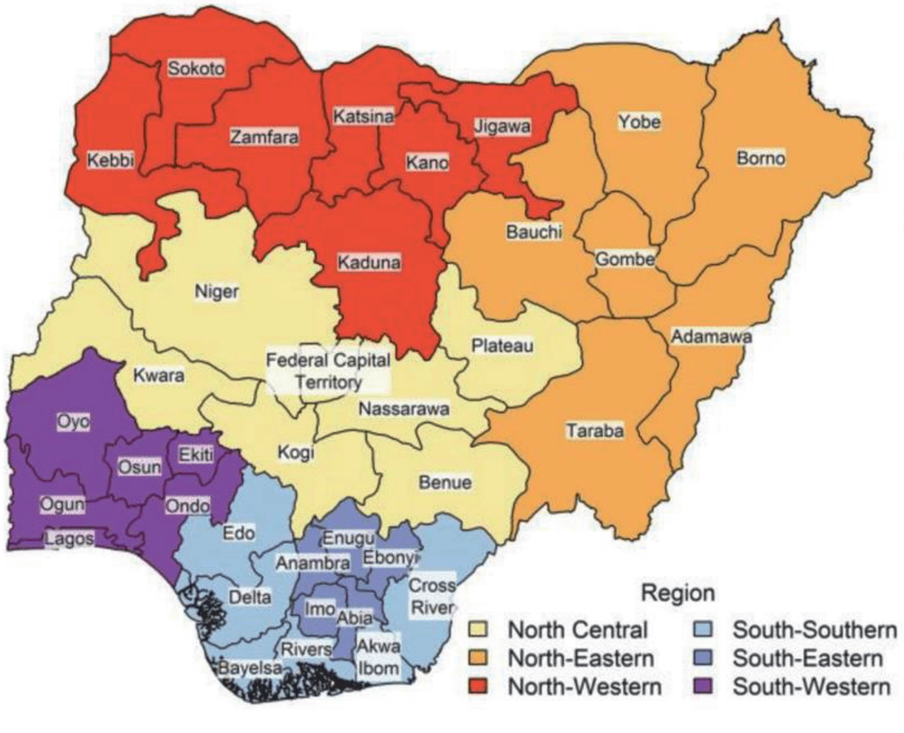

Figure 1.
Map of Nigeria showing the six Hydrological Basin.

Indicators	NE	NW	NC	SE	SW	SS	National	Rural	Urban
Safe water source (%)	30.7	50.64	48.9	40.8	73.5	45.9	51.4	40.4	73.4
Water treatment before drinking (%)	4.6	7.5	14.1	11.4	20.4	5.8	11.3	14.5	9.7

NE: North East, NW: North West, NC: North Central, SE: South East, SW: South West, SS: South–South.
Source: Extracted from Amakom [48].

Table 4.
Evaluation of regional access to water supply in Nigeria.

improved water sources while 43% of the rural populations do not have ready access. Regionally, access to improved drinking water sources in the north central, north eastern and north western zones is 52.2%, 27.3%, 42.5%, respectively. Access to improved drinking water sources is 72.7% and 54.1% in the south western and south eastern zones of Nigeria, respectively. Thus, high disparity exists between the urban and rural populations regarding their access to good water. A similar disparity between the northern and southern regions of Nigeria is clearly shown as depicted in **Table 4**. It can be inferred from the table that the SW and NW zones and the urban areas have demonstrably higher access to a safe water supply. The problem of water pollution arising from petroleum oil exploration in the south tends to limit the availability of freshwater resources from the natural sources [46, 47]. In most parts of the Niger- Delta (SS) region of Nigeria, the major challenge for survival is the availability of good quality (potable) water free of environmental pollution and degradation. According to Raimi [46], the sources and percentage frequencies of water in the oil producing communities in the Central Senatorial District of the Bayelsa State is: rain (61%), rivers (13%), pipe-borne (33%) borehole (91%) and hand-dug well (3%). This distribution of water sources is similar in most cities in the other parts and zones in the country. Thus, it implies that the most frequently used water sources in Nigeria are borehole, rain water and pipe-borne water except in the rural areas where the major sources are hand dug wells and rivers.

6. Water quality indices of surface and underground water sources in Nigeria

This section provides the water quality indices of surface and underground water sources from different part of Nigeria. Several authors have applied water quality index (WQI) to evaluate the quality of water from different water sources especially surface and underground water across the different zones in the country [18, 47, 49–51]. Herein, the country is divided into four regions (south, east, west and north) and the WQI of water from different sources including rivers, boreholes, hand-dung wells etc. of the country is discussed.

Several researchers have assessed and reported the WQI of water bodies in the Southern states of the country [47, 52–55]. Most of the rivers investigated in Bayelsa: Korama, Otamiri, Oramiukwu, Ase, and Orashi Rivers showed poor water quality, and water environment clearly unsuitable for drinking [46]. The Otamiri and Orimiukwu Rivers have very bad water quality based on the WQI while the Ase River was observed to have bad water quality with a high degree of deterioration at the downstream [52]. The Orashi River displayed a marginal level of pollution as about 50% of parameters failed to meet the required standards [54]. The Brass River in Bayelsa State was considered to be far from excellent [53].

Aigberua and Tarawou [56] investigated the WQI of some surface waters (rivers) in the Rivers State along the Taylor Creek area of the state. Their calculated water quality indices (WQIs) scores fall within the range which indicates water quality status tending from "poor water quality" to "unsuitable for drinking". Taylor Creek shows a slightly acidic water environment that contains high levels of nitrate loading, pH, total dissolved solids and *E. coli* in addition to an objectionable level of color and unsightly appearance. The WQI assessment reflects water of poor quality and generally unsuitable for public consumption. The presence of multiple dumpsites mostly from leachates along the stretch of the river may be responsible for the poor degradation in water quality. It was therefore recommended that the water is not fit for human consumption or and recreational purposes. Overall, the WQI assessment of Taylor Creek revealed that water is unsuitable for drinking and may pose serious health risks.

The water quality index (WQI) approach was used to assess the suitability of water from three local government areas in River state by Chinwendu [57]. The result of these assessments indicated that borehole water was unsafe for human and animal consumption. These waters had an acidic pH while the dissolved oxygen, temperature and calcium values were not within the WHO and NSDWQ permissible drinking water standards. The water quality index of the borehole waters in the region exceeded permissible water quality standards in all sampling locations due to groundwater contamination resulting in water that was unsafe for human and animal consumption.

The suitability of water from different sources (stream, borehole and pipe - born water) were assessed using the WQI in the Niger Delta region of Nigeria by Etim et al. [58]. The concentrations of the respective parameters are below the WHO/ICMR standards. The quality of water based on the index number representing overall suitability of the water indicated that the water samples analyzed from pipe born and borehole water were safe for human consumption and domestic purposes while the samples analyzed from stream water are not safe for human consumption.

The quality of some river bodies around the Warri metropolis was evaluated by Godwin and Oborakpororo [59] based on their various physico-chemical parameters. The results obtained from the study showed that all the surface water samples were found to be unfit for human consumption with very high turbidity and suspended solids. The presence of fecal coliform in the various water bodies was much higher than the stated standard of regulatory agencies. The physicochemical parameters of groundwater in 12 cluster boreholes in Enugu North district/region, southeast Nigeria categorized all the water samples within the range of good to excellent [60].

The quality of 12 different water sources and 2 treated water used by peri-urban town in the West region of Nigeria were evaluated to assess their suitability for drinking and domestic us [61]. Water quality parameters included pH, temperature, acidity, total alkalinity, chloride content and coliform. The results indicated that all the physicochemical parameters of the water samples complied with regulatory standards. Similarly, most sites complied with heavy metals criteria. At these sites, fecal coliform and *E. coli* tested positive for all the samples except one tap water sample. The majority of the water samples (86%) were rated as excellent based on the physicochemical parameters. However, the inclusion of microbiological data in the WQI revealed that only 7% of the samples analyzed can be regarded as excellent water. Akoteyan and his team [62] studied the water quality characteristics of Owo river for municipal water supply in Lagos-Nigeria. The study showed that the physical parameters assessed (electrical conductivity, pH, total hardness, anions and cations) were within the maximum permissible limit of WHO standard for drinking water quality. The calculated WQI showed that the water is suitable for human use. Olagbemide [63] applied the WQI for the assessment of Eleyele Lake, Ibadan, to check the quality of the lake water with respect to different physicochemical parameters using standard methods. Water samples were collected from different river sites (i.e., before the lake, on the lake and after the lake). The results of the Water Quality Index showed that the water quality at these sites was poor. This suggests that the lake is polluted and not totally safe for human consumption without proper treatment. Very high values were obtained for color, turbidity, total solid, total suspended solid, BOD, COD, alkalinity, phosphate, chloride, magnesium, nitrate, total organic carbon, total organic matter were observed and all were above the permissible WHO values.

Murtala and Ahaneku [64], studied some physicochemical parameters (pH, dissolved oxygen, temperature, turbidity, total dissolved solid, nitrate, ammonia, iron, lead and chromium) from the river Asa in Illorin (Kwara state) and presented the complex water quality data of the river as the WQI that can easily be understood by the technical and non-technical personnel. The result of the Water Quality Index showed that three of the four stations investigated should be ranked as poor and the remaining station as marginal. The implication is that the river failed the Drinking Water Quality Index and is not suited as a potable source of drinking water. The seasonal variation of some physicochemical properties of River Asa in Kwara state was also assessed and the river water quality status was evaluated using CCME Water Quality Index. The result of the study revealed the river is not suitable source for drinking water.

Ogbozige and co-workers [65] assessed 12 water quality parameters (turbidity, TDS, pH, Cl^-, EC, DO, BOD_5, COD, total nitrogen, total phosphorus, Fe and Mn) for the River Kaduna, Nigeria on a monthly basis for a period of one year at 15 sampling locations using standard methods. The data were used to develop Water Quality Index (WQI) across the 15 sampling locations. The WQI revealed that the water quality of four (4) sampling locations was poor and the general water quality of the remaining 11 sampling locations was marginal. The water quality assessment of water consumed in Kaduna State revealed that among the 15 rivers, 4 of the rivers (Kutimbi, Kigo, Breweries and Rigasa) recorded poor WQI while the river upstream of Narayi community was marginal. Results indicated that the quality of the rivers at Narayi and Rigasa communities was bad. The water qualities of the remaining 8 rivers were of better quality including River Romi. Based on the results, the WQI of River Kaduna on the Canadian scale is mostly marginal. Yisa [37] evaluated the quality of selected hand-dug wells in Maikunkele area in Niger state using WQI technique. These results indicated that the quality of the samples was marginal while one location was extremely bad. The results also revealed a high contamination of coliform in the samples and nitrate concentration above standard of WHO, EPA, APHA and the Nigeria drinking water standards.

The Water Quality Index and heavy metal contents of underground water sources in Doma Local Government Area, Nasarawa State, Nigeria was investigated to ascertain the suitability of the water for domestic purpose using physicochemical parameters: temperature, turbidity, TDS, TSS, pH, EC, total hardness, alkalinity, chloride, nitrate and sulphates in the water samples [66]. The physicochemical parameters determined for borehole and hand dug well water samples (i.e., temperature, turbidity, total dissolved solids, total suspended solids, electrical conductivity, total hardness, alkalinity, chloride, nitrate, and sulphate) were all within the standards recommended by regulatory bodies NSDWQ and WHO. The mean pH for the hand dug well water was within the recommended standard values; however, the pH value for the borehole was outside the range recommended standards (the water was slightly acidic). The WQI evaluated for both borehole and hand dug well water samples showed the ground water sources presented good water quality.

The results of the mean metal concentrations in borehole and hand dug well water samples shows that the concentrations of Cd, Cu, Pb and Zn are within the permissible limit recommended by regulatory bodies while those of Cr and Fe are higher than standard values. Oko and his crew [67] collected water samples from boreholes and hand dug wells located in two wards in Wukari town in Taraba state and assessed some physico-chemical parameters using analytical methods. The calculated WQI showed that the water samples from the borehole was of better quality for drinking than the hand dug well.

7. Conclusion

In Nigeria, the most frequent water sources are surface waters (rivers, streams, ponds and lakes) and groundwater (borehole and hand-dug wells). The physico-chemical assessments of water samples showed that while some of the parameters are within permissible limits, many exceeded the stipulated standards. Application of the water quality index (WQI) to determine the suitability of the water for an intended use indicated that most water sources in the western part of the country are good and suitable for human consumption except for incidences of high levels of fecal contamination in some rivers. The WQI for most locations in the northern part of the country is either bad or poor and not suitable for human consumption. In the eastern and southern part of the country, the WQI index indicated marginal quality that was not suitable for human consumption without treatment. This marginal quality could be as a result of the high levels of nitrate and acidic pH of most of the waterbodies in the area. In all, it is recommended that prior treatment of the water is very important before consumption so as to avoid water-borne related diseases and illnesses.

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