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Critical Analysis and Evaluation of the Surface Water Quality Index: A Case Study of Asejire Dam, Ibadan, Oyo State Nigeria

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Abstract Due to the worldwide concern that good quality freshwater may become a scarce resource in the near future, developing countries and countries with transition economies have increased their interest in water quality monitoring programs during the past decades. In Nigeria (South- Western) different kinds of environmental problems, caused by a disordered economic growth and the excessive water use associated with it, are affecting both the availability and the quality of freshwater. The Asejire Dam, located in Oyo State, drains an important agricultural watershed. Considerable amounts of water are extracted for use in irrigation agriculture and for the production of drinking water for the City of Asejire. The river also receives the city's urban waste water, which – until recently – was discharged without any previous treatment. Surface water pollution in the watershed is supposed to be mainly related to the disposal of organic waste and the low dilution capacity of the river during the dry period, when discharge rates are low. Comparing four methods of evaluating surface water quality, the CWQII is a feasible method for evaluating the water quality conditions of Asejire River and its tributaries. The SFE method only considers the most prominent factor and not all factors are considered in the resulting water quality evaluation. This means that the SFE method is limited in its ability to characterize the comprehensive water quality condition. Because of overemphasizing the influence of the maximum factor, the Comprehensive Water Pollution Index method and Nemerow-Sumitomo Water Quality Index method cannot effectively evaluate the comprehensive water quality condition.

Keywords Surface Water, Quality-Index, Asejire Dam, Freshwater

1. Introduction

Water is a very important resource for living organisms and human society [6]. Without water, existence of man would be threatened. The quality of deteriorating water has been a growing source of concern for the international community [2]. The issues of water quality have become a common challenge to many countries WEPA Secretariat. In order to prevent water pollution, many countries have issued policies to address its sources, and one very significant link was the evaluation of water environment quality. In recent years in African countries, evaluation of surface water quality has become a critical issue [3].

Water quality evaluation is one of the basic tasks of an environmental protection administration, and researchers have designed numerous approaches for evaluating surface water quality. The comprehensive evaluation of water quality has attracted a lot of interest in recent years [4]. The pollution index method is a kind of water quality evaluation method stemming from the 1970s [5], the pollution index methods include a single factor pollution index method and comprehensive pollution index method. It is used a pollution index method to evaluate the water quality in the coastal waters of Bohai and both Chemical Oxygen Demand (COD) and phosphate were main pollution factors. However, this method cannot judge water quality class according to Nigerian national standards [9].

Hence long-term monitoring programs have been developed for assessing surface water quality in many countries, generating complex multidimensional data due to multiple constituents, different sampling frequencies and many monitoring stations. Appropriate assessment of long term monitoring data is essential for water quality evaluation. Furthermore, determining the potential pollution sources and major constituents that significantly contribute to the temporal and spatial variations in water quality is often the key issue to evaluate water quality

2. Material and Method

2.1. Research Area

The Asejire Reservoir is the current main source for Ibadan Water Supply Scheme. The dam was built in the late 1960s and was opened on 17 November, 1972 with a capacity of about 80 million litres of water per day, majority of which is consumed for domestic purposes [10].

The major purpose of the construction of the dam, otherwise known as Ibadan Water Supply expansion Scheme was to supply the people of Ibadan with ample water supply for all their domestic and industrial activities [9]. The facility now completed under the scheme include a dam across the Osun River, with ancillary features, treatment plants, pumping stations, major pipelines, administrative buildings and staff houses.

Bearing in mind the total area of land claimed for both the impoundment site and the dam site (1,215.6 lectures), one cannot but expect that the Asejire dam will definitely have some impacts on the people of this rural area of Egbeda Local Government of Oyo State (see fig. 2.1).

The study area is made up of five villages, which are: Olukeye-Asejire, Erinmi, Alabuke, Faleti, and Aba Alufa. These villages are within Egbeda Local Government area of Oyo state of Nigeria (see fig.2. 1). River Osun is the main river in the study area, and others like Omi, Idogun, and Okoseru are tributaries to it. These tributaries together with River Osun usually overflow their banks during the rainy season in May to October. But Osun is the only permanent river in the area, while some of the other that are tributaries to it are seasonal, some of them drying up completely during the dry season [9].

Table 1: General features of the Asejire Dam area

Parameter	**Asejire Dam**
Location	30km East of Ibadan, Oyo State of Nigeria
Latitude	$07^{\circ}21'$N
Longitude	$04^{\circ}07'$E
Elevation	137m above sea level
Geology	Precambrian Metamorphic rocks
Climate	Dry season: November to April
	Rainy Season: May to October
Annual Mean Temperature	27.3°C
Annual Mean rainfall	14.7mm
Annual Mean humidity	79%

Source [8]

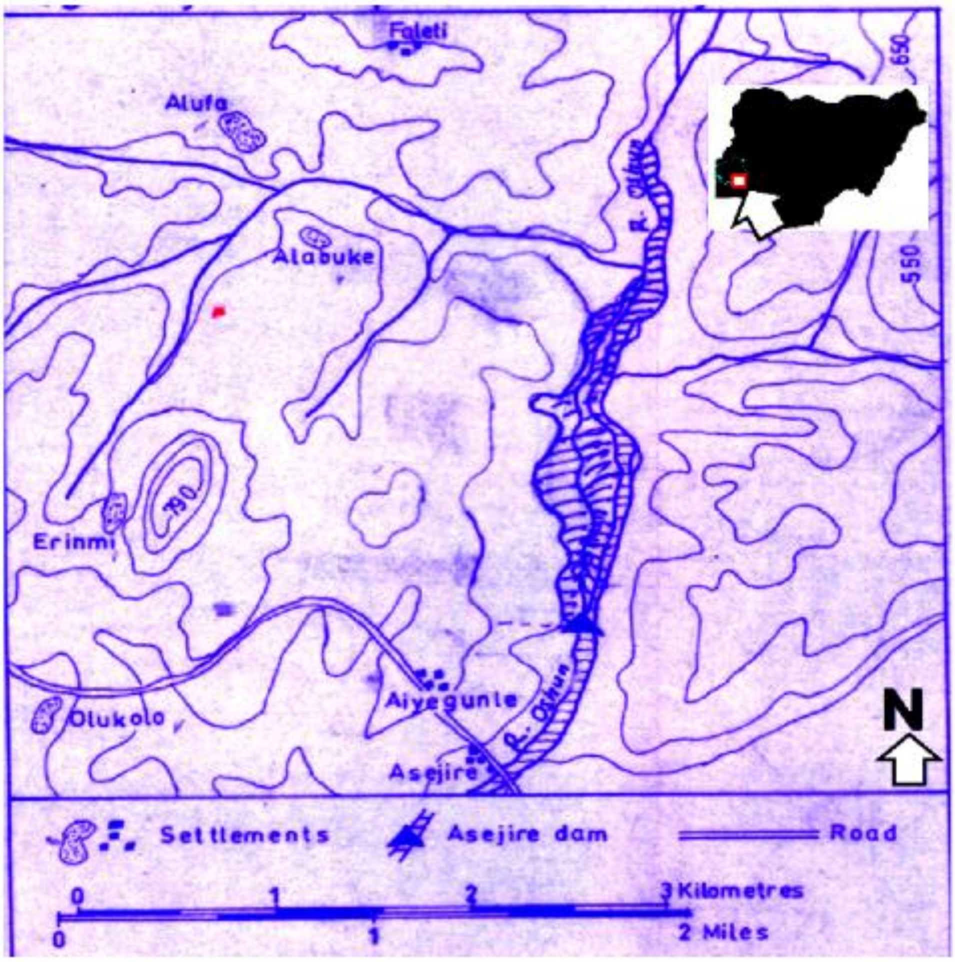

Figure 2.1: The study area showing Asejire Dam and the neighboring/host communities.

2.2. Data Source

Water quality data from 5 monitoring sites was collected between 2015 and 2017 from the Asejire River basin. The municipal environmental department of local government's water quality parameters include COD, petroleum, BOD5, ammonia nitrogen, Total Phosphorus and the Permanganate Index. According to the goals of the 'Water Pollution Prevention Action Plan' proposed by Nigeria, the proportion of Class 3 water available should be higher than 70%. So this paper adopted the Class 3 criteria as the preferred water quality standard.

For water quality evaluation, the SFE method is used according to the maximum membership class's principle [7]. This determines that if only one parameter exceeds the standard, all functions of the water body will be lost. The formula for the SFA method is:

$$F = F_a \max$$

F is the class of surface water, which is classified into classes 1 to (see Table 2). The value of the Surface Water Standard Concentration (The Ministry of Environmental Protection of the People's Republic of Nigeria (MEP), 2010) for each of the five classes is shown in Table 3.

Table 2: Water Environmental Quality Standard GB3838-MEP

Class I – Mainly applicable to the national nature reserves.
Class II – Mainly applicable to class A water source protection area for centralized drinking water.
Class III – Mainly applicable to a water source protection area
Class IV – Mainly applicable to water bodies for industrial water supply in which there is not direct human contact with the water.

Class V – Mainly applicable to agricultural water supply and landscape requirements.
Class V+ - Essentially unusable.

Data from: Nigeria's Ministry of Environmental Protection (MEP)

Table 3: Value of Surface Water Quality Standard Concentration in Nigeria (mg/L)

	Class 1	**Class 2**	**Class 3**	**Class 4**	**Class 5**
Permanganate Index (mg/L)	2.0	4.0	6.0	10.0	15.0
COD (mg/L)	15.0	15.0	20.0	30.0	40.0
BOD5(mg/L)	3.0	3.0	4.0	6.0	10.0
NH3-N (mg/L)	0.15	0.5	1.0	1.5	2.0
TP(mg/L)	0.02	0.1	0.2	0.3	0.4
Petroleum (mg/L)	0.05	0.05	0.05	0.5	1.0

Data from: Nigeria's Ministry of Environmental Protection (MEP)

2.3. Comprehensive Water Pollution Index （CWPI）

The Single Factor Evaluation (SFE) method is used to create a Comprehensive Water Pollution Index (CWPI). The SFE (excluding DO) increases with the pollutant's concentration, and its equation is as follows:

$$I_a = \frac{C_a}{S_{oa}}$$

where the pollution index of water quality index a, C_a (mg/L), was the measured concentration of water quality index a, and S_{oa} (mg/L) was the concentration limit of water quality index a. F_{cip} referred to the arithmetic mean of n water quality indexes. The equation was as follows:

$$F_{cip} = \frac{1}{n}\sum_{n=1}^{n} I_a$$

n is the number of selected pollutants. In this research *n*=6.

2.4. Nemerow-Sumitomo Water Quality Index (NWQI)

The Nemerow-Sumitomo Water Quality Index (NWQI) is a weighted-type water quality index (excluding DO) which takes into account the average and maximum, and its calculation formula is as follows:

$$F_{nwqi} = \sqrt{\frac{\max(\mathrm{I}_a)^2 + avg(\mathrm{I}_a)^2}{2}}$$

$$avg(\mathrm{I}_i) = \frac{1}{n}\sum_{i=1}^{n} I_a$$

2.5. Comprehensive Water Quality Identification Index (CWQII) As a relatively new method, the CWQII could be used to evaluate the water quality of surface water. The Single Factor Identification Index (SFII) is a basic part of the CWQII, and its equation was as follows (excludes DO).

$$P_{SFI} = P_1 P_2$$

Where P_1 is between 1 and 5, corresponding to its water quality, from Class 1 to 5. When the index was not the index for dissolved oxygen (DO), the equation was as follows.

$$P_2 = \frac{C_a - S_{ab}}{S_{ab\max} - S_{ab\min}} * 10$$

C_a is the concentration of the *a*th water quality index, and $S_{ab\max}$ and $S_{ab\min}$ are the upper limit and lower limit of the concentration interval of Class *b* water in the *a*th index, respectively. The equation is as follows:

$$P_C = P_1P_2P_3P_4$$

$$P1P2 = \frac{1}{6}\left(P_{COD_{mn}} + P_{BOD_5} + P_{NH3-N} + P_{Tp} + P_{petroleum} + \frac{1}{n}\sum_{a=1}^{n} P_a\right)$$

$P_{COD_{mn}}$, P_{BOD_5}, P_{NH3-N} and P_{Tp} are the P_{SFI} of COD, BOD5, NH3-N and TP. *a* refers to other indexes incorporated in the comprehensive water quality evaluation. P_a was the single factor identification index. P_3 refers to the number of water quality indexes that were worse than the water quality for functional areas in the urban water environment. If P_3 =0, the indexes incorporated in the evaluation all meet the water quality standard for functional areas. If P_3 =1, one index does not achieve the functional area standard. If P_3 =2, two indexes do not meet the standard, and so on. P_4 was used to judge whether the comprehensive water quality was worse than that of water in a functional area.

If the comprehensive water quality was better than that in a functional area, P_4 =0. If the water quality exceeded the standards, then:

$$P_4 = P_{1-} f_a$$

Where *fa* refers to the water quality category for water in functional areas of the urban water environment. If P_4 =1, the water quality is one level higher than the standard. If P_4 =2, the water quality is two levels higher than the standard.

3. Result and Discussion

3.1.Descriptive Statistics of the Water Quality

The descriptive statistics of the water quality are shown in Table 4 below. The average concentration of CODmn, COD, BOD5, Petroleum, NH3-N and TP were 7.78 (Class 4), 25.56 (Class 4), 6.29 (Class 5), 0.33 (Class 4), 1.19 (Class 4) and 0.18 (Class 3), respectively. For CODmn, 97% of the samples were Class 3 and only 3% exceeded Class 4 (Class 5), The lowest concentration of CODmn was 6.24 mg/L and the highest was 10.67mg/L. COD was worse than CODmn, only 15% of the samples were Class 3 and 70% were Class 4, while 15% had Class 5 water quality standards. The lowest was 17.87mg/L and the highest was 36.63mg/L. For BOD5, 3% of the samples were Class 3, 49% were Class 4 and 48% were Class 5 water quality standards. The lowest concentration of BOD5 was 3.70mg/L and the highest was 8.67mg/L. For Petroleum, 0% of the samples were Class 3, 97% were Class 4 and 3% were Class 5. The lowest concentration of Petroleum was 0.16mg/L and the highest was 0.64mg/L. For NH3-N, 49% of the samples were Class 3, 27% were Class 4 and 15% were Class 5. 9% were worse than Class 5. The lowest concentration of NH3-N was 0.44 mg/L and the highest was 3.90mg/L. For TP, 3% of the samples were Class 1, 79% were Class 2, and 18% were Class 3. The lowest concentration of TP was 0.07mg/L and the highest was 0.63mg/L.

Table 4: Descriptive statistics for six parameters (mg/L)

	COD mn	COD	BOD5	Petroleum	NH3-N	TP
Number of samples	33	33	33	33	33	33
Average	7.78	25.56	6.29	0.33	1.19	0.18
Standard Deviation	1.02	4.95	1.38	0.11	0.67	0.10
Minimum	6.24	17.87	3.70	0.16	0.44	0.07
Maximum	10.67	36.63	8.67	0.64	3.90	0.63

3.2. Single Factor Evaluation (SFE) Method

Depending on the results of the SFE method (Figure 3.1), the level of water quality is determined by the worst index. All rivers in the Asejire River basin were inferior, Class 4, and the worst water quality was found in the Aba Alufa River (A4) in both 2015 and 2017, and Olukeye-Asejire River (A6) in 2017. The water quality was worse than Class 5 because the surface water quality standard for the concentration of NH3-N was Class 5. In addition, the concentration of TP was Class 5 in Olukeye-Asejire River (A6) in 2011. However, this method only considered the most prominent factor (NH3-N) and other factors were weakened, not all factors were considered in the result of water quality evaluation.

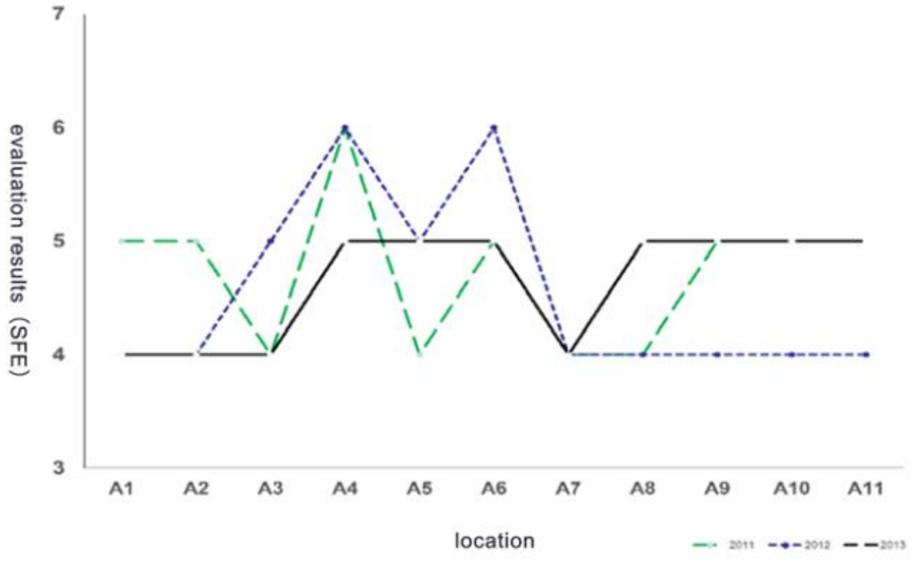

Figure 3.1: Single Factor Evaluation (SFE) method results

3.3. Comprehensive Water Pollution Index (CWPI) Method

Results of the Comprehensive Water Pollution Index (CWPI) are shown in Figure 3.2 below. These results show the period between 2015 -2017. The comprehensive water quality in Olukeye-Asejire River (A6) was the worst, however, according to the CWPI of Olukeye-Asejire River (A6), the level of pollution lightened to a certain extent from 2015-2017 (the CWPI was 2.373, 1.803 and 1.482 in 2015, 2016 and 2017, respectively). The CWPI in Alabuke River (A3) was best, and in 2017 the CWPI of Alabuke River was 0.851.

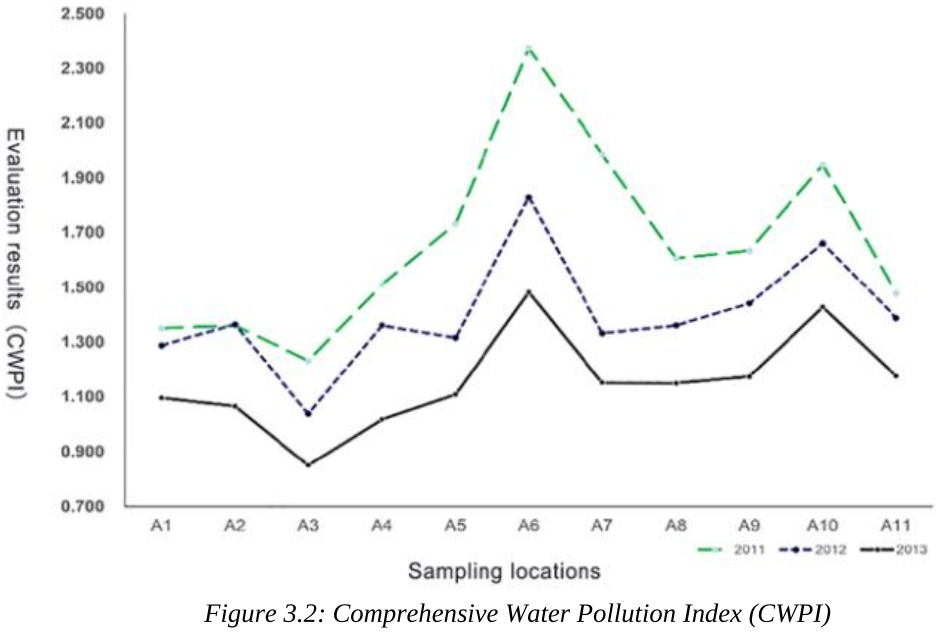

Figure 3.2: Comprehensive Water Pollution Index (CWPI)

Although the CWPI provides a comprehensive water quality status, this method could not determine the water quality classes according to the surface water environment standards. Moreover, because in the CWPI method all12 IRSPSD International, Vol.5 No.4 (2017), 4-18 factors have the same contribution to the overall water quality, this method cannot reflect a genuine decrease of water quality.

3.4. Nemerow-Sumitomo Water Quality Index (NWQI) Method

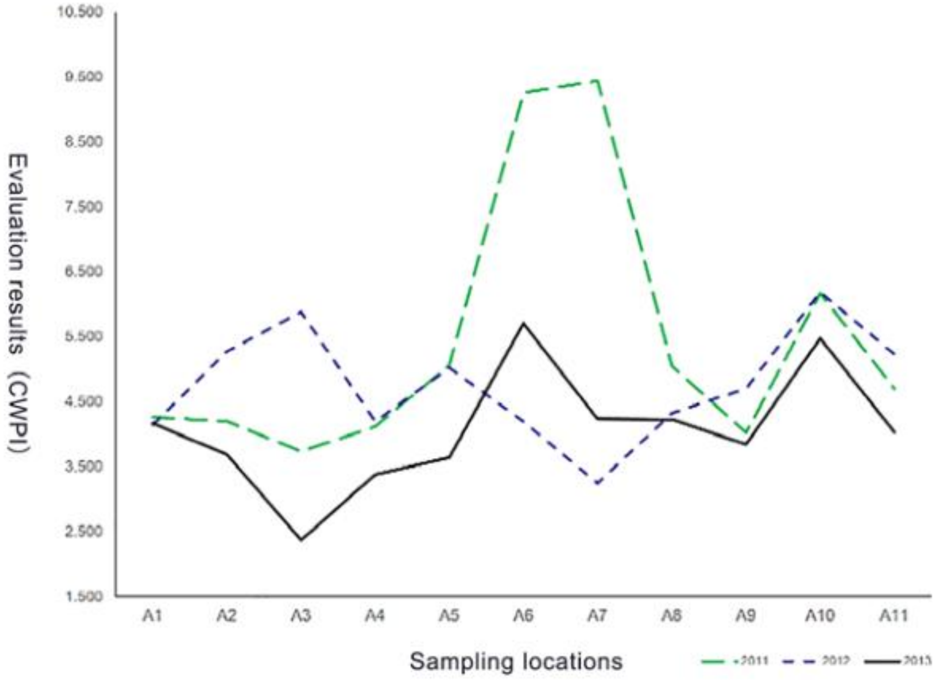

Figure 3.3: Nemerow-Sumitomo Water Quality Index

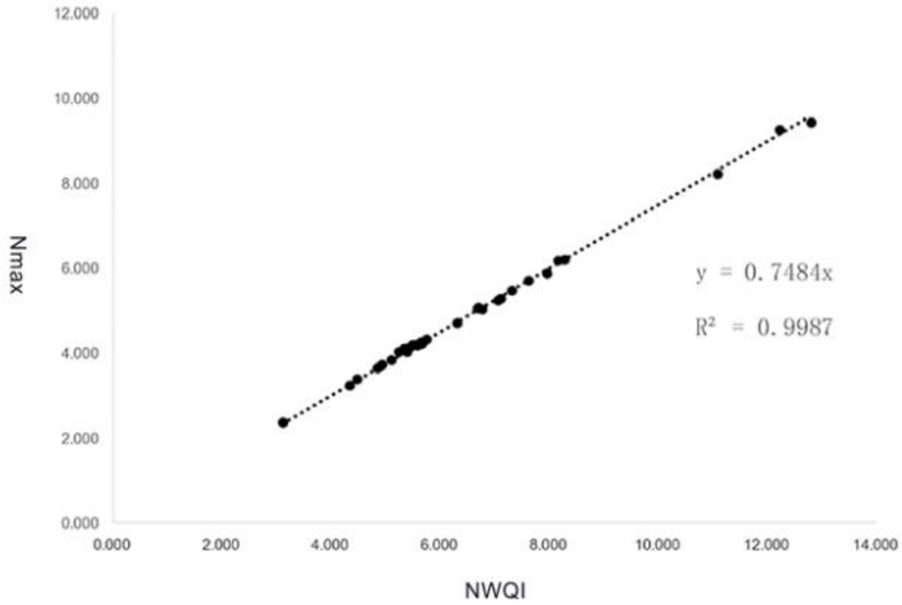

Figure 3.4: The correlation between Nmax and NWQI

The results of the NWQI are shown in Figure 6. Based on the results, the water quality index of Erinmi River (A7) in 2011 was the worst and the water quality of Alabuke River in 2013 was the best (NWQI was under 1.0). Compared with the SFE and CWPI, the maximum and average factor contributions of all factors are considered in the NWQI. From the correlation seen between the maximum factor and Nemerow-Sumitomo Index in Figure 3.5 it can be seen that this method tends to overemphasize the influence of the maximum evaluation factor

(Nmax). When one factor is much higher than the others, the NWQI will be increased. Like the CWPI, this method could not determine the water quality classes according to the surface water environment standards.

Comprehensive Water Quality Identification Index (CWQII) Method

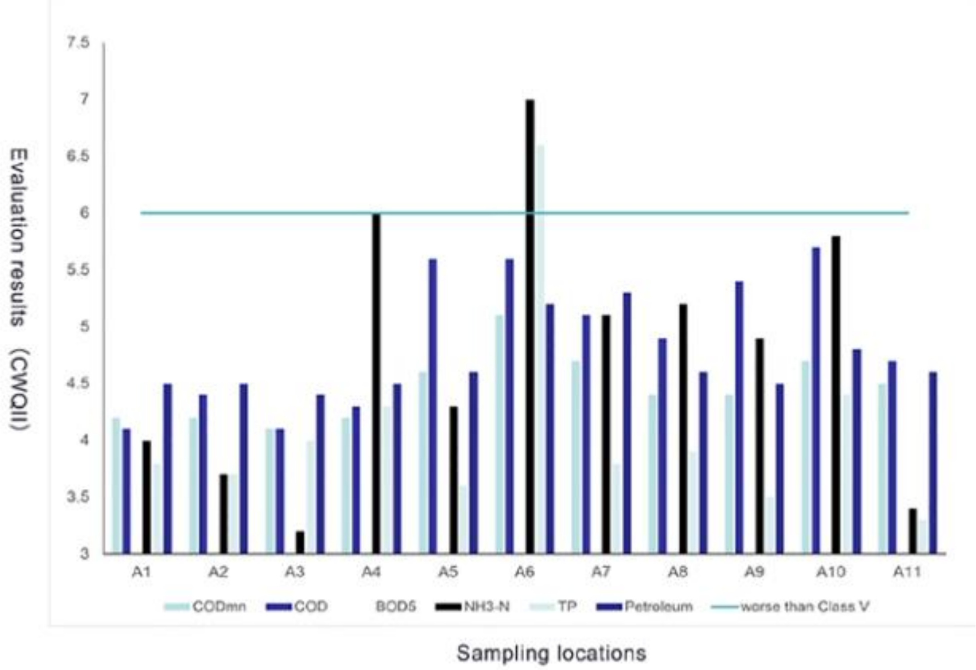

Figure 3.5: The result of water quality assessment using CWQII on Asejire River in 2015

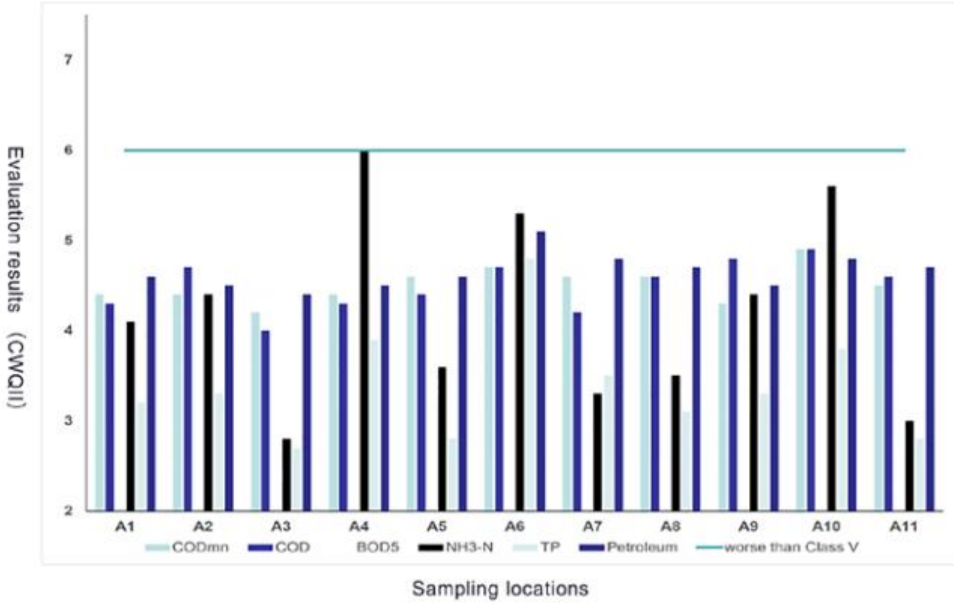

Figure 3.6: The result of water quality assessment using CWQII on Asejire River in 2016

The water quality classification for each factor was determined according to the CWQII method. The results are shown in Figures 8-10. Like for the SFE method, NH3-N in the Aba Alufa River in 2015 and 2016 and in the Olukeye-Asejire River (A6) in 2016 were Class 5 pollutants, as was the TP of Olukeye-Asejire River in 2015. The CWQII of Petroleum and BOD5 showed Petroleum and organics contamination in Asejire River and its tributaries. For Petroleum, the lowest concentration of was 0.16mg/L and the highest was 0.64mg/L, three times and 12.8 times Class 3, respectively.

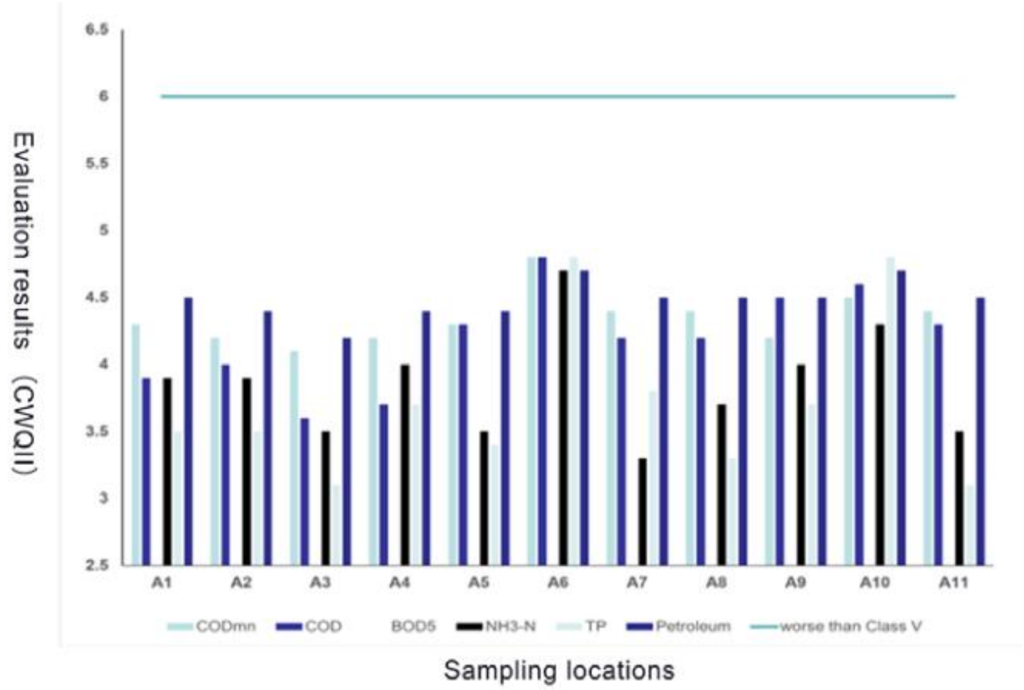

Figure 3.7: The result of water quality assessment using CWQII on Asejire River in 2017

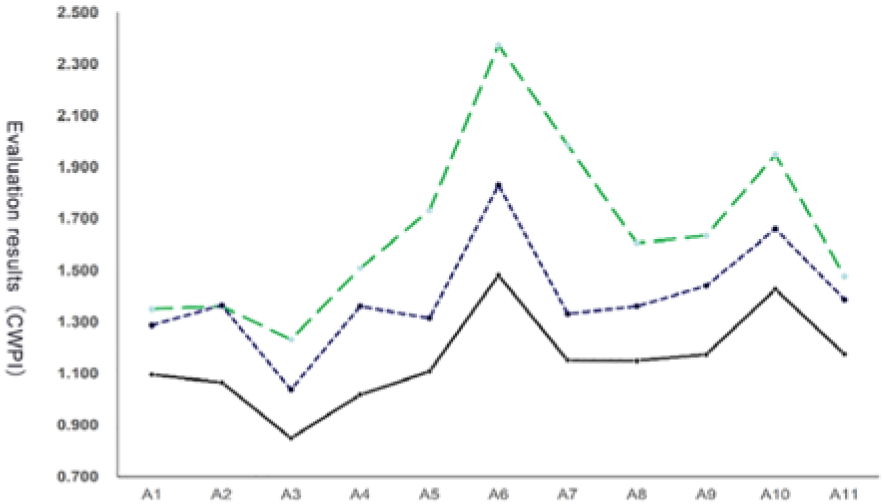

Figure 3.8: The results of CWQII from 2015-2017

According to the results of the water quality evaluation by using the CWQII method, the comprehensive water quality of the Faleti River was the best and was the worst for Olukeye-Asejire River (Figure 3.8). Olukeye-Asejire River was the most polluted water body of Ibadan City, where water quality was affected by industrial and domestic sewage. Faleti River is located in the Wetlands Reserve of Asejire province's delta area and local government have taken a series of important measures to protect the water quality of the wetlands, like creating the Wetland Protection Plan of Ibadan City. Year to year variation from 2015-2017 is shown in Figure 3.9. From 2015- 2017, except for Alabuke River in 2015-2017, the water quality improved in all sections. Olukeye-Asejire River, Erinmi River (2011-2012) and Aba Alufa River (2016-2017) showed significant improvement (13.4% 14.4% and 14.7%, respectively). It means that the government has done something useful to protect the environment. However, in order to achieve the environmental targets of the 'Water Pollution Prevention Action Plan' by 2020, petroleum and COD5 controls need be improved.

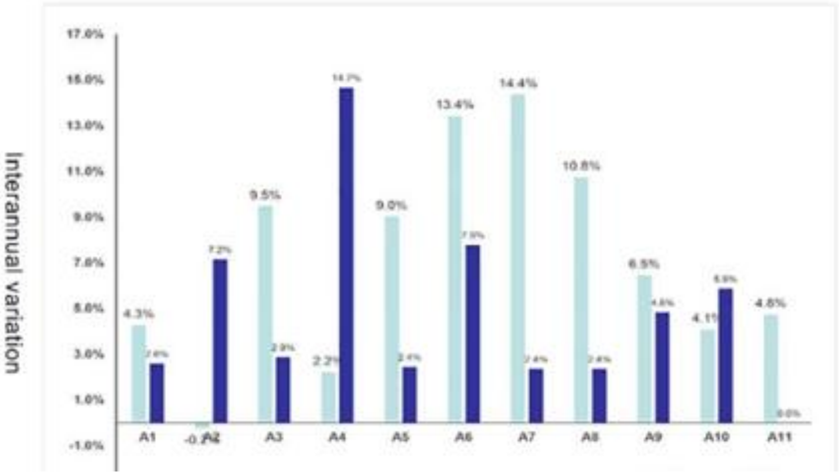

Figure 3.8: Comprehensive water quality change from 2015-2016 and 2016-2017

Table 5: Comparison of different methods for the evaluation of surface water quality

	Considers a group of factors instead of using the worst evaluation factor	**Compares single and comprehensive water qualities within the same class**	**Assesses the comprehensive water quality qualitatively and quantitatively**
Single Factor Evaluation (SFE) Method	×	×	×
Comprehensive Water Pollution Index (CWPI) Method	✓	×	×
Nemerow-Sumitomo Water Quality Index (NWQI) Method	✓	✓	×
Comprehensive Water Quality Identification Index (CWQII) Method	✓	✓	✓

According to evaluation of the CWQII method, the results showed this method was considered the best method for evaluating the water quality conditions of Asejire River and its tributaries, as shown in Table 5. Firstly, this method can evaluate water quality by using a group of evaluation factors instead of using the worst evaluation factor, so compared with the single factor method, the result of the CWQII is more reasonable. Secondly, compared with other methods, the CWQII can also be used to compare single and comprehensive water qualities within the same class and can also evaluate water quality when the water quality is lower than a Class 5. Thirdly, this method can assess the comprehensive water quality qualitatively as well as quantitatively. This method is suitable for assessing water quality in Asejire River and can provide useful information for water quality protection.

4. Conclusion and Recommendation

Comparing four methods of evaluating surface water quality, the CWQII is a feasible method for evaluating the water quality conditions of Asejire River and its tributaries. The SFE method only considers the most prominent factor and not all factors are considered in the resulting water quality evaluation. This means that the SFE method is limited in its ability to characterize the comprehensive water quality condition. Because of overemphasizing the influence of the maximum factor, the Comprehensive Water Pollution Index method and

Nemerow-Sumitomo Water Quality Index method cannot effectively evaluate the comprehensive water quality condition. Moreover, these methods could not determine the water quality classes according to the surface water environment standards of Nigeria. The CWQII method was the best method because this method used a group of evaluation factors instead of using only the worst evaluation factor, giving a more balanced result. The CWQII can also be used to compare single factor and comprehensive water quality within the same classification and can evaluate water quality when the classification is lower than a Class 5. This method can also evaluate the comprehensive water quality qualitatively and quantitatively. The CWQII method is an efficient tool to classify the water quality of the river and give rapid and precise information about the situation of the river that can provide useful information for water quality management and decision making.

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