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Irrigation Water Quality Index Assessment of Ele River in Parts of Anambra State of Nigeria

C. Emmanuel Chukwuma[1*], C. Godwin Chukwuma[1], I. Joseph Uba[1], C. Louis Orakwe[1] and N. Kingsley Ogbu[1]

[1]Department of Agricultural and Bioresources Engineering, Faculty of Engineering, Nnamdi Azikiwe University, Awka, Anambra State, Nigeria.

Authors' contributions

This work was carried out in collaboration between all authors. Authors CEC and CGC designed the study, wrote the protocol, and wrote the first draft of the manuscript. Authors IJU and NKO anchored the field study and gathered the initial data. Authors CLO and CEC managed the literature searches, and preliminary data analyses of the study. All authors read and approved the final manuscript.

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ABSTRACT

Due to concentration of industries in the study area and indiscriminate disposal of industrial effluent into Ele River, this study therefore aims at assessing the suitability of Ele River in Nnewi, Anambra State of Nigeria for irrigation purpose. Water samples were collected from three sampling points: Point 1 is at the point of effluent entrance, while point 2 is 100 m away from the point of discharging effluent and point 3 is 250 m away from the discharging effluent. To determine the suitability of Ele River as dry season (for the months of November, December and January) irrigation water supply, irrigation water quality index was used. Variables used for the assessment includes: Electrical Conductivity (EC), Sodium Absorption Ratio (SAR), Cl^-, Total Hardness, Na^+ and HCO_3. These variables were integrated to obtain a single number that represents the irrigation water quality. The result of the study shows that the IWQI of the month of November ranges from 39.88 at point 1 to 40.07 and 43.03 at point 2 and 3 respectively. While the month of December

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**Corresponding author: Email: Ecchukwuma@yahoo.com, ecchukwuma12@gmail.com;*

had 41.02, 42.51 and 43.33 at point 1, 2 and 3 respectively. The IWQI obtained for the month of January were 34.25, 36.96, and 40.25 for point 1, 2 and 3. This indicates that the River is severely polluted and the water quality could be classified as between high restriction to severe restriction usage based on water use restriction criteria in this study.

Keywords: IWQI; SAR; industrial effluent; irrigation water use; Ele River.

1. INTRODUCTION

Over the past years, in many African countries including Nigeria, considerable population growth has taken place, accompanied by a steep increase in urbanization, industrial and agricultural land use. This entailed a tremendous increase in generation of wastes usually discharged to receiving water bodies and has caused undesirable effects on the different components of the aquatic environment and on fisheries in particular [1]. These effluents produced as result of industrial activities have a great deal of influence on the quality of the water body and can alter the physical, chemical and biological nature of the receiving water body, thereby polluting it [2]. The quality of river water is crucial in crop production, maintenance of soil productivity, and protection of the environment [3]. In the last century, surface water resources have been polluted to such levels that they could no longer be used not only in direct human consumption but also in agricultural irrigation, therefore the index techniques have been developed as a result of this need [4]. One of the difficult tasks facing managers (workers) in irrigation field is how to transfer their interpretation of complex water quality data into information that is understandable and useful to technicians, planners and decision makers. The possible solution to this problem is to reduce the multivariate property of water quality data by employing an index that will mathematically combine all water quality measures and provide a general and readily understood description of water [5]. A WQI in a simplified concept is a way of combining complex water quality data into a single value or single statement. Irrigation water quality index (IWQI) has an advantage of reflecting the suitability of water for specific use (e.g. irrigation water supply) and using a combination of many parameters that limits water suitability to soil characteristics or crop yield. IWQI provides a single number that expresses overall water quality assessment at certain location and time based on several water quality parameters. Since 1965, when Horton proposed the first water quality index (WQI), a great deal of consideration has been given to the development of 'water quality index' methods with the intent of providing a tool for simplifying the reporting of water quality data [6]. A major objective of water quality assessment for irrigation is to determine whether or not the water quality meets the objective of irrigation for use in agriculture, to describe water quality at regional or national scales, and also to investigate temporal change of quality. It has been reported that water quality criteria must be interpreted in the context of overall salt balances and toxicities and its effects on soil [7]. It is commonly accepted that the problems originating from irrigation water quality vary in type and severity as a function of numerous factors including the type of soil and the crop, the climate of the area as well as the farmer who utilizes the water. So, evaluation of water used for irrigation is a prime need for sustainable crop production as well as food security. The main trust of this work is to determine the suitability of Ele River as dry season irrigation water supply source for vegetable production as it receives industrial effluent from nearby Industries.

2. MATERIALS AND METHODS

2.1 Description of the Study Area

Ele River is located in Uru Umudim Nnewi, Anambra State, Nigeria. The study area Nnewi, lies between Longitudes $6°91^{1}$E and $6°55^{1}$ E and Latitudes $6°16^{1}$ N and $6°10^{1}$ N. The climate is tropical. It has an average annual rainfall of 200 mm and mean temperature of 27℃. The months of April to October experience heavy rainfall, while low rainfall, higher temperature and low humidity characterize the months of November to February. As of 2006, Nnewi has an estimated population of 391,227 according to the Nigerian census. The city spans over 2,789 km^2 in Anambra State. Umudim, the location of the Ele River is a quarter that comprises of numerous industries such as: Food processing industries, table water factory, motorcycle manufacturing industry, vehicle manufacturing/assembly plant, electrical production industries etc. Since Ele River is located close to these industries, effluents from these industries deposited in the

River could be a source of pollution of the water body. This river also serves as a source of irrigation water supply for farms within the study area. The study area is shown in Fig. 1.

2.2 Collection of Water Samples

The water sampling and analysis was done during dry season period which ranges from November 2014 to January 2015. Ele River based on a preliminary survey was divided into three sampling points. The sampling points were then designated as: Point 1 (Point of entry of industrial effluent to the river), Point 2 (100 m away from point 1) and Point 3 (250 m away from point 1). Point 1(Entry point of effluent) is located upstream while Point 3 is at the downstream. From each sampling stations, water samples were collected using 1.5 litre sterile plastic bottles. Samples were transported to the laboratory immediately after collection for water quality analysis.

2.3 Irrigation Water Quality Index Calculation

To determine the suitability of Ele River as dry season irrigation water supply for agricultural purpose which is the objective of this study, IWQI was used. Water quality parameters used for this assessment include: Electrical Conductivity, Sodium Absorption Ratio (SAR), Chlorine (Cl^-), Total Hardness (TH), and Sodium (Na^+). SAR has been used by several researchers in assessing and classifying irrigation water quality and is given as follows:

$$SAR = \frac{Na^+}{\sqrt{\frac{(Mg^{+2})+(Ca^{+2})}{2}}} \quad (1)$$

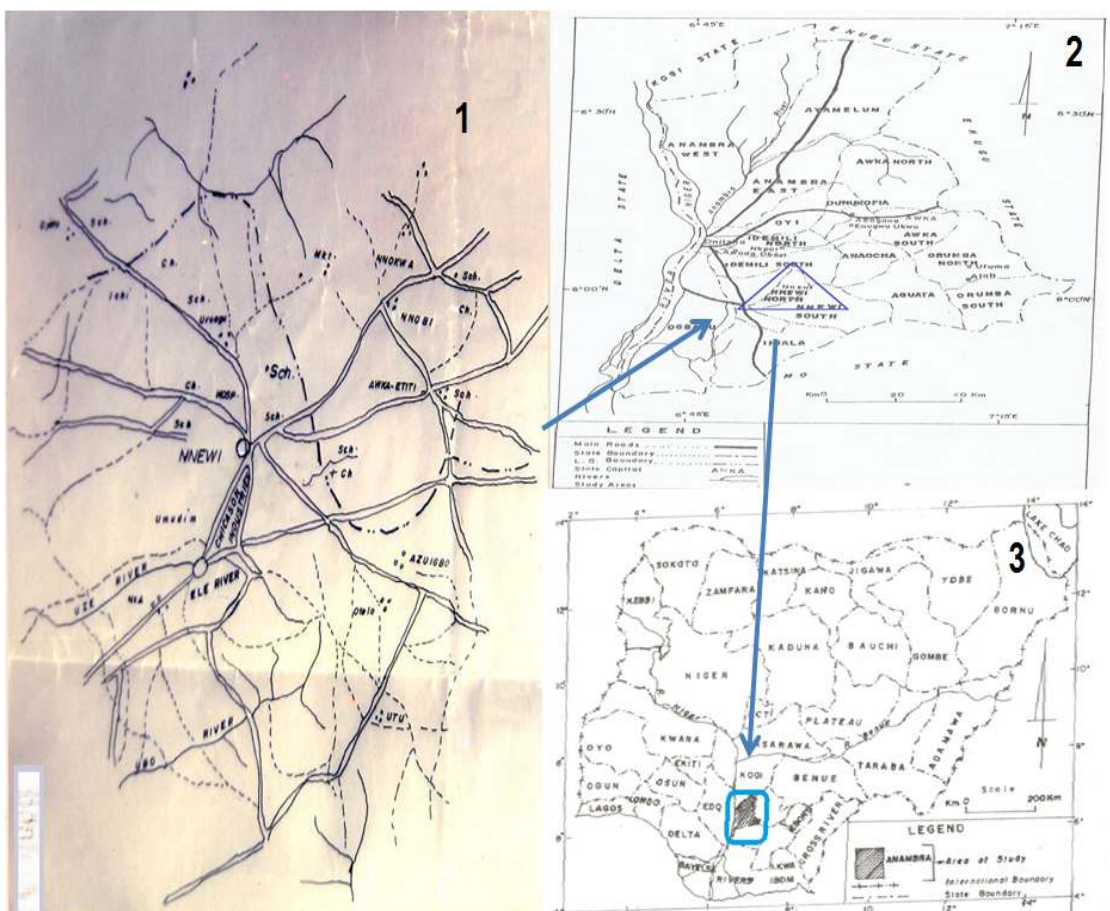

Fig. 1. Map of Nnewi showing the study area (Map 1) in Anambra State (Map 2) of Nigeria (Map 3)

The Irrigation water quality index (IWQI) model was applied in this study as used by Hussain et al. [8]. The model was development follows two stages [9]. The first stage involves identification of parameters that is known to impact most variability in the irrigation water quality. While in stage two, a classification of quality capacity values (q_c) is made and total weights (w_t) established using similar procedures established by [7], as shown in Tables 1 and 2 below. q_t estimate were calculated using equation 2, based on the suitable bounds presented in Table 1 and laboratory results of water quality analysis:

$$q_t = q_{imax} - \left[\frac{O_{ij} - O_{inf}}{V_{range}}\right] q_{iamp} \qquad (2)$$

where q_{imax} is the highest value of q_t for the class; O_{ij} is the observed value for the parameter; O_{inf} is the corresponding value to the observed lower limit of the class to which the parameter belongs; q_{iamp} is class range; V_{range} is class range to which the parameter belongs. In order to evaluate V_{range} of the last class of each parameter, the upper limit was considered to be the highest value determined in the physico-chemical analysis of the water samples. Each parameter weight used in the IWQI was obtained by [9] as shown in Table 2. The w_t values were normalized such that their sum equals one.

The irrigation water quality index (IWQI) was estimated using:

$$IWQI = \sum_{i=1}^{n} q_t \times w_t \qquad (3)$$

IWQI is measurement value that spans from 0 to 100; while q_t is the quality of the $_i$th value, a number from 0 to 100 which indicates its degree of concentration. W_t is the standardized weight of the ith value. In this study EC, SAR, Na^+, Cl^- and HCO_3 were unified to obtain a particular number that indicates the irrigation water quality [9]. The parameter limiting values for quality measurement (q_t) and weights for IWQI parameter estimation according to Meireles et al. [9] are shown in the Tables 1 and 2.

3. RESULTS AND DISCUSSION

The result of the water quality sample for irrigation assessment is shown in Table 3.

Using the values in the above Tables and equation 1, 2 and 3 above, the IWQI were obtained for the dry season period which includes the month of November, December and January. The IWQI was plotted graphical and is as shown in Fig. 2.

From Fig. 2, there is a general improvement or increase in the IWQI from point 1 to 2 and from point 2 to 3. This suggests that the industrial effluents could be the major source of pollution of the river body in the dry season period. The IWQI of the month of November ranges from 39.88 at point 1 to 40.07 and 43.03 at point 2 and 3 respectively. While the month of December had 41.02, 42.51 and 43.33 at point 1, 2 and 3 respectively. This indicates slight improvement in the IWQI from the month of November to December. There was a decline in

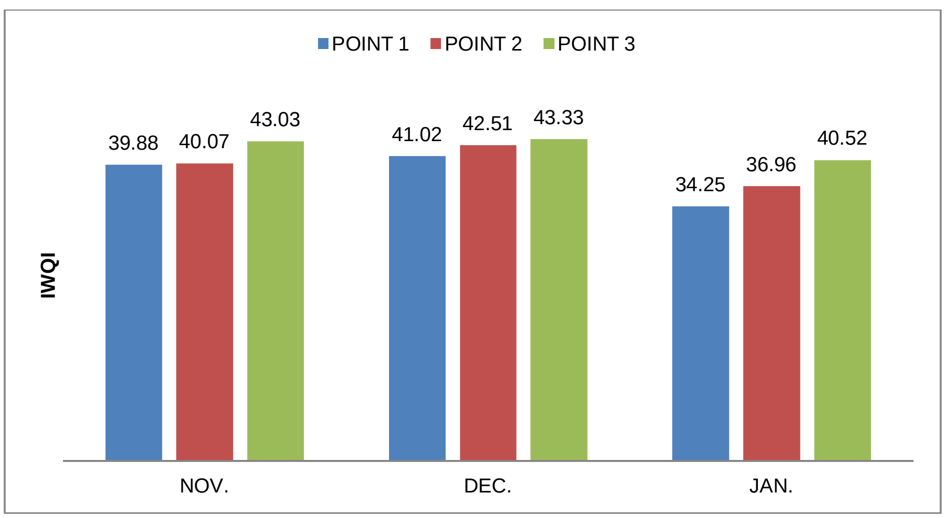

Fig. 2. Irrigation water quality index of Ele River

Table 1. Parameter limiting values for quality measurement (qi)

q_t	EC	SAR	Na^+	Cl^-	HCO_3
85-100	200≤EC<750	2≤SAR<3	2≤Na<3	1≤Cl<4	1≤ HCO_3<1.5
60-85	750≤EC<1500	3≤SAR<6	3≤Na<6	4≤Cl<7	1.5≤ HCO_3<4.5
35-60	1500≤EC<3000	6≤SAR<12	6≤Na<9	7≤Cl<10	4.5≤ HCO_3<8.5
0-35	EC<200 or EC≥3000	SAR>2 or SAR≥12	Na<2 or Na≥9	Cl<1 or Cl≥10	HCO_3<1 or HCO_3≥8.5

(Meireles et al., 2010) [9]

Table 2. Weights for the IWQI parameters

Water quality parameters	w_t
EC	0.211
Na^+	0.204
Cl^-	0.194
HCO_3	0.202
SAR	0.189
Total	1.00

(Meireles et al., 2010) [9]

Table 3. Dry season water quality parameters

Station	EC (us/cm)	Sodium (ppm)	Chloride (ppm)	Magnesium (ppm)	Hardness (mg/l)	Calcium (ppm)	SAR
Month of November							
Point 1	46.80	3.88	138	10.22	71.6	14.98	0.38645725
Point 2	35.60	5.13	94	10.56	84.8	17.33	0.485694418
Point 3	62.60	6.03	106	11.27	47.6	11.73	0.625543242
Month of December							
Point 1	46.50	3.90	130	12.43	68.8	15.33	0.370105
Point 2	36.50	4.76	122	11.65	79.9	16.99	0.444724
Point 3	63.60	4.89	97	11.23	46.8	15.88	0.469585
Month of January							
Point 1	53.10	5.03	128	9.63	72.6	20.33	0.45948
Point 2	43.70	7.72	84	15.8	89.7	20.52	0.640493
Point 3	76.60	7.47	91	17.85	48.4	16.67	0.635704

the IWQI in the month of January in comparison to the previous months, the IWQI obtained were 34.25, 36.96, and 40.25 for point 1, 2 and 3 respectively. This could be attributed to either increase in industrial effluents discharged or drastic decrease in the volume of Ele River as a result of cessation of precipitation or a combination of both factors. Generally as dry season set in, there is usual decrease in the quantity of water in rivers and it tends to increase as the dry season months goes by. However, considering the improvement in the IWQI from downstream, there is possibility of obtaining suitable water for irrigation purpose far downstream. Several researchers have given various values on the restriction criteria of irrigation water quality. So it was reported that irrigation water of IWQI values that ranges from 40-55 should be highly restricted and used for irrigation of plants with moderate to high tolerance to salts with special salinity control practices and IWQI values less than 40 should be severely restricted [9]. The IWQI rating of Ele river ranged from 34.25 to 43.33, using the classification criteria according to [9], it could be said that for irrigation water use, the river is classified between high restrictions to severe restriction usage. It should be avoided on soil for irrigation purpose under normal conditions and restricted to plants with high salt tolerance.

4. CONCLUSION

Investigation on the suitability of Ele River for irrigation purpose using the IWQI shows that the values on the basis of the suitability for irrigation purpose ranges from 39.88 at point 1 to 40.07 and 43.03 at point 2 and 3 respectively for the month of November, While the month of December had 41.02, 42.51 and 43.33 at point 1, 2 and 3 respectively. In comparison to the above previous months, the month of January had the least IWQI, the IWOI obtained were 34.25, 36.96, and 40.25 for point 1, 2 and 3 respectively. Based on the assessment it could be inferred that Ele River is unsuitable for irrigation purpose from the assessed points. However, there are indications that farther away from the points of pollution source, IWQI values could be improved.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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