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Assessment of Surface Water Qualities in Ihetutu Mining Areas of Ishiagu, Nigeria, using Water Quality Index Model

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Abstract

The quality of surface water from rivers, streams and ponds around Ihetutu mining areas in Ishiagu, was evaluated using Water Quality Index (WQI) model, to assess their suitability for drinking purposes at different seasons. Surface water samples were collected in rainy, late rainy, dry and late dry seasons, from 10 cm below water surface of the streams, ponds, and mine pits into 1.0 L polyethylene bottles, rinsed thoroughly with deionized water. The samples were preserved at 4oC in an ice box and then transported to the laboratory for analysis. Samples were digested and analyzed, using standard methods for nine physico-chemical parameters including pH, Cl^-, SO_4^{2-}, NO_3^-, DO, BOD_5, Ca^{2+}, Mg^{2+}, K^+. NESREA regulatory values for surface water were used as standard values while mean values of the physico-chemical parameters were used as observed values to determine the WQI for each sampling station. Ranges of the physico-chemical parameters were: pH = 6.52–7.49; Cl^- = 13.70–795.25 mg/L; SO_4^{2-} = 19.28-229.25 mg/L; NO_3^- = 0.33–3.72 mg/L; DO = 5.72–8.76 mg/L; BOD_5 = 12.19–18.20 mg/L; Ca^{2+} = 6.56–130.44 mg/L; Mg^{2+} = 2.06–20.89 mg/L; and K^+ = 4.51-32.93 mg/L. Average and seasonal WQI values were found to be >100 which indicated that the surface water resources in the area were unsuitable for drinking, though Iyiogwe stream had a WQI value of 98 in the late dry season, indicating rather a very poor quality of its surface water. The results revealed that untreated mine wastewater, dumps, and other contaminants discharged from point and non-point sources into the rivers, streams, and ponds/pits were responsible for the extremely poor quality of the surface water, and must therefore be treated properly before use to avoid water related ailments. The study created a database for current status of surface water on Ihetutu hills, which can be used for the management of ponds/pits, stream and river water in the area, and the study of the impact of mining activities on the surface water qualities.

Keywords: Contamination • Index • Mining • Quality • Surface water.

Introduction

Water is the most important, abundant and useful natural resources on the earth; and without it life cannot exist. It is the basic necessity of human lives and thus should be at an optimal level in quality. Water quality, which refers to the chemical, physical and biological characteristics of water [1] is more important in water supply planning than its quantity just as its purity is also important for the purpose of drinking [2]. Water quality is a measure of the condition of water with respect to the needs of biotic species and or to any human need or purpose [3].

Ihetutu is located in Ishiagu, Ebonyi State of Nigeria, within the Lower Benue trough where Pb- Zn mining has been going on for several decades now. There are a good number of rivers, streams, ponds dotting the area, and that are used by the inhabitants for various purposes including drinking, bathing, irrigation, and washing. The prolonged mining activities in the area, despite the huge economic benefits, were suspected to have serious negative impacts on the environment, especially the qualities of the surface water resources. The mining operations and associated industries generate large volumes of wastewater, drainage wastes and tailings, which plunders the landscape and contaminate the surrounding environment with inorganic pollutants, particularly heavy metals [4].

Various chemicals used during ore processing cause high degree of pollution of surface and groundwater bodies, mostly through wrong application, faulty disposal system, poor storage system and several other conditions prevalent at the time of operations, and these chemicals used at mine sites could also cause intense pollution of the environment [5]. Water pollution increases also in response to human population size, industrialization, the use of fertilizers in agriculture and man-made activity [6], which include mining operations, artisan activities, etc. Some important factors that determine growth of living organisms in a water body include temperature, turbidity, nutrients, hardness, alkalinity, dissolved oxygen, etc. [7].

The suspicion that the qualities of the surface water resources in the study area are seriously deteriorate by wastes from point and non-point sources, mostly the mining processes have made it imperative to carry out this study. Toxic chemical substances constantly being discharged into surface water bodies have become sources of contamination and threat to aquatic biota, as they deteriorate the water qualities. Availability of quality drinking water is of utmost importance to all humans; hence the significance of this research to ascertain the quality of the available surface water resources around Ihetutu. The objective of the study was therefore to assess the suitability of the surface water resources in the study area especially for drinking, using the Water Quality Index (WQI) model.

Materials and Methods

Sample collection and analysis

Samples were collected in four seasons; rainy season, late rainy season, dry season, and late dry season from both study and control areas (12 km away from the study area). Five surface water samples were collected in each season from the river, stream or pond, about 10 cm below the water surface to collect about 500 mL of water sample; and labeled as: SSW3, SSW6, SSW7, SSW8, and CSW1 (Table 1). Collected surface water samples were digested and analyzed for the various physico- chemical parameters using standard methods [8]. Temperature, pH, turbidity, and electrical conductivity were

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determined in-situ. NESREA [9] regulatory values for surface water were used as standard values to determine the WQI values.

Estimation of Water Quality Index (WQI)

This is a mathematical model that provides a single number that expresses the overall quality of water at a given location and time, based on several water quality parameters; and it can be applied in comparing the quality of water from different sources [10]. WQI also gives the public a general idea of the possible problems with water in a particular area or place. WQI, which is one of the most widely used water quality tool among the existing ones, is defined as a rating reflecting the overall influence of different the various water quality parameters [2].

Water Quality Index (WQI) is calculated using the model proposed by Horton and further developed by Brown et al. [11]; and is expressed arithmetically as:

$$WQI = \sum_{i=1}^{n} \mathrm{wiqi} / \sum_{i=1}^{n} \mathrm{wi} \quad (1)$$

Where, n is the number of parameters; and w_i which is the unit weight of the i^{th} water quality parameter, is inversely proportional to the recommended standards for the corresponding parameters, and is expressed as:

$$w_i = K/S_i \quad (2)$$

where K (Constant) = 1/(1/S1+1/S2+1/S3+......+1/Sn)

Saxena and Sharma expressed as the inverse of the sum of inverses of standard parameters used [2], in order to make the parameters expressed by large numbers to weigh less in the final formula (Equation 1) [12]; and S_i = Standard values for different water quality parameters, q_i is the water quality rating of the i^{th} parameter, and is expressed as:

$$q_i = 100\,[(V_{actual} - V_{ideal})/(Si - V_{ideal})] \quad (3)$$

where V_{actual} is the observed (measured) value of the i^{th} parameter; S_i is the standard permissible value of the i^{th} parameter; V_{ideal} is the ideal value of the i^{th} parameter in pure water, and are taken as zero for drinking water except for pH and DO which are 7.0 and 14.6 mg/L respectively [2,10,13].

The calculated Water Quality Index (WQI) values are used to express/ assess the status of the water quality at the given location and time on the scale (Table 2) [10].

Results and Discussion

Tables 2-7 below give the observed (mean) values (v_i), National Environmental Standards and Regulations Enforcement Agency [9] standard surface water values (s_i), unit weights (w_i), water quality ratings (qi) and wiqi of the selected physico-chemical parameters in the various surface water samples.

Assessment of quality parameters

•**pH:** Mean pH ranged from 6.52–7.49 with SSW3 having the lowest value while SSW7 has the highest (Table 8). The lower pH at the mine pit (SSW3) was due to the presence of sulfides such as pyrites (FeS2) which when exposed to water and atmospheric air were oxidized to sulfuric acid and formed Acid Mine Drain (AMD). The generated AMD infiltrated the surface water body and therefore reduced the pH [14].

•**Calcium and Magnesium:** Range of Ca^{2+} concentration was 6.56–130.44 mg/L (SSW7– SSW3) while that of Mg^{2+} was 2.06–20.89 mg/L (SSW8–SSW6) (Table 8). Calcium availability in water is directly related to hardness of the water [15], as the sum of the levels of Ca^{2+} and Mg^{2+} gives the total hardness of thewater. The high level of calcium could be due to weathering of limestone in the surrounding rocks/soils and underground water beds. Concentrations of magnesium in the surface water were generally found to be lower than the levels of calcium, though both are associated with each other in all kinds of water [2].

•**Chloride:** Mean concentrations of Cl^- ranged from 13.70 mg/L at SSW8 to 795.25 mg/L at SSW3 (Table 8). The presence of chloride in the surface water was related to the agricultural and industrial activities, and chloride rich rocks in the area [16]. High chloride content in water causes eye and nose irritation, stomach discomfort, and increase in corrosive character of the water [17].

•**Sulphate:** SO_4^{2-} mean concentrations ranged from 19.28 mg/L at SSW8 to 229.25 mg/L at SSW3 (Table 8). The high sulphate concentration in surface water at SSW3, SSW6 and SSW7 could be related to the constant excavation, discharge and dumping of mine wastes containing sulphate salts such as pyrites (FeS) in the surface water bodies.

•**Nitrate:** Mean NO_3^- concentrations ranged from 0.33 to 3.72 mg/L (Table 8). The low nitrate levels in the surface water could be due to its constant utilization by plankton and aquatic plants for metabolic activities [6].

•**Dissolved oxygen:** DO levels ranged from 5.72–8.76 mg/L (SSW8–SSW6) (Table 8). The low level of DO at SSW3 could be due to chemical and biochemical activities going on in the water body which depended mostly on the dissolved oxygen [18]. Also, the increased water temperature in the semi-

Table 1. Summary of sampling field data.

Sampling Stations	Sampling Dates	Sampling Seasons	Station Locations	Latitude	Longitude
CSW1 (Control Station)	11/05/2018;29/09/2018; 30/11/2018; 12/04/2019	RNS; LRS; DRS; LDS	Aku Stream, Uturu.	N 5°51'34"	E 7°31'13"
SSW3	11/05/2018;29/09/2018; 01/12/2018; 13/04/2019	RNS; LRS; DRS; LDS	Pb-Zn mine pit, Ihetutu.	N 5°51'35"	E 7°31'13"
SSW6	12/05/2018;29/09/2018; 01/12/2018; 13/04/2019	RNS; LRS; DRS; LDS	Pb-Zn mine downstream/ run-off, Ihetutu.	N 5°55'50"	E 7°29'1"
SSW7	12/05/2018;30/09/2018; 01/12/2018; 13/04/2019	RNS; LRS; DRS; LDS	NNPC pipeline stream, Ihetutu.	N 5°56'5"	E 7°31'6"
SSW8	12/05/2018;30/09/2018; 01/12/2018; 13/04/2019	RNS; LRS; DRS; LDS	Iyiogwe stream, Ihetutu.	N 5°56'53"	E 7°32'35"

RNS = Rainy Season; LRS = Late Rainy Season; DRS = Dry Season; LDS = Late Dry Season

Table 2. Water Quality Index (WQI) and status of water quality.

WQI	Water Quality Status
0 – 25	Excellent
26 – 50	Good
51 – 75	Poor
76 – 100	Very Poor
>100	Unsuitable for drinking

Table 3. Mean values and water quality ratings for parameters in Pb-Zn Mining Pit.

	SSW3				
	Observed values	Standard values	Unit weight	Quality rating	
Parameters	(v_i)	(s_i)	(w_i)	(q_i)	w_iq_i
pH	6.52	6.5 - 8.5	0.19	32	6.21
Cl^- (mg/L)	795.25	350	0.01	227.21	1.14
SO_4^{2-} (mg/L)	229.25	500	-	45.85	0.14
NO_3^- (mg/L)	3.72	40	0.04	9.3	0.38
DO (mg/L)	5.75	4	0.41	143.75	59.08
BOD_5 (mg/L)	18.2	6	0.27	303.33	83.11
Ca^{2+} (mg/L)	130.44	180	0.01	72.47	0.65
Mg^{2+} (mg/L)	12.8	40	0.04	32	1.31
K^+ (mg/L)	12.93	50	0.03	25.86	0.85

Table 4. M Mean Values and Water Quality Ratings for Parameters in Pb-Zn mine downstream/run-off.

	SSW6				
Parameters	Observed values (v_i)	Standard values (s_i)	Unit weight (w_i)	Quality rating (q_i)	w_iq_i
pH	7.00	6.5 - 8.5	0.19	-	-
Cl^- (mg/L)	792.75	350.00	0.01	226.50	1.13
SO_4^{2-} (mg/L)	171.75	500.00	-	34.35	0.10
NO_3^- (mg/L)	2.67	40.00	0.04	6.68	0.27
DO (mg/L)	8.76	4.00	0.41	219.00	90.01
BOD_5 (mg/L)	13.87	6.00	0.27	231.17	63.34
Ca^{2+} (mg/L)	43.95	180.00	0.01	24.42	0.22
Mg^{2+} (mg/L)	20.89	40.00	0.04	52.23	2.14
K^+ (mg/L)	32.93	50.00	0.03	65.86	2.17

Table 5. Mean values and water quality ratings for parameters in NNPC pipeline stream.

	SSW7				
Parameters	Observed values (v_i)	Standard values (s_i)	Unit weight (w_i)	Quality rating (q_i)	w_iq_i
pH	7.49	6.5 - 8.5	0.19	32.60	6.32
Cl^- (mg/L)	85.50	350.00	0.01	24.43	0.12
SO_4^{2-} (mg/L)	112.50	500.00	-	22.50	0.07
NO_3^- (mg/L)	0.33	40.00	0.04	0.83	0.03
DO (mg/L)	7.10	4.00	0.41	177.50	72.95
BOD_5 (mg/L)	13.14	6.00	0.27	219.00	60.01
Ca^{2+} (mg/L)	6.56	180.00	0.01	3.64	0.03
Mg^{2+} (mg/L)	3.20	40.00	0.04	8.00	0.33
K^+ (mg/L)	5.10	50.00	0.03	10.20	0.34

Table 6. Mean values and water quality ratings for parameters in Iyiogwe stream.

	SSW8				
Parameters	Observed values (vi)	Standard values (si)	Unit weight (wi)	Quality rating (qi)	w_iq_i
pH	6.85	6.5 - 8.5	0.19	10	1.94
Cl^- (mg/L)	13.7	350	0.01	3.91	0.02
SO_4^{2-} (mg/L)	19.28	500	-	3.86	0.01
NO_3^- (mg/L)	0.74	40	0.04	1.85	0.08
DO (mg/L)	7.37	4	0.41	184.25	75.73
BOD_5 (mg/L)	12.19	6	0.27	203.17	55.67
Ca^{2+} (mg/L)	13.9	180	0.01	7.72	0.07
Mg^{2+} (mg/L)	2.06	40	0.04	5.15	0.21
K^+ (mg/L)	4.51	50	0.03	9.02	0.3

closed mine pit due to the concentration of solar energy on the small surface area [19], could hinder the dissolution of oxygen in the water.

•**Biochemical oxygen demand:** BOD_5 mean levels ranged from 12.19–18.20 mg/L (SSW8– SSW3) (Table 8). This is the amount of oxygen required by microorganisms to decompose organic matter present in the water body [20]. Increase in BOD in could be due to increase in effluent discharge and dumping of organic waste to the stream/river [21]. This includes fertilizers and other organic wastes materials from the farmlands and domestic sources.

•**Potassium:** K^+ concentrations ranged from 4.51 mg/L at SSW8 to 32.93 mg/L at SSW6 (Table 8). The high K^+ level could be due to discharge of agricultural wastes including fertilizers containing potassium, from surrounding farmlands [22]. It could also occur naturally in feldspar, micas and clay minerals in the surrounding rocks/soil [18], from where it could leach/sip into the water bodies.

Estimation of WQI in surface water

Average and seasonal WQI values and status of surface water from

Table 7. Mean values and water quality ratings for parameters in control sample.

	CSW1				
Parameters	Observed values (v_i)	Standard values (s_i)	Unit weight (w_i)	Quality rating (q_i)	w_iq_i
pH	7.72	6.5 - 8.5	0.19	48.00	9.31
Cl^- (mg/L)	35.13	350.00	0.01	10.04	0.05
SO_4^{2-} (mg/L)	51.50	500.00	-	10.30	0.03
NO_3^- (mg/L)	0.10	40.00	0.04	0.25	0.01
DO (mg/L)	5.58	4.00	0.41	139.50	57.33
BOD_5 (mg/L)	12.95	6.00	0.27	215.83	59.14
Ca^{2+} (mg/L)	2.30	180.00	0.01	1.28	0.01
Mg^{2+} (mg/L)	2.93	40.00	0.04	7.33	0.30
K^+ (mg/L)	2.39	50.00	0.03	4.78	0.16

Table 8. Average WQI values and status of surface water at various sampling stations.

Sampling Station	ph	Cl^- (mg/L)	SO_4^{2-} (mg/L)	NO_3- (mg/L)	DO (mg/L)	BOD_5 (mg/L)	Ca^{2+} (mg/L)	Mg^{2+} (mg/L)	K^+ (mg/L)	WQI Value	Water Status
CSW1 (control)	7.72	35.13	51.50	0.10	5.58	12.95	2.30	2.93	2.39	124.97	Unsuitable for drinking
SSW3	6.52	795.25	229.25	3.72	5.72	18.20	130.44	12.80	12.93	151.21	Unsuitable for drinking
SSW6	7.00	792.75	171.75	2.67	8.76	13.87	43.95	20.89	32.93	157.66	Unsuitable for drinking
SSW7	7.49	85.50	112.50	0.33	7.10	13.14	6.56	3.20	5.10	138.68	Unsuitable for drinking
SSW8	6.85	13.70	19.28	0.74	7.37	12.19	13.90	2.06	4.51	132.56	Unsuitable for drinking

Table 9. Seasonal WQI values and status of surface water in study and control areas.

	Sampling Seasons							
		RNS		LRS		DRS		LDS
Sampling Station	WQI Value	Water Status	WQI Value	Water Status	WQI Value	Water Status	WQI Value	Water Status
CSW1 (control)	100.18	Unsuitable for drinking	132.98	Unsuitable for drinking	130.00	Unsuitable for drinking	120.31	Unsuitable for drinking
SSW3	164.79	Unsuitable for drinking	163.58	Unsuitable for drinking	111.24	Unsuitable for drinking	168.05	Unsuitable for drinking
SSW6	193.00	Unsuitable for drinking	222.88	Unsuitable for drinking	116.46	Unsuitable for drinking	117.60	Unsuitable for drinking
SSW7	149.73	Unsuitable for drinking	171.68	Unsuitable for drinking	122.32	Unsuitable for drinking	110.65	Unsuitable for drinking
SSW8	163.97	Unsuitable for drinking	164.93	Unsuitable for drinking	109.91	Unsuitable for drinking	98.00	Very Poor

RNS = Rainy Season, LRS = Late Rainy Season, DRS = Dry Season, LDS = Late Dry Season

various sampling stations in the control and study areas are also presented in Tables 8 and 9. The WQI values, which indicated the overall status or qualities of water at the sampling stations, depending on selected quality parameters were determined, using Equation 1. NESREA (2011) regulatory values for surface water were used as standard values [9], and mean values of the physico- chemical parameters used as observed values. The trend of deterioration of surface water qualities at different sampling stations, based on average WQI values was in the order of Pb-Zn mine downstream/run-off (SS6)>Pb-Zn mine site (SS3)>NNPC pipeline (SS7)>Iyiogwe stream (SS8). WQI values for all sampling stations in the study area were higher than that of the control station (CSW1) (Table 8). This confirmed a deterioration of the water qualities. Generally, the status of surface water samples from the study area were "Unsuitable for drinking" with average WQI values >100 [10] in all stations (Table 8). Also, status of surface water from the study area in the various seasons indicated unsuitability for drinking, as the respective seasonal WQI values for all the samples were >100 [10], exception of the late dry season (LDS) surface water status at Iyiogwe stream (SSW8), with WQI value of 98.00 (very poor) (Table 9). The extremely poor (unsuitable) quality/status of the surface water in the study area was due majorly to the high levels of toxic chemical substances discharged into the water bodies (rivers, streams and ponds/pits) both from point and non-point sources such as mine waste dumps, tailings, mine drains, washouts, and surface run-offs, especially in the rainy seasons. These toxic chemical species heavily contaminate/pollute the surface water in the area and thus drastically deteriorate their qualities, and also render them unsuitable for drinking and other domestic purposes.

Conclusion

Results from the study revealed that most of the physico-chemical parameters of surface water in Ihetutu mining areas of Ishiagu were higher than those of the control (background) samples, thereby indicating a deterioration of the water quality in the study area. Average and seasonal WQI values were found to be above 100 which also indicated that the surface water resources in the area were unsuitable for drinking. WQI value for Iyiogwe stream was 98 in the late dry season which also indicated a very poor quality of its water in the season. The results revealed that untreated mine wastewater, dumps, and other contaminants discharged from point and non-point sources into the rivers, streams, and ponds/pits were responsible for the poor qualities of the surface water. Both government and mining companies operating in the area must treat these available surface water resources and make them suitable for drinking and other domestic purposes, and to avoid prevalence water related ailments when consumed. Measures must be taken by the companies operating in the area to ensure that their wastes and other toxic chemical substances generated are not carelessly discharged into the water bodies. Regulatory bodies must also ensure proper monitoring of the activities of these mining companies in the area, and also enforce strict compliance with laid down standards/regulations, to safeguard the surface water in the rivers from being contaminated. This study only covers the status of surface water in the area. Similar studies should therefore be carried out on groundwater status/ qualities in the area.

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