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The impacts of waste-stream from Aluminium Extrusion Plant on the Inyishi River and its Watershed , Niger Delta Basin, Southeastern Nigeria

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ABSTRACT

The impacts of waste-stream from aluminium plant on the Inyishi River was investigated by analyzing the physical and chemical contents of the river using Atomic Absorption Spectrophotometer (AAS) and digital meters. The results shows that the pH of the river varies from 5.80 to 6.10 while the total dissolved solids (TDS) varies from 13.50 to 20.50mg/l. The electrical conductivity varies from 22.50 to 34.17µS/cm while total alkalinity range from 9.80 to 12.50mg/l. The concentrations of Ca^{2+} varies from 2.80 to 3.10mg/l while Mg^{2+} range from 2.60 to 2.86mg/l. Na^{+} concentrations varies from 5.85 to 7.10mg/l while K^{+} varies from 9.00 to 11.00mg/l. The concentrations of HCO_3^- varies from 20.50 to 21.90mg/l while that of SO_4^{2-} range from 3.29 to 4.90mg/l. Al^{3+} concentrations varies from 0.22 to 0.29mg/l while total iron concentrations range from 0.50 to 0.64mg/l. F^- concentrations varies from 0.30 to 0.80mg/l while that of BOD range from 3.60 to 5.40mg/l. Dissolved oxygen (DO) concentrations varies from 6.50 to 7.10mg/l while the total coli form range from 50 to 80 cfu/100ml. The results also show that the Sodium Adsorption Ratio (SAR) of the river varies from 0.58 to 0.74 while the Pollution Index (PI) varies from 0.68 to 0.72. Except for the pH, total coli form and Al^{3+} , the concentrations of other measured parameters conformed to World Health Organization (WHO) 2006 and Nigerian Water (2008) safe standards f0r drinking water. The acidic nature of the river, high concentrations of Al^{3+} and significant concentrations of total iron, F^- and BOD are attributed to the waste-stream which is discharged into it from the Aluminium Extrusion plants in the study area. The impacts of the waste-stream on the river and its watershed include damage of coconut (*cocos nucifera*) trees and raffia palms (*raphia ruffia*) resulting in the decline of coconut, rope, local gin and palm wine production as well as decline in the cultivation of certain varieties of vegetables such as fluted pumpkin (*telfairia occidentalis*), water leaf (*talonum tiangulare*), garden eggs (*salomum macrocarpum*) and green (*amarantus hybridias*) near the river; it has also resulted in the decline in fishing activities and use of the water for drinking purposes. About 1,000 persons who live at a distance of 0.5km away from the river were observed to be at very high risk to the impacts of the waste-stream on the river. Pre-disposal treatment of the waste-stream and well programmed monitoring of the physical and bio-chemical characteristics of the Inyishi River is the best approach to maintain is resource status and usefulness.

1.0. Introduction

Inyishi River in the Niger Delta Basin is precisely located within Latitudes 5^0 $30^/$ and 5^0 $37.5^/$ North and Longitudes 7^0 $08^/$ and 7^0 $11^/$ East (Figure 1). The river is a second order river in Imo State, Southeastern Nigeria. It flows in a North-South direction and joins the Oramiriukwa river in its Southern part; the Oramiriukwa river joins the Otamiri river further Southwards (Figure 1) and both flows into the Atlantic Ocean. The river has a shoreline length of about 17.5km, mean depth of 4.6m and a flow velocity of about 0.35m/s. Although the Inyishi River is small when compared to other freshwater resources in Nigeria like rivers Niger and Benue, it is however, of strategic importance to both the local community living near its shores and Imo State Government. To the former, it provides water for domestic and commercial purposes and also serves for recreation, irrigation and fishing activities. To the latter, it provides a focal point for research, tourism and transport development. It is a fact that human and even natural activities within and around the river have the potential to modify the physical and bio-chemical characteristics of the river and thus alter its resource status and usefulness. Untreated waste-stream from the two aluminium extrusion plants located near the watershed of Inyishi River are discharged into the river. The waste-stream and pollutants from anthropogenic sources constitute a threat to the river. Waste from aluminium plants usually contains significant concentrations of Al^{3+} and F^- which are inimical to the recipient environment (Petrela et al., 2001). Iharia and Lennart (1984) observed high concentrations of Polycyclic Aromatic Hydrocarbon (PAH) and Mutagens in waste from aluminium plants.

Although some studies (Ahiarakwem et al., 2012; Ibe and Onu, 1999, Nwankwor and Okpala, 1993 and Uma, 1984) have been carried out on the water resources of Southeastern Nigeria, there is paucity of literature on the impact of industrial activities

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on these resources that would ensure future projections on pollution loads. The continuous discharge of untreated waste-stream into the Inyishi river calls for proper monitoring of the water quality.

One approach that is required to maintain the resource status and usefulness of the Inyishi River, is development of appropriate pollution preventive and mitigation strategy. This can be realized through a well programmed monitoring system that will involve a detailed periodic assessment of the Inyishi River ecosystem.

2.0 Climatic setting

The study area is located within the equatorial belt of Nigeria. The mean monthly temperature of the area ranged from 25 to 28.5 ^{o} C while the mean annual rainfall is about 2.500 mm most of which fall between the months of May and October (National Root Crop Research Institute' 2012). The rainy period (May-October) is characterized by moderate temperature and high relative humidity. The months of November to April have scanty rainfall, higher of temperatures and low relative humidity (Uma, 1984). The wind direction in Owerri area and environs (of which the study area is a part) is mainly South-West, North-West and West. However, the South-West wind direction is the strongest (Anyanwu and Oueke. 2003). The area is part of the rain forest belt and the vegetation cover include shrubs, economic trees such as oil palm (arecaceae), Indian bamboo (bambusae), iroko (African teak), avocado pea (*Persia Americana*),African bread fruit (*Trelulia Africana*), oil bean (*pentaclethra mahophlla*) , miracle (*spondias mombin*) and raffia palms (*raphia ruffia*). However, field observation shows that most of the vegetation especially near the waste-stream discharge point have died; the most affected being the coco nut *cocos* nucifera) and raffia palms (*raphia rufia*).

3.0 Geology

The study area is underlain by the Benin Formation (a major stratigraphic unit in the Niger Delta basin (Figure 2). The Benin Formation consists of friable sands with intercalations of shale/clay lenses of Pliocene to Miocene age(Short and Stauble, 1967). The formation contains some isolated gravels, conglomerates, very coarse sandstone (Ananaba et al., 1993). The average thickness of the formation in the study area is about 800 m while the average depth to water table is about 18.3 m (Avbovbo, 1978). The formation is overlain by Alluvium deposits and underlain by the Ogwashi-Asaba Formation which consists of lignite, sandstones, clays and shale. The Benin Formation provides the aquifer for groundwater storage because of its high porosity and permeability. The incidence of high porosity and permeability as well as shallow water table makes the groundwater in the area very vulnerable to pollution. The geologic setting of the area, therefore, calls for proper land use and waste management so as to protect the sooil and water resources of the area.

4.0 Materials and methods

Surface water samples obtained at four gauge stations (SW_1 to SW_4) were obtained along the stretch of the Inyishi River (Figure 1). The sampling procedure was carried out using the discharge point of the waste-stream from the two aluminium extrusion plants as a parametric control. The sampling points, SW_1, SW_2, SW_3 and SW_4 were located at distances of 0.1, 0.5, 1.0 and 2km respectively (Figure 1) from the discharge point of the waste-stream taking cognizance of the flow direction of the river (North to South). The flow direction corresponds to the adopted sampling procedure (SW_1 to SW_4). Sampling was carried out in July, 2012 and the samples were obtained with the aid of three 1.5 liters plastic containers that were previously prepared (treated) using the grab method. The containers were corked under water immediately the samples were obtained so as to prevent the oxidation of the constituents. Of the three samples collected, one was immediately analyzed or the following parameters Dissolved Oxygen (DO), pH, Electrical Conductivity, Total Alkalinity and Total Dissolved Solids (TDS) using Digital Meters. A second sample was preserved in a cooler of ice (usually below 5^0C) and later sent to the laboratory. Part of the sample was used to conduct microbial analysis with Standard Plate Counts while the other part was analyzed for major constituent cations (Ca^{2+}, $Mg^{2+,}$ Na^+ , $Al^{3+}$and K^+) and anions (HCO_3^- , SO_4^{2-} , Cl^- , F^- and NO_3^-) using the Atomic Absorption Spectrophotometer (AAS). The AAS was also used to determine the concentrations of Pb^{2+} , Zn^{2+} , and Cu^{2+} .

Third sample used for the determination of the Biochemical Oxygen Demand (BOD) was treated in quick successIons in 1ml Potassium Fluoride solution nd 2ml Manganese Sulphate solution and properly corked (air-tight). The corked sample waslater sent to the laboratory within 24 hours for analysis. The BOD was determined by first diluting the sample and incubating it in the dark at 20^0C and measuring the amount of oxygen consumed.

The concentrations of the major constituent cations and anions in milligram/liter (mg/l) were converted to milliequivalent/liter (meq/l) using the equation 1 developed by Todd (1980)

$$\text{Milliequivalent/liter (meq/l)} = \frac{\text{Milligram /liter}}{\text{Equivalent mass}} \quad \text{...........(Equ. 1)}$$

The concentrations in meq/l were used to prepare Piper trilinear and Stiff diagrams as well as calculation of Sodium Adsorption Ratio (SAR). The SAR was determined using the equation 2 (Wilcox,1955).

$$S\ AR= \frac{Na^+}{\sqrt{\frac{(Ca^{2+} + Mg^{2+})}{2}}} \quad \text{…………………………(Equ. 2)}$$

The total hardness as ($CaCO_3$) of the Inyishi River water was determined using the equation 3 Todd (1980).

$$\text{Total hardness as } CaCO_3 \text{ mg/l} = 2.5\,[Ca^{2+}] + 4.1\,[Mg^{2+}] \quad \text{.......................…………..(Equ.3)}$$

The parameters considered for the determination of the pollution index (PI) of the Inyishi River water samples were pH, Total Alkalinity, Total Hardness, Total dissolved solids (TDS), sulphate and chloride. The PI was calculated using the equation 4 developed by Horton (1965).

$$PI= \sqrt{\frac{(maxC_i/L_j)^2 + (meanC_i/L_j)^2}{2}} \quad \text{………….(Equ.4)}$$

Where

C_i = concentration of chemical parameters

L_j = World Health Organization (2006) permissible limit.

5.0 Results and discussion

The results of the physical and bio-chemical characteristics of the Inyishi River is shown in Table 1 while the major constituent cations and anions and pollution index are shown in Tables 2 and 3 respectively.

5.1 Physical Parameters of the Inyishi River Water

The concentrations of the pH of the Inyishi River varies from 5.80 to 6.10 and this does not conform to both Nigerian Standard for drinking Water (NSDW) 2008 and World Health Organization (WHO) 2006 safe standard for drinking water.

The pH was observed to increase slightly as one moves away (downstream) from the discharge point of the waste-stream .The acidic nature of the river water is attributed to the waste-stream from the aluminium plants in the area .Waste-stream from aluminium plants increases the acidity of surface water resources and also introduces dissolved Al^{3+}, F^-, iron and BOD into them (Petrela et al., 2001). At a pH range of 5.00-5.50, aluminium is toxic to fish at 0.10mg/l (Bouredemos, 1974). There are virtually absence of aquatic plants on the river partly due to the acidic nature and low nutrient level of the river water. Aquatic plants such as water hyacinth grow best between pH of 7.0 and 9.20 (Bourodemos, 1974). As acidity of surface water increases, submerged aquatic plants decreases and deprives water fowls of their basic food source. At pH of 6.0 (as is the case with the study area), freshwater shrimp cannot survive; at pH of about 5.50, bottom-dwelling bacteria decomposer begins to die leaving un-decomposed leaf litter and other organic debris to collect on the bottom. This deprives planktons their food resulting in their death. As un-decomposed organic leave litter increases due to the loss of bottom- dwelling bacteria, toxic metals such as aluminums, mercury and lead within the litter are released. These toxic metals are inimical to the human health (Bourodemos, 1974). It is therefore imperative to monitor the pH of the river on a regular basis so as to guard against the introduction of aluminium and the other toxic metals from the above-mentioned process in addition to the ones from the waste-stream. Below pH value of about 4.50, all fish will die (Bourodemos, 1974). On the basis of the pH values of the river, pre-use treatment with sodium bicarbonate is recommended.

The Total Dissolved Solids (TDS) varies from 13.50 to 20.50mg/l while the electrical conductivity ranged from 22.50 to 34.17µS/cm. Both conformed to NSDW (2008) and WHO (2006) standard for safe drinking water. Water samples with TDS range of 0 to 1,000 are classified as fresh (Carrol, 1962); the Inyishi River water is therefore classified as fresh based on the TDS values.

The Total Alkalinity varies from 9.80 to 12.50mg/l and this implies that slight liming of fish ponds which depends on the river may be necessary. Liming is required for Total Alkalinity value of less than 20mg/l (Boyd and Lightropper, 1979).

5.2 DO and BOD

The concentrations of dissolved oxygen (DO) of Inyishi River varies from 6.50 to 7.10mg'l while Biochemical Oxygen Demand (BOD) varies from 3.60 to 5.40mg/l. The DO range indicates that the river is well oxgenated, a condition that is favourable for the survival of aquatic life such as fish (Clark et al., 1972). However, the BOD values indicates slight pollution of the river (Prat et al., 1970) and this implies significant input of organic materials from the waste-stream and anthropogenic sources. Continuous influx of organic input into the river can result in heavy pollution of river ecosystem.

5.3 Major Cations and Anions

The concentrations of the major constituent cations and anions (Table 1) conformed to both NSDW (2008) and WHO (2006) standard for safe drinking water. The concentrations of Ca^{2+} varies from 2.80 to 3.10mg/l while Mg^{2+} ranged from 2.60 to 2.8mg/l. Na^+ concentrations varies from 5.85 to 7.10mg/l while K^+ varies from 9.90 o 1.0mg/l. The concentrations of HCO_3^- varies from 20.50 to 21.90mg/l while SO_4^{2-} concentrations ranged from 3.40 to 4.90mg/l. The concentrations of Cl^- ranged from 14.4 to 17.00mg/l. The results indicate that the concentrations of the constituent major cations and anions of the Inyishi River water is generally low (Tables 2 and 3).This typical of most tropical African surface water resources (Oliver, 2005). The water characteristics of the river follow the trend $Na^+ > K^+ > Ca^{2+} > Mg^{2+}$ for cations and $HCO_3^- > Cl^- > SO_4^{2-}$ for the anions. This trend is not typical is of typical of most surface water resources of Southeastern Nigeria and this may be due to the modification of the water chemistry of the Inyishi River by the waste-stream.

5.4 Total Hardness as $CaCO_3$

The total hardness as $CaCO_3$ of the Inyishi River water is low and conformed to both NSDW (2008) and WHO (2006) safe standard for drinking water. The concentrations of total hardness ranged from 18.04 to 18.88 mg/l (Table 1).The low hardness values is due to low concentrations of Ca^{2+} and Mg^{2+} ion in the river water. According to Wilcork (1993), water samples with total hardness range of 0 to 50mg/l (as is the case with the Inyishi River water) are classified as being soft.

5.5 Al^{3+} and F^-

The input of AL^{3+} and F^- constituents into the Inyishi River is mainly from the waste-stream from the aluminium plants in the area. Dissolved aluminium exist in water as Al^{3+}, $Al(OH)_4$ and particulate aluminium. The concentrations of Al^{3+}varies from 0.21 to 0.28mg/l and this is not in conformity with NSDW (2008) standard for safe drinking water. High aluminium intake is associated with vitamin deficiency, nerve damage or neuro-degenerative disorders and cancer. Dissolved Al^{3+} is toxic to plants as it affects roots and prevents nutrient intake. In acidic water (pH:5.0 -5.5), Al^{3+} is toxic to fish at 0.01mg/l. (Bouredemos, 1974). Dissolved Al^{3+} interferes with fish ills functions thus causing fish to lose electrolytes. Field observations indicates that the coconut (*cocos nucifera*) and raffia palms (*raphia ruffia*) near the discharge point of the waste-stream were dead resulting in the decline in coconut, rope, local gin and palm wine production in the area. It was also observed that certain varieties of vegetables such as fluted pumpkin (*telfairia occidentalis*), water leaf (*talinum triangulare*), garden egg (*salomum macrocarpum*) and green (*amarantus hybridus*) no longer survive near the river because of prevention of nutrient intake by Al^{3+} .It was also observed that fishing activity in the river has been on the decline since the aluminium plants became operational. The use of the river water for domestic purposes such as drinking was also observed to have declined. Some water boreholes have been constructed in the area as a remediation measure to the impacts of the waste-stream on the river and its watershed. However, a long term measure would be adequate treatment of the waste-stream before its discharge into the recipient environment. This long term measure is necessary because continuous loading of dissolved Al^{3+} can also pollute the Oramiriukwa and Otamiri rivers (Figure1) which have connection with the Inyishi river. Such a pollution would pose adverse impacts on the people living near and within the water shed of these rivers in terms of human health, recreational and fishing activities.

The concentrations of F^- in the Inyishi River varies from 0.30 to 0.80mg/l and is thus in conformity with NSDW (2008) standard for safe drinking water at the moment. However, F^- maximum limit of 1.5mg/l might be exceeded in the near future if appropriate preventive pollution mitigation measures are not put in place. High intake of F^- causes fluorosis, skeletal tissue (bones and teeth) morbidity.

Demographic survey shows that about 1,000 and 2,000 persons live 0,5km and 1km away from the river respectively.

The survey also shows that about 5,000 persons live 2km while about 12,000 persons live 5km away from the stream. Based on this survey, the 1,000 persons living closest to the river are at high risk to the pollution of the river and in fact its water shed.

The impacts of waste from aluminium plants on the environment is a challenge to both developing and developed Nations of the World. Since the aluminium plant in Balligian, Mukah in Malaysia became operational in 2009, vegetation within 200m from the factory has died; about 2,000 longhouse people staying adjacent to the plant complain of acute respiratory sickness which cause them between RN200 and 500 for treatment per month per family (Peoples documentary, 2012).

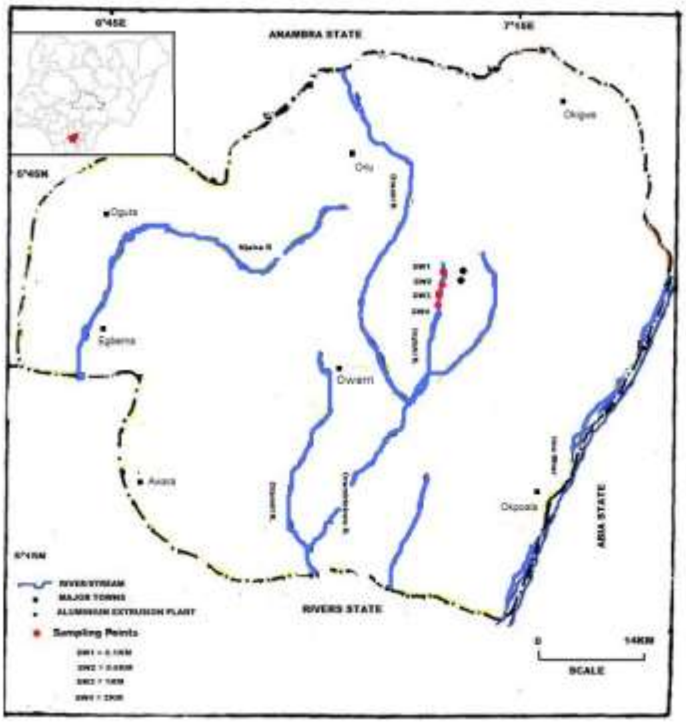

Figure 1: Map of the study area showing sampling points

5.6 Total iron and Heavy metals

The concentrations of total iron of the Inyishi River water varies from 0.50 to 0.64mg/l and this is in conformity to WHO (2006) standard for safe drinking water. However, it must be pointed out that the concentrations of total iron in the river water is high when compared with other surface water resources in Southeastern Nigeria. Aluminium ore (Bauxite) usually contains silicon dioxide, titanium and iron oxides as impurities; since iron oxide is part of impurities associated with aluminium ore from where the raw aluminium is extruded, the significant values of total iron is also attributed to the waste-stream. Although iron is essential to the building of the human hemoglobin, excessive concentrations stains laundry.

The concentrations of heavy metals Pb^{2+}, Zn^{2+}, Cu^{2+} and Cd^{2+}) were in conformity to NSDW (2008) and WHO (2006) standard for safe drinking water. Except for Pb^{2+}, that has concentration less than 0.0001mg/l, other heavy metals mentioned above were not detected.

5.7 Microbial Assay

The total coli form count of the Inyishi River water varies from 50 to 80cfu/100ml. These values do not conform to both the NSDW (2008) and WHO (2006 standard for safe drinking water. The poor microbial assay is typical of most surface resources in the tropics; the microbial assay of the river waters, is mainly due to pollution from widespread and indiscriminate human and animal defecation and very poor land use or poor waste disposal practices. Poor microbial assay of water resources can cause dysentery, cholera, bilharzias, typhoid, gastrointestinal disorders and hepatitis. Pre-use treatment with chlorine is recommended as a remediation measure to health hazards associated with the poor microbial characteristics of the river.

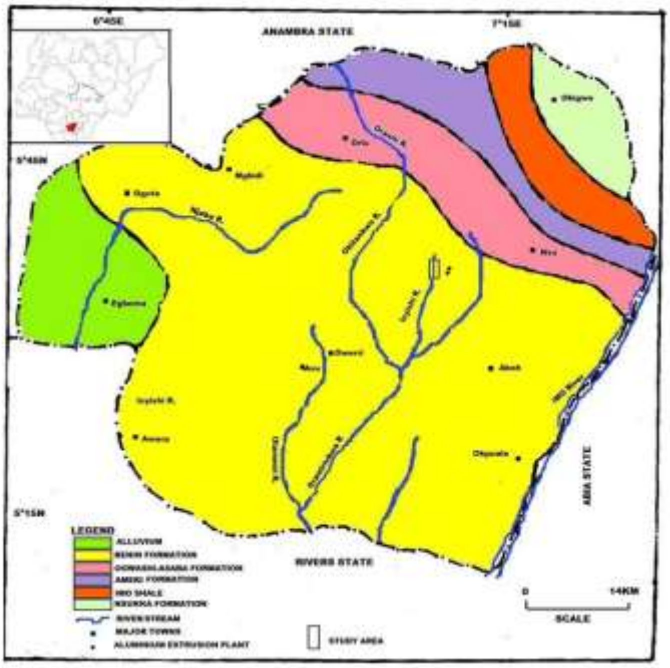

Figure 2: Geological map of the study area

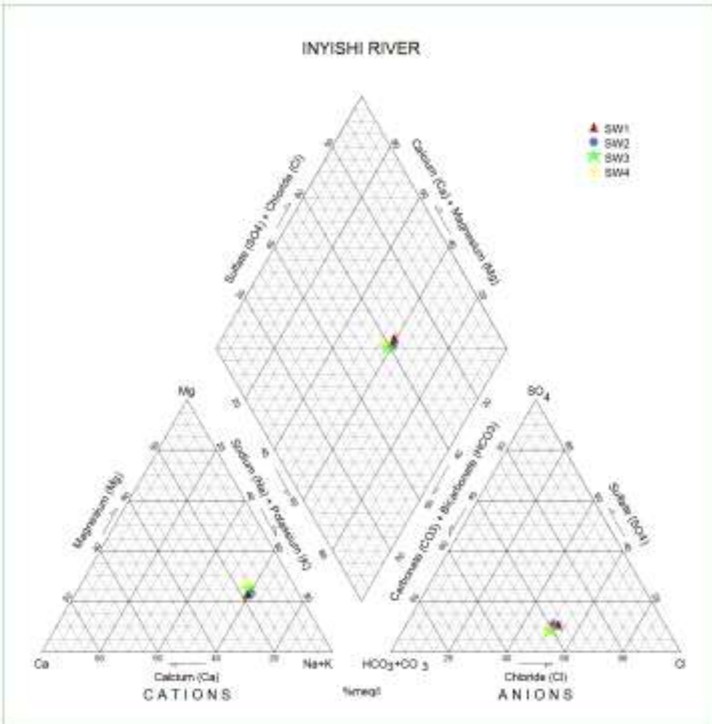

Figure 3. Piper trilinear diagram of the Inishi River

5.8 Sodium Adsorption Ratio (SAR

The computed SAR ratio values of the Inyishi River water varies 0.58 to 0.74 . According to Wilcox Wilcox (1955) , SAR value of 1 to 10 is classified as excellent for irrigation purposes while those with SAR values above 26 are considered poor. Based on this classification scheme, the Inyishi River water is excellent for irrigation although it has to be treated for pH and Al^{3+}.

Table 1. Physico-chemical and microbial analysis of Inyishi river water

	SAMPLING POINTS					
PARAMETERS	SW_1	SW_2	SW_3	SW_4	NSDW (2008)	WHO (2006)
pH	5.80	5.90	6.00	6.10	6.50-8.50	6.0-9.00
TDS, mg/l	20.50	18.40	15.20	13.50	500	1,500
Electrical conductivity (µS/cm)	34.17	30.67	25.33	22.50	1,000	1,400
Total hardness as $CaCO_3$, mg/l	18.88	18.41	18.04	18.73	150	150
Total alkalinity, mg/l	10.50	12.50	10.60	9.80		
Total iron, mg/l	0.57	0.64	0.50	0.54	0.30	0.30-1.00
DO, mg/l	6.50	6.60	6.80	7.10		
BOD, mg/l	5.40	4.80	4..50	3.60		
Ca^{2+} ,mg/l	3.06	3.10	2.87	2.80	200	200
Mg^{2+}, mg/l	2.74	2.60	2.65	2.86	150	150
K^+, mg/l	11.00	10.30	10.20	9.90	50	50
Na^+, mg/l	7.10	6.80	5.98	5.85	200	500
HCO_3^-, mg/l	20.50	21.90	20.90	20.50		500
SO_4^{2-}, mg/l	4.77	4.90	3.29	3.40	100	400
Cl^-, mg/l	17.0	16.70	15.20	14.54	250	500
F^-, mg/l	0.80	0.60	0.50	0.30	1.50	
Pb^{2+}, mg/l	<0.0001	<0.0001	<0.0001	<0.0001	0.01	0.05
Zn^{2+}, mg/l	ND	ND	ND	ND	3.0	5.0
Cu^{2+}, mg/l	ND	ND	ND	ND	1.0	1.0
Cd^{2+}, mg/l	ND	ND	ND	ND	0.003	0.05
Al^{3+}, mg/l	0.28	0.26	0.23	0.21	0.20	
Total coli form (cfu/100ml)	75	80	64	50	10	10
Distance from waste-stream discharge point (Km)	0.10	0.50	1.00	2.00		

Table 2. Major cations and anions in milliequivalent/liter (meq/l) and SAR values of Inyishi river

	Concentrations (meq/l)				%, epm			
PARAMETERS	SW_1	SW_2	SW_3	SW_4	SW_1	SW_2	SW_3	SW_4
Ca^{2+}	0.153	0.155	0.144	0.140	18.5	16.7	16.3	16.0
Mg^{2+}	0.225	0.213	0.217	0.234	27.2	23	24.6	26.7
K^+	0.281	0.263	0.261	0.253	15.4	28,4	29.6	28.8
Na^+	0.322	0.296	0.260	0.250	38.9	31.9	29.5	28.5
Total	0.828	0.927	0.882	0.877	100	100	100	100
HCO_3^-	0.336	0.359	0.343	0.336	36.8	38.6	40.8	41.2
SO_4^{2-}	0.099	0.102	0.069	0.076	10.8	11.0	8.2	8.6
Cl^-	0.478	0.40	0.428	0.409	52.4	50,4	51	50.2
Total	0.914	0.931	0.840	0.815	100	100	100	100
SAR	0.74	0.69	0.61	0.58				

Table 3. Pollution index (PI) of the Inyishi river

	C_i				C_i/L_j				
PARAMETERS	SW_1	SW_2	SW_3	SW_4	L_j	SW_1	SW_2	SW_3	SW_4
pH	5.80	5.90	6.00	6.10	6.50	0.892	0.908	0.923	0.939
TDS, mg/l	8.83	9.00	8.00	7.60	500	0.018	0.018	0.016	0.015
Total hardness, mg/l	18.8	18.41	18.04	18.72	100	0.189	0.184	0.180	0.187
Total alkalinity, mg/l	10.50	12.50	10.60	9.80	50	0.210	0.250	0.212	0.146
SO_4^{2-}, mg/l	4.77	4.90	3.29	3.40	400	0.012	0.012	0.008	0.009
Cl^-, mg/l	17.00	16.70	15,20	14.52	250	0.068	0.067	0.061	0.058
TOTAL						1.389	1.439	1.220	1.354
MEAN						0.232	0.240	0.203	0.226
PI						0.65	0.66	0.67	0.68

5.9 Pollution Index (PI)

The pollution index (PI) of the Inyishi River water varies from 0.65 to 0.68. It has been noted that the critical value of pollution index is 1; hence pollution index of more than 1 indicates very high degree of pollution (Horton, 1965). Although, the PI is yet to reach the critical value of 1, there is need to monitor the PI value since it is already tending to 1.

5.10 Geochemical Models

Piper Trilinear diagram (Figure 3) shows a close relationship in the chemistry of the river water along its stretch. All the samples plotted within the potable water zone (based on the major constituent cations and anions) of the diamond portion of the Piper diagram. The diagram also shows that the facies types are $Na^+ + K^+$ and Cl^- thus indicating $Na^+ + K^+ + Cl^-$ water. It is imperative to note that most surface water resources of Southeastern Nigeria are mostly $NaHCO_3$ water type (Ahiarakwem et al., 2012). The trend obtained at Inyishi River is again attributed to the modifiation of the water chemistry by the waste-stream from the aluminium plants. Stiff diagram of the river water (Figure 4) gives a further confirmation of the close relationship of the chemistry of the river water along its stretch. All the sampled gauge stations exhibited similar shape although with slight variations in the sizes (concentrations) of constituents (Figure 4).

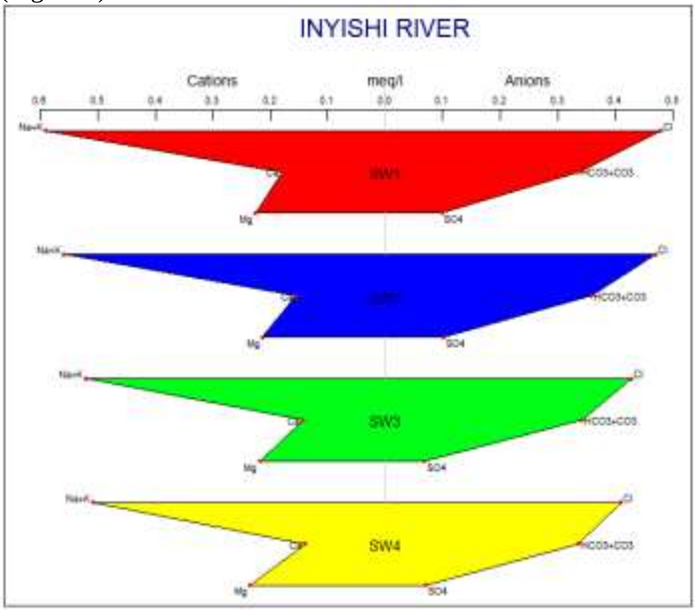

Figure 4: Stiff diagram of Inyisshi River

The Scholler diagram (Figure 5) also indicated similar chemical trend of the ions along the stretch of the river. The Scholler diagram confirms the slight variations in the chemical characteristics of the river water. There is also a confirmation of the close chemical trend of the river water from the computed SAR and PI values (Tables 2 and 3). The close chemical trends indicates fairly uniform modification of the water chemistry by similar pollution sources.

6.0 Conclusions

The physical and biochemical characteristics of Inyishi River indicated some environmental problems (low pH, poor microbial assay, high Al^{3+} contents and significant concentrations of BOD, total ion and F^-). The low pH, high level of Al^{3+} and significant concentrations of total iron, BOD and F^- in the Inyishi River water are attributed to the waste-stream from the two aluminium plants in the area. The impacts of the waste-stream on the river and its watershed include damage of some economic trees such as coconut (*cocos nucifera*) and raffia palms (raphia ruffia) as well as destruction of certain species of vegetables such as garden eggs (*salomum macrocarpum)*, water leaf (*talinum triangulare*), green (*amarantus* hybridus) and fluted pumpkin (*telfairia occidentalis*}. This has reduced the production of coconut, rope, local gin, palm wine and vegetables in the area. Piper trilinear, Stiff and Scholler diagrams as well as SAR and PI values of the river water shows a close relationship in the chemistry of the river along its stretch. The SAR values also indicates that the river water is excellent for irrigation purposes although it has to be treated to correct the PH and Al^{3+} levels. Although the pollution index (PI) of the river water is yet to reach the critical value of 1, it is already tending to it.

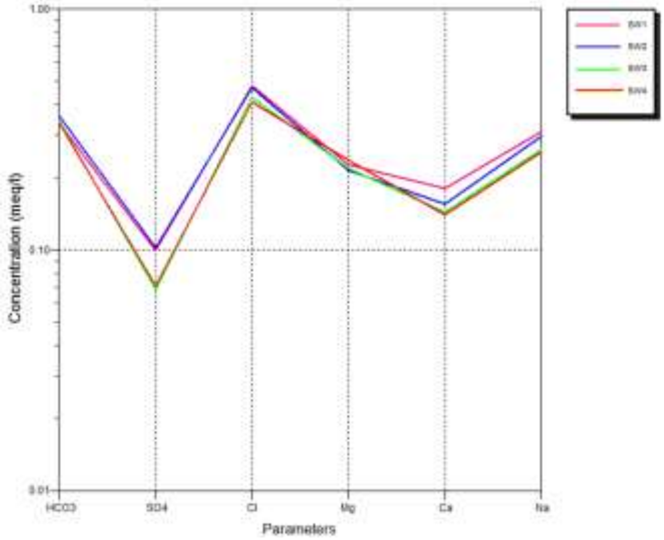

Figure 5: Scholler diagram of Inyishi River

Generally, the Inyishi River water can be described as acidic, soft, fresh but with levels of Al^{3+} with significant concentrations of BOD, total iron and F^-. The water type is essentially $Na^+ + K^+ + Cl^-$. The resource status of the river can be maintained through regular monitoring of its physical and biochemical characteristics and ensuring adequate treatment of the waste-stream before being discharged into it.

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