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The impacts of Njoku sawmill landfill on the water quality of the Otamiri River, Owerri metropolis, Niger Delta Basin, Southeastern Nigeria.

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Abstract:- The impacts of Njoku sawmill landfill on the water quality of Otamiri river was investigated through bio-chemical analysis of the river and air quality analysis over a period of three years using Atomic Absorption Spectrophotometer (AAS) , standard plate count , Growcon gas monitor and digital meters. The results indicates that the mean pH concentrations of the Otamiri river in 2008, 2009 and 2010 were 6.20, 6.32 and 6.25 respectively while the mean total iron concentrations were 4.50, 6.70 and 7.20 mg/l respectively. The mean concentrations of Pb^{2+} were 1.06, 1.10 and 1.20 mg/l respectively while the mean concentrations of Cd^{2+} were 0.54, 0.60 and 0.70 mg/l respectively. The mean values of Cr^{6+} were 0.32, 0.35 and 0.45 mg/l respectively while the mean Mn^{2+} values were 0.25, 0.36 and 0.34mg/l respectively. The mean values of Ni^{+} were 0.04, 0.05 and 0.08 mg/l respectively while the mean total coli form were 95, 105 and 85 cfu/100ml respectively .The results of ambient air quality indicates that the concentrations of SO_2 were 14.6, 12.3 and 16.7ppm respectively while NO_2 concentrations were 0.20, 0.25 and 0.34ppm respectively. These values do not conform to United States Environmental Protection Agency (USEPA) 2004 standard for safe air quality. The mean biological oxygen demand (BOD) were 6.0, 6.2 and 7.5 mg/l respectively. The mean pH, total coli form, BOD, Pb^{2+},Cd^{2+},Cr^{6+},Mn^{2+} , Ni^{+} and total iron concentrations were not in conformity with World Health Organization (WHO) 2006 standard for safe drinking water and thus constitute a threat to the quality of the River; these pollutants are attributed to the Njoku sawmill landfill. The Sodium Adsorption Ratio (SAR) of the river indicates that it is excellent for irrigation purposes although correction of the pH must be done. The pollution index (PI) of the river shows that it is tending towards its critical value of 1. The results also show that the concentrations of the major constituent captions (Ca^{2+} ,Mg^{2+} ,Na^{+} and K^{+}) and anions (HCO_3^-, SO_4^{2-}, Cl^-) conformed to WHO (2006) standard for safe drinking water . The pH of the water can be treated using sodium bicarbonate while the Mn^{2+} and iron can be treated using aeration method. The excessive concentrations of heavy metals can be treated using acornic acid while the microbial constituents can be reduced by chlorination.

Keywords:- pH, aeration, acornic acid, landfill and heavy metals

I. INTRODUCTION

The six principal methods of disposing solid wastes are sanitary landfill, ordinary landfill, open dump, incineration, swine feeding and composting. These disposal methods can constitute a threat to our air, soil and water resources. However, sanitary landfill has been recognized as the best method of disposing solid wastes because of the minimal environmental impacts offered by it. Unfortunately, sanitary landfill is yet to be embraced by many developing Nations of the World such as Nigeria. The study area (Otamiri River) is located very close to Njoku sawmill landfill which is one of the Imo State Environmental Protection Agency (ISEPA) waste disposal sites in Owerri metropolis, Nigeria (Fig. 1). It is located between latitudes 5 ^{0} 27 $^{/}$N and longitudes 7 ^{o} 14 $^{/}$ E on an elevation of about 65m above sea level. The Njoku sawmill landfill is an ordinary landfill and thus constitute environmental problems to the Otamiri River and environs. The landfill which started receiving wastes in 2004 occupy an area of about 5.5 km ^{2}.

The landfill is located within the drainage basin of the Otamiri River and its mean distance from the river is approximately 30 m.

Some aspects of the geochemistry of the Otamiri River has been studied (Ahiarakwem, 2012; Ibe and Onu, 1999, Ananaba et. al., 1993, Uma, 1984). However, the impacts of the Njoku sawmill landfill on the quality of the river is yet to be investigated. It has been observed that surface water resources are more vulnerable to pollution compared to groundwater resources (Ogunbanjo and Rolajo, 204). This implies the need for adequate protection of surface water resources so as to maintain their resource status and usefulness.

Apart from serving as domestic water supply source to inhabitants of q1`Owerri metropolis and environs, the Otamiri River is used for recreation, fishing and sand extraction activities. It also serves as a research and tourist centre. The chemistry of Otamiri River near Njoku sawmill is constantly modified by the wastes disposed at its drainage basin in addition to other activities such as fishing and farming. The composition of waste disposed at Njoku sawmill landfill indicates that it consists of about 50, 20, .10.2 and 8.1% of vegetable/food, electronic waste (e-waste), plastics and bottles/glass respectively (Table1 and Fig.2). Leachate produced at landfills can release toxic metals such as Cd^{2+}, Hg^{2+}, Pb^{2+}, Zn^{2+}, $Ni^{+}{}_{+}$ and Mn^{2+} into the environment (Aucott, 2008). Apart from the production of leachate due to infiltration of water into the waste, obnoxious gases (SO_2, NO_2, CH_4, CO, NH_3, and H_2 S) are released following biochemical decomposition of organic materials at the landfill. Gaseous migration from landfills can modify the environment by causing air, soil and water pollution. Case histories of gas migration from landfills have been presented by Mohsen (1975) while the interaction of the various factors that influence gaseous emissions at landfills were described by Farguhar and Rovers (1975).The reaction of some of these gases (such as NO_2 and SO_2) with water to form acid rain have been discussed by Sharon (1988).

It is therefore evident that the Njoku sawmill wastes which can be broadly classified into degradable and non-degradable have the potential to pollute the Otamiri river thus altering its resource status and usefulness. The resource status can be maintained by putting in place appropriate pollution mitigation strategy for the river ecosystem; this can be achieved through constant biochemical analysis.

II. CLIMATIC CONDITIONS

The study area is located within the equatorial belt of Nigeria. The mean monthly temperature of the area varies 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, 2010). The rainy

Season (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). However, the current climate change have resulted in heavy rainfall in the month of November in recent times. 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 Ogbueke. 2003). The area is part of the rain forest belt and the vegetation cover include shrubs and economic trees such as oil palm (arecaceae), Indian bamboo (bambusae), , avocado pea (*Persia Americana*),African bread fruit (*Trelulia Africana*), oil bean (*pentaclethra mahophlla*) , miracle (*spondias mombin*) and raffia palms (*raphia ruffia*).Most of the vegetation have been removed through human activities such as farming and construction of civil structures.

III. GEOLOGICAL SETTING

The study area is underlain by the Benin Formation (a major stratigraphic unit in the Niger Delta basin (Fig. 1). The Benin Formation consists of friable sands with intercalations of shale/clay of Pliocene to Miocene age(Short and Stauble, 1967). The formation contains some isolated gravels, conglomerates, very coarse sandstone in some places (Ananaba et al., 1993). The mean thickness of the formation in the study area is about 800m while the mean depth to water table is about 18.3m (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 practices so as to protect the soil and water resources of the area.

IV. MATERIALS AND METHODS

Water samples were obtained at three strategic gauge stations designated S_1 to S_3 along the stretch of the river (Fig. 1). Sampling was carried out over a period of three years commencing from 2008 ending in 2010. Sampling was carried out on a bi-monthly basis commencing from January each year and ending in November. A total of fifty-four water samples of the Otamiri river were obtained during the sampling period. Three 2.5 liters sample bottles were used to collect the water samples at each gauge station using the grab method. The sample bottles were corked under water immediately so as to prevent oxidation of the constituents. One of the sample bottles was tested for pH, total dissolved solids (TDS), electrical conductivity, total alkalinity and dissolved oxygen using digital meters. The second sample bottle was sent to the laboratory for analysis of heavy metals, major constituent cations and anions using Atomic Absorption Spectrophotometer (AAS) and microbial analysis using standard plate. The third sample bottle meant for laboratory determination of dissolved oxygen and consequently bio-chemical oxygen (BOD) was treated in quick succession in 1 ml potassium fluoride solution and 2 ml manganese sulphate and properly mixed and corked. The third bottle was later sent to the laboratory within 24 hours of collection for analysis. The BOD was measured by diluting the sample and incubating it in the dark at a temperature of about 20^{o}C and measuring the amount of oxygen that has been consumed. The gaseous emissions (CO, SO_2, NO_2,NH_3, CH_4 and H_2S)released at the landfill were measured using Growcon digital air monitors. Sampling was done on a quarterly basis at three strategic gauge stations within the landfill commencing from March and ending in December; the mean yearly concentrations of the measured gaseous emissions were computed and recorded.

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)

$$\text{Concentrations (meq/l)} = \frac{\text{Concentrations (mg/l)}}{\text{Equivalent mass}} \quad \ldots\ldots\ldots\ldots\text{(equ. 1)}$$

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

$$SAR = \frac{Na^{+}}{\sqrt{\frac{(Ca^{2+} + Mg^{2+})}{2}}} \quad \ldots\ldots\ldots\ldots\text{(equ. 2)}$$

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

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

The parameters considered for the determination of the pollution index (PI) of the Otamiri 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).

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

Where

C_i = concentration of chemical parameters

L_j = World Health Organization (2006) permissible limit.

V. RESULTS AND DISCUSSION

5.1 Physical parameters

5.1.1 pH

The mean pH concentrations of the Otamiri river in 2008, 2009 and 2010 were 6.20, 6.32 and 6.25 respectively (Table 2 and Fig.3). These values do not conform to WHO (2006) standard for safe drinking water. The lowest mean pH value (6.20) representing highest mean acidity was obtained in year 2008 while the highest (6.32) representing lowest acidity was obtained in 2009 (Fig.3) . The impact of the landfill on the river in terms of acidity level, therefore, got to a peak in year 2008 (Fig.3).

The pH values indicates that the Otamiri River is acidic. As acidity of surface water increases, submerged aquatic plants decreases and deprives water fowls of their basic food source. At pH of 6.0, 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 into it. Below pH value of about 4.50, all fish will die (Bourodemos, 1974). The acidic nature of the river is attributed to the gaseous emissions at the landfill. On the basis of the pH values of the river, pre-use treatment with sodium bicarbonate is recommended.

5.1.2 Electrical Conductivity and TDS

The mean concentrations of electrical conductivity of the Otamiri river at Njoku sawmill in 2008, 2009 and 2010 were 25.0, 36.0 and 28.40 µS/cm respectively (Table 2 and Fig.4) while the mean concentrations of total dissolved solids (TDS) were 14.80, 19.60 and 17.40 mg/l respectively (Table 2 and Fig. 5. The concentrations of TDS and electrical conductivity conformed to WWHO (2006) standard for safe drinking water.TheTDS values indicates that the river is fresh (Carrol,1962) while the electrical conductivity values shows no salinity hazards (Todd, 1980).The lowest mean electrical conductivity and TDS values were obtained in year 008 while the highest values were in 2009; this implies a peak level of electrical conductivity and TDS in year 2009 (Figures 4 and 5) .

5.1.3 Total Alkalinity and Total Hardness

The mean concentrations of total alkalinity of the river in 2008, 2009 and 2010 were 14.50, 13.40 and 12.70mg/l respectively. Boyd and Lightropper (1979) observed that surface water with total alkalinity value of less than 20mg/l (as is the case with the Otamiri river) requires slight liming for survival of aquatic life such as fish. The hardness values during the same study period were 3.88, 4.14 and 4.42mg/l respectively .These values areless than 50mg/l and thus indicates that the water is soft (Wilcork, 1993).

5.2 BOD and DO

The mean concentrations of Biological oxygen demand (BOD) of the river in 2008, 2009 and 2010 were 6.00, 6.80 and 6.50 mg/l respectively while the mean values of Dissolved Oxygen (DO) were 6.10, 6.50 and 6.00 mg/l respectively (Table 2 and Fig. 5) . According to Prat et. al. (1970) classification of surface water quality, surface water with BOD concentration of 6.0 mg/l is slightly polluted while those with BOD value of 12 is classified as polluted. Surface water with BOD values of 1.5 and 3.0 mg/l are classified as excellent and acceptable respectively. The BOD concentrations indicates consistent organic input into the river which has resulted in its slight pollution. Continuous input of organic materials into the river may result in serious pollution ; there is therefore the need for appropriate pollution preventive mitigation strategy for the river ecosystem. Most of the BOD are derived from the Njoku sawmill landfill. According to Prat et. al. (1970) classification of surface water, surface water with DO of 4.6, 6.2 and 7.8 mg/l are classified as slightly polluted, acceptable and excellent respectively. The DO of the river falls within acceptable levels based on Prat et. al. (1970).

5.3 Major cations and anions

The mean concentrations of Ca^{2+} in 2008, 2009 and 2010 were 1.04, 1.08 and 1.14 mg/l respectively while the mean concentrations of Mg^{2+} were 0.30, 0.35 and 0.40 mg/l respectively. The mean concentrations of Na^{+} for the same period were 1.50, 2.20 and 2.40 mg/l respectively while the mean values of K^{+} were 0.35, 0.30 and 0.42 mg/l respectively. The concentrations of the major constituent cations are generally low and conformed to WHO (2006) standard for safe drinking water . The relative abundance of the major constituent cations follows the trend Na^{+} > Ca^{2+} > K+ > Mg^{2+} . The mean concentrations of HCO_3^- in 2008, 2009 and 2010 are 13.5, 17.5 and 15.0mg/l respectively while the mean concentrations of SO_4^{2-} are 0.60, 0.75 and 0.70 mg/l respectively.

The mean values of Cl- were 6.20, 6.70 and 7.0mg/l respectively. The major anions also conformed to WHO (2006) standard for safe drinking water . The chloride content of the river implies that it lacks the potential to cause laxative effects to consumers. The relative abundance of major anions follow the trend HCO_3- > Cl- > SO_4^{2-} . The water type is Sodium Bicarbonate ($NaHCO_3$-) and this typical of most surface water resources in Southeastern Nigera (Oliver, 2005). The variation of the major constituent cations and anions during the study area is shown graphically in Figure 5.

5.4Chemical models

Piper trilinear diagram of the major cations and anions plotted within the potable zone of the diamond part of the diagram (Fig.6). The Piper plot as well as Stiff, Schooler and Durov (Figures 7, 8, and 9) shows a slight variation in the concentrations of the major constituent cations and anions during the study period. These geochemical diagrams also indicates that the major cation and anions during the study period were Na^{+} +K^{+} and HCO_3^- respectively.

5.5 Total iron

The mean concentrations of total iron during the study period were 4.50, 6.70 and 7.20mg/l respectively (Fig. 5). These values do not conform to WHO (2006) standard for safe drinking water. Although iron is useful in building the human hemoglobin, excessive concentrations can stain laundry.

5.6 Heavy metals

The mean concentrations of Cu^{2+} of the Otamiri river at Njoku sawmill in 2008, 2009 and 2010 were 0.82,0.70 and 0.80 mg/l respectively while the mean concentrations of Zn^{2+} were 2.6, 3.2 and 3.8 mg/l respectively. The mean concentrations of Cd^{2+} during the study period were 0.54, 0.60 and 0.70 mg/l respectively while the mean concentrations of Cr^{6+} were 0.32, 0.36 and 0.45 mg/l respectively. The mean concentrations of Mn^{2+} were 0.25, 0.36 and 0.34 mg/l respectively while the mean vales of Pb^{2+} were 1.06, 1.10 and 1.20 mg/l respectively. The mean values of Ni were 0.04, 0.05 and 0.08 mg/l respectively (Fig.5) . Except for Cu^{2+} and Zn^{2+}, the concentrations of other measured heavy metals (Cd^{2+}, Cr^{6+}, Pb^{2+} Ni and Mn^{2+}) did not conform to WHO (2006) standard for safe drinking water and thus constitute a threat to the Otamiri river. However, the concentrations of Zn^{2+} and Cu^{2+}were quite significant and may exceed the permissible limit in the near future .It is important to note that these heavy metals are part of the constituents of the leachate from the Njoku sawmill landfill which were later washed down the Otamiri river. The heavy metals owe their sources mainly from discarded electronic wastes (e-wastes) components of the landfill (Table 1 and Fig. 2). Although many heavy metals are problematic environmental pollutants , nevertheless, because of their useful physical and chemical properties, some heavy metals, including , Pb^{2+}, Cd^{2+}, Zn^{2+} and Ni (to mention but a few) are intentionally are added to certain consumer and industrial products such as switches, batteries, circuit boards, cell phones, and some pigments. These products, when discarded, are disposed in waste dumps like landfills. It is estimated that about 400 tons of Hg^{2+}, 3,000 tons of Cd^{2+} , 14,000 tons of Ni, 20,000 tons of Cu^{2+}, and nearly 100,000 tons each of Cr^{6+}, Pb^{2+}, and Zn^{2+} are disposed in landfills each year in United States of America (Aucott, 2008). The disposal of discarded products that are capable of releasing heavy metals in landfills is more worrisome in developing Nations such as Nigeria where the importation of used electronic wares is still in vogue. This has resulted in an increase in e-wastes at landfills in developing Nations such as Nigeria and consequently a significant increase in the heavy metal contents of the recipient environment. Excessive concentrations of heavy metals in water constitutes a variety of health hazards to both humans and animals. For instance, high levels of Cd^{2+} in water is toxic to the kidney while high concentrations of Cr^{6+} causes cancer and also aggravates diabetes. High concentrations of Pb^{2+} causes cancer and interference with vitamin D metabolism; it also affects mental development in infants and is toxic to the central and peripheral nervous systems. High levels of Mn^{2+} in water causes neurological disorders. It should be noted that ingestion of these heavy metals by aquatic life such as fish can result in serious food poisoning. The relative abundance of the measured heavy metals at Otamiri river follow the trend $Zn^{2+} > Pb^{2+} > Cu^{2+} > Cd^{2+} > Cr^{6+} > Mn^{2+} > Ni^{+}$. This trend is consistent with the findings of Moller et. al. (2010) that Cd^{2+} and Cu^{2+} are more efficiently removed from leachates than $Cr^{6+.}$ An effective solution to the problem of heavy metal pollution of the Otamiri river at Njoku sawmill is immediate closure of the landfill and its replacement elsewhere with a sanitary landfill. This is because the Njoku sawmill landfill is an ordinary landfill without any leachate collector , treatment facilities , clay liners and gas scrubbers. Furthermore, the landfill is located within the drainage basin of the River at a distance of approximately 30 m from it. However pre-use treatment of the water from the river is recommended. The iron and manganese can be treated using aeration or ozonation methods while other heavy metals can be treated using atomic acid, chemical precipitation or any other standard methods.

5.7 Ambient Air Quality at Njoku sawmill Landfill

The results of ambient air quality at Njoku sawmill landfill indicates that the mean concentrations of CO in 2008, 2009 and 2010 were 24.50, 26.0 and 30.40ppm respectively while the mean NO_2 values were 0.20, 0.25 and .34ppm respectively (Table 4 and Figures 10,11 , 12 and 13). The mean concentrations of SO_2during the same period were 14.60, 12.39 and 16.70ppm respectively while the mean NH_3 values were 1.40, 1.55 and 2.40ppm respectively. The mean concentrations ofH_2S were 1.20, 1.70 and 2.00ppm respectively while the CH_4 were 1.50, 2.20 and 2.80 ppm respectively (Table 4 and Fig.5). Except for SO_2 and NO_2, other measured gases conformed to United States of America Environmental Protection Agency (USEPA) 2004 standard for safe air. Apart from respiratory illness, aesthetic damage and global warming, some of these gases (SO_2 and NO_2) contributes to acid rain deposition. For instance, NO_2 reacts with water to form two strong acids (Nitrous and Nitric acids) and this reduces the pH of soil and water resources of the immediate environment (equations5 and 6).

$NO + NO_2 \rightleftharpoons HNO_2$ ………………… (equ… 5)
(In the presence H_2O Nitrous acid

$NO_3 + NO_2 \rightleftharpoons HNO_3$ ……………………(equ. 6)
(In the presence of H_2O) Nitric acid

SO_2 also reacts with water forming two strong acids (Sulphrous and Sulphuric acids), equations 7 and 8).

$SO_{2\,(g)} + H_2O_{(l)} \rightleftharpoons H_2SO_3$ (Sulphurous acid) …………………(equ. 7)

$SO_{2\,(g)} + 2OH^- \rightleftharpoons H_2SO_4$ (Sulpuric acid) ……………….(equ. 8)

The slightly acidic nature of the Otamiri River is attributed to the release of excessive concentrations of SO_2 and NO_2 gases at the landfill.

The gaseous emissions at the Njoku sawmill landfill can be minimized by installing scrubbers. Landfill gas can be treated to remove impurities, condensate, and particulates. The treatment system depends on the use of the gas. Minimal treatment is required for the direct use of landfill gas in boiler, furnaces or kilns. Using the gas in electricity generation typically requires more in-depth treatment.

The treatment systems are divided into primary and secondary treatment processing. Primary processing systems remove moisture and particulates. Secondary treatment systems employ multiple cleanup processes, physical and chemical, depending on the specifications of end use. It is also possible to convert landfill gas to high Btu gas by reducing its carbon dioxide, nitrogen and oxygen content. The high-Btu can be piped into existing natural gas pipelines or in form of Compressed Natural Gas (CNG) or Liquefied Natural Gas (LNG). The CNG and LNG can be sold commercially (Urban et al., 2009).

5.8 Sodium Adsorption Ratio (SAR)

The sodium adsorption ratio (SAR) values of the river in 2008, 2009 and 2010 were 1.93, 2.02 and 1.70 respectively (Table 3). According to Wilcox (1955), water resources with SAR value of between 0 and 10 (as is the case with the Otamiri River) are classified as excellent for irrigation purpose while those with SAR value of more than 26 are classified as poor for irrigation purposes.

5.9 Pollution Index (PI)

The mean pollution index (PI) of the Otamiri river in 208, 2009 and 2010 were 0.64, 0.73 and 0.70 respectively. 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 Microbial constituents

The mean total coli form count of the Otamiri River in 2008, 2009 and 2010 were95, 105 and 85 cfu/100ml respectively (Table 2 and Fig. 14). These values fails to conform to WHO(2006) standard for safe drinking water and thus constitute an environmental problem. The disposal of diapers at the landfill in addition to defecations within and around the watershed of the river are responsible for its poor microbial assay. The presence of bacteria in water can cause cholera, hepatitis, dysentery and typhoid. Pre-use treatment with chlorine is recommended.

VI. CONCLUSION

The Otamiri river at Njoku sawmill is polluted with respect to total iron, pH, microbial constituents as well as heavy metal (Pb^{2+}, Cd^{2+}, Cr^{6+}, Ni and Mn^{2+}) contents. These pollutants are attributed to the waste disposed at Njoku sawmill landfill. This calls for proper waste management practices and pre-use treatment of the river water with chlorine and sodium bicarbonate so as to reduce the microbial constituents and raise the pH of the water respectively. The heavy metals would be treated using acornic acid while iron can be treated using aeration method.

The replacement of the landfill with a sanitary one which must be located outside the Otamiri watershed is strongly recommended. Meanwhile, the gaseous emissions at the landfill can be reduced by installing scrubbers as well as harnessing the gases for generation of electricity. The SAR values of the river indicates that it is excellent for irrigation purposes. However, the pollution index (PI) of the river is already tending to the critical value of1. Generally, the Otamiri River can be described as slightly acidic, soft, fresh but with excessive concentrations of certain heavy metals. There is need for constant monitoring of the bio-chemical characteristics of the river with special attention to heavy metal contents.

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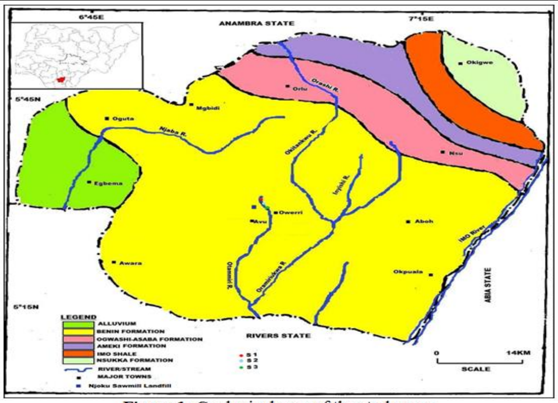

Figure 1: Geological map of the study area

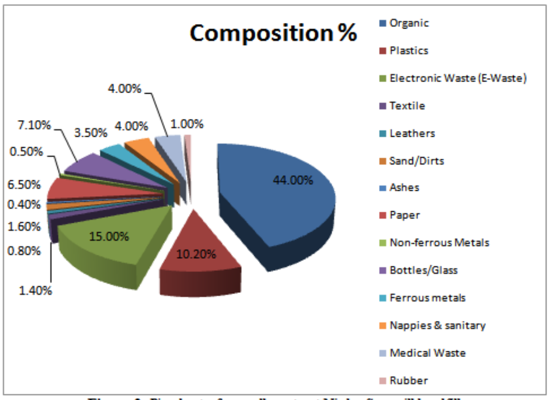

Figure 2: Pie chart of overall waste at Njoku Sawmill landfill

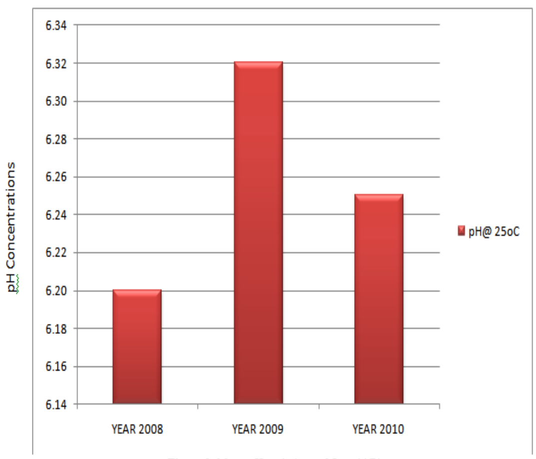

Figure 3: Mean pH variations of Otamiri River

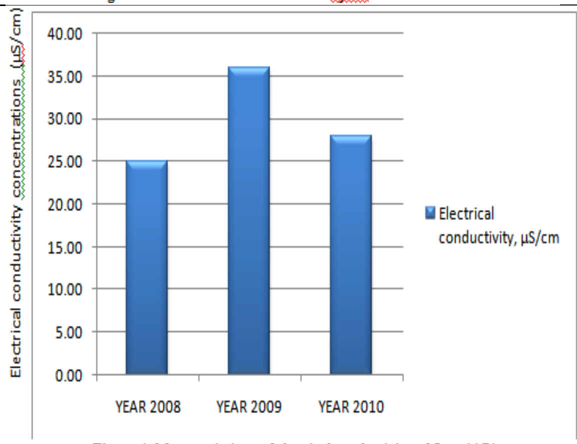

Figure 4: Mean variations of electrical conductivity of Otamiri River

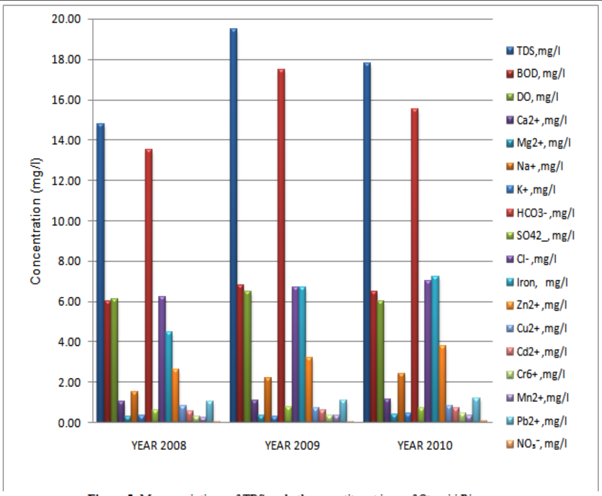

Figure 5: Mean variations of TDS and other constituent ions of Otamiri River

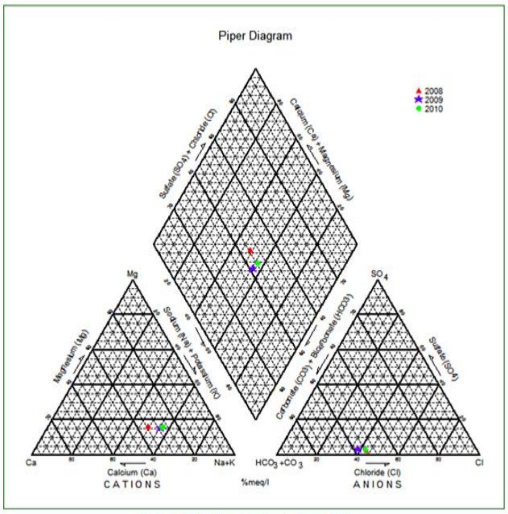

Figure 6: Piper trilinear diagram of Otamiri River

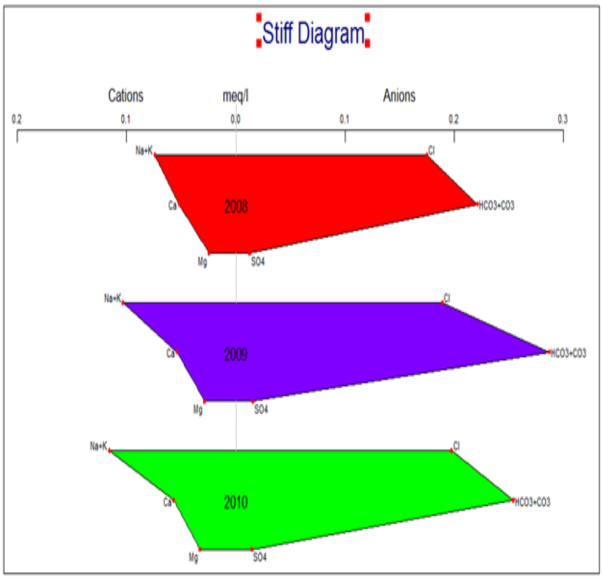

Figure 7: Stiff diagram of Otamiri River

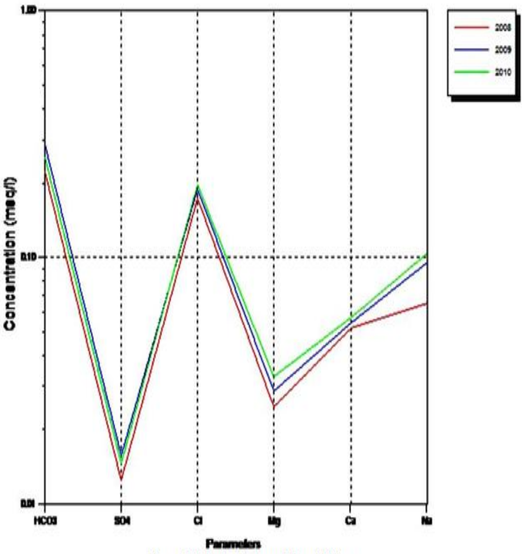

Figure 8: Schooler diagram of Otamiri River

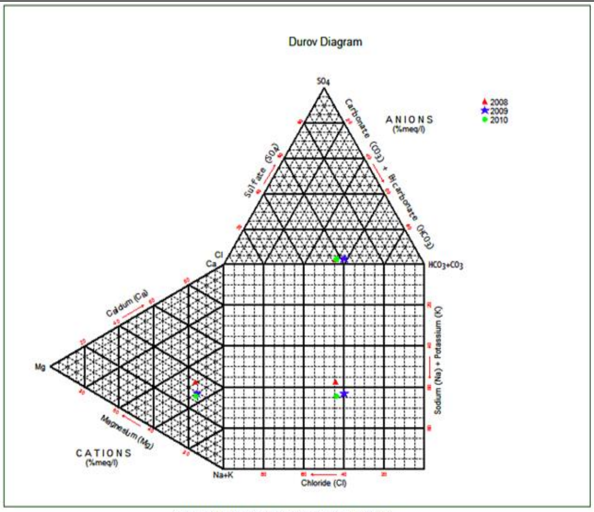

Figure 9: Durov diagram of Otamiri River

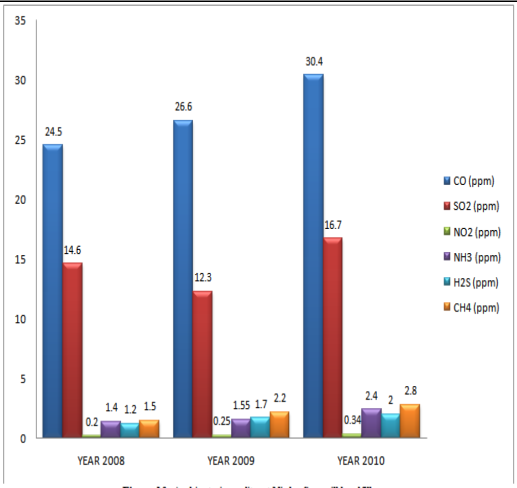

Figure 10: Ambient air quality at Njoku Sawmill landfill

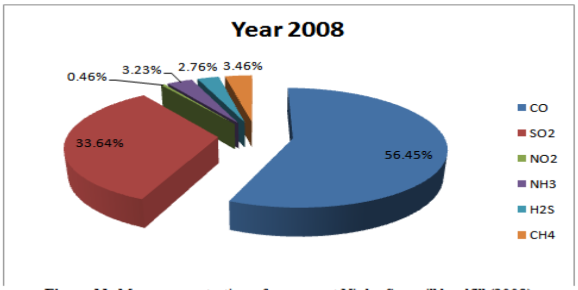

Figure 11: Mean concentration of gaseous at Njoku Sawmill landfill (2008)

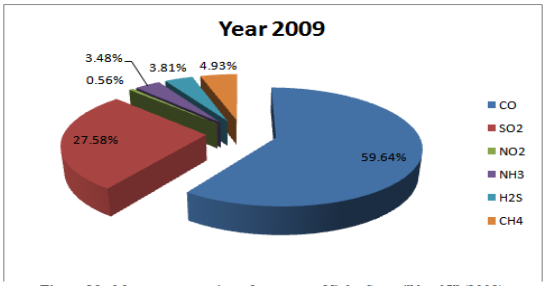

Figure 12: Mean concentration of gaseous at Njoku Sawmill landfill (2009)

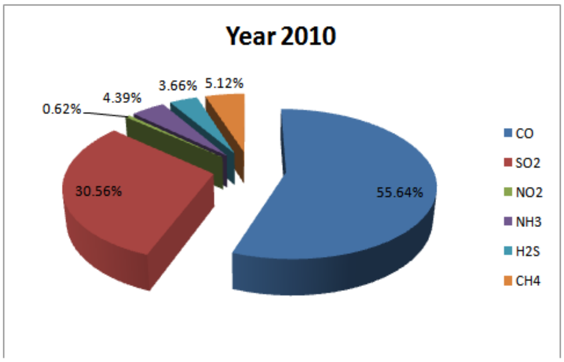

Figure 12: Mean concentration of gaseous at Njoku Sawmill landfill (2010)

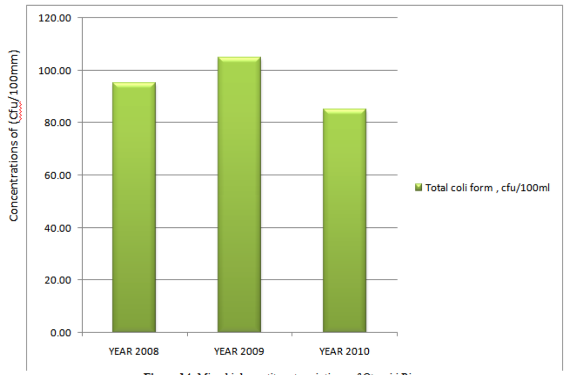

Figure 14: Microbial constituent variations of Otamiri River.

Table 1: Waste type proportion of overall waste stream at Njoku sawmill landfill

	Type of Waste	Composition %
1	Organic	44.00
2	Plastics	10.20
3	Electronic Waste (E-Waste)	15.00
4	Textile	1.40
5	Leathers	0.80
6	Sand/Dirts	1.60
7	Ashes	0.40
8	Paper	6.50
9	Non-ferrous Metals	0.5
10	Bottles/Glass	7.10
11	Ferrous metals	3.50
12	Nappies & sanitary	4.00
13	Medical Waste	4.00
14	Rubber	1.0

Table 2. Bio-chemical characteristics of Otamiri River at Njoku sawmill landfill

2008		2009		2010
PARAMETERS	RANGE MEAN	RANGE MEAN	RANGE MEAN	WHO (2006)
pH@25°C	6.10-6.40 6.20	6.00-6.46 6.32	5.90-6.40 6.25	6.50-9.00
Electrical conductivity, µS/cm	20.40-35.0 25.0	23.0-40.0 36.0	20.0-48.0 28.0	1,400
Total dissolved solid ,mg/l	13.0-21.0 14.8	14.8-24.0 19.5	12.0-28.8 17.8	1,500
BOD, mg/l	5.40-6.60 6.0	5.60-7.40 6.8	6.0-7.00 6.50	
DO, mg/l	5.80-6.6 6.10	6.10-6.90 6.50	5.70-6.50 6.00	
Ca^{2+},mg/l	0.95-1.06 1.04	1.00-1.20-1.08	1.10-1.30 1.14	
Mg^{2+}, mg/l	0.20-0.34 0.30	0.30-0.50 0.35	0.32-0.56 0.40	
Na^{+},mg/l	1.20-3.20 1.50	1.40-3.80 2.20	1.80-3.40 2.40	
K^{+} ,mg/l	0.40-0.60 0.35	0.30-0.70 0.30	0.40-0.80 0.45	
HCO_3^- ,mg/l	12-18 13.5	14-24 17.5	13-19.8 15.5	
SO_4^{2}-, mg/l	0.50-0.80 0.60	0.60-0.90 0.75	0.60-0.85 0.70	
Cl^- ,mg/l	3.5-7.8 6.2	6.2-8.5 6.7	6.2-9.0 7.0	
Total iron, mg/l	3.0-5.5 4.5	5.0-8.0 6.7	4.5-8.5 7.2	0.03-1.0
Zn^{2+},mg/l	2.20-3.40 2.60	2.50-4.0 3.20	3.10-4.80 3.80	5.0
Cu^{2+},mg/l	0.70-0.90 0.82	0.65-0.80 0.70	0.60=0.92 0.80	2.0
Cd^{2+},mg/l	0.45-0.60 0.54	0.55-0.70 0.6	0.60-0.78 0.70	0.05
Cr^{6+},mg/l	0.30-0.45 0.30	0.40-0.60 0.35	0.35-0.64 0.45	0.05
Mn^{2+},mg/l	0.30-0.45 0.25	0.30-0.54 0.36	0.28 -0.50 0.34	0.02
Pb^{2+},mg/l	1.0-1.30 1.06	1.o2-1.40 1.10	1.10-1.48 1.20	0.05
Ni, mg/l	0.03-0.06 0.04	0.04-0.08 0.05	0.06=0.12 0.08	0.02
Total coli form , cfu/100ml	80-120 95	100-130 105	75-107 85	10
Total Hardness as $CaCO_3$,mg/l	3.70-4,23 3.88	4.10-4.40 4.14	4.30-4.64 4.42	
Total Alkalinity,mg/l	12.40-17.89 14.5	10.4-15.8 13.4	11.34-14.87 12.7	

Table 3. Mean concentrations of major cations and anions in miliequivalent/litre (meq/l) and SAR values.

	Concentrations (meq/l)			Concentrations (%)		
PARAMETERS	2008	2009	2010	2008	2009	2010
Ca^{2+}	0.052	0.054	0.057	13.30	11.00	12.40
Mg^{2+}	0.003	0.028	0.033	0.80	5.70	7.20
Na^{+}	0.326	0.410	0.360	83.60	81.60	78.30
K^{+}	0.009	0.008	0.010	2.30	1.70	2.10
TOTAL	0.390	0.490	0.460	100	100	100
HCO_3^-	0.271	0.287	0.246	54.00	58.30	53.70
SO_4^{2-}	0.013	0.016	0,015	3.20	3.30	3.30
Cl^-	0.175	0.189	0.197	42.80	38.40	43.00
TOTAL	0.409	0.492	0.458	100	100	100
SAR	1.93	2.02	1.70			

Table 4: Ambient air quality at Njoku Sawmill

	Mean concentrations at five gauge stations			
PARAMETERS	2008	2009	2010	USEPA (2004)
CO, ppm	24.50 (56.4%)	26.60 (59.6%)	30.40 (55.6%)	<35.50
SO_2, ppm	14.60 (33.6%)	12.30 (27.5%)	16.70 (30.6%)	0.145
NO_2, ppm	0.20 (0.5%)	0.25 (0.6%)	0.34 (0.6%)	0.155
NH_3, ppm	1.40 (3.2%)	1.55 (3.5%)	2.40 (4.4%)	
H_2S, ppm	1.20 (2.8%)	1.70 (3.8%)	2.00 (3.7%)	
CH_4, ppm	1.50 (3.5%)	2.20 (5.0%)	2.80 (5.1%)	

Table 5, Pollution index of Otamiri River

		Mean concentrations (C_i)			(C_i/L_i)		
PARAMETERS	L_i	2008	2009	2010	2008	2009	2010
pH	6.50	6.20	6.32	6.25	0.954	0.972	0.962
TDS, mg/l	500	14.80	19.50	17.80	0.030	0.039	0.036
Total Hardness as $CaCO_3$ mg/l	50	3.88	4.14	4.42	0.078	0.083	0.088
Total Alkalinity, mg/l	100	14.50	13.40	12.70	0.145	0.134	0.127
SO_4^{2-}	400	0.60	0,75	0.70	0.002	0.002	0.002
Cl^-, mg/l	250	6.20	6.70	7.00	0.025	0.027	0.028
TOTAL					1.234	1.257	1.243
PI					0.64	0.73	0.70