

# IMPACT ASSESSMENT OF PLASTIC WASTES IN WOJI AND NEW CALABAR RIVERS

<sup>1</sup>Manna Emmanuel Harris & <sup>2</sup>Prof. Ibiseme Estela

Institute of Natural Resources, Environmental and Sustainable Development (INRES),  
University of Port Harcourt

## Abstract

*This study examines the effect of plastic waste on the environment. This study examined the resistivity and impact assessment of plastic wastes in Woji and New Calabar River. The objectives were to determine the physico-chemical properties of plastics; physico-chemical properties of water; toxic impact of plastic wastes on the aquatic life and assess the resistivity of different plastic wastes along the Woji and New Calabar Rivers. Standard Analytical Methods were used. Findings showed that the major type of plastic found in the study area (New Calabar and Woji Rivers) were Plastic bags; there is significant difference in the physical properties of plastics at the New Calabar and Woji River; most plastics collected from the Woji axis were combustible; No fish was found in the Woji River which was linked to the high level of industrial wastes in the River; Water quality parameters of the New Calabar River such as turbidity, conductivity, salinity, TDS, DO, BOD<sub>5</sub>, Nitrate and Phosphate varied significantly ( $p < 0.05$ ) when compared to the water quality parameters of Woji River; major impact of plastic wastes in this study were death, perforated gut, biochemical/cellular death and increased population size; measures of stopping plastic waste disposal with respect to Sustainable Development Goal (SDG) 14 includes prevention of plastic littering, improving waste collection, handling transfer stations and proper transportation, improve final disposal site, introduce plastic waste separation at source and increase plastic waste recovery and recycling. The study concludes that plastic wastes obtained from the study area are characterized by high resistivity values which is as a result of the nature of plastics found. It is therefore recommended amongst others that enforcement of actions should be in place to reduce illegal dumping and open burning of plastic waste at disposal sites.*

**Keywords:** Waste, Plastic, River, Woji, New Calabar, Chemical

## Introduction

The term plastics comes from the Greek word “plastikos” meaning “fit for molding,” and refers to the plasticity of these materials during their manufacture (Liddell *et al.* 1968). Nowadays, plastics is the term applied to a wide range of synthetic organic compounds that are produced by polymerization, and these consist of many repeating units (monomers) that come together to create copolymers. The plasticity of plastics allows them to be pressed or extruded into many different shapes and forms. Because of their sometimes in finitely long molecular structures, they can be very flexible and strong. Plastics have been developed to replace depleted natural resources since ancient times. Polymers were used in 1600 B.C. by the ancient Mesoamericans, the first to process natural rubber, to make figurines and bands (Hosler *et al.*, 1999). Several semisynthetic plastics like polystyrene (PS) and polyvinyl chloride (PVC) were discovered in the nineteenth century, which marks the beginning of the plastic era (Ebewele, 2000). Initially, plastics could not be used in commercial products because of their often rigid and brittle structure. This changed in 1909, when the first true synthetic phenol-formaldehyde plastic material (Bakelite) was discovered and was used in many different products, from telephone handsets to engine parts (Groot, 2009). Later, in 1926, the modern form, PVC, was created as a plasticized polyvinyl chloride (vinyl), and in 1933 polyvinylidene chloride (PVDC), or Saran, was introduced by Ralph Wiley (Morris, 1986).

Polyurethane (PUR), a flexible foam, was invented in 1937. In 1938, polystyrene (PS) became commercially practical and was used in peanut packaging; in this same year, polytetra fluoroethylene (PTFE) or Teflon was invented by Roy Plunkett. In 1939, nylon and

Neoprene were invented by Wallace Carothers. Polyethylene terephthalate (PET), also known as polyester, was introduced by John Rex Whinfield in 1941. Polyester is primarily used in the manufacture of beverage bottles (PackagingToday, 2009).

World War II increased the worldwide demand for plastics because copper, aluminum, and steel became so valuable for military use. Thereafter, plastics quickly gained use as a manufacturing material, and consequently material manufacturers, machine builders, and mold-makers flourished (Beall, 2009). After the Second World War ended, civilian outlets were needed for plastics to keep the factories in business. The market was rapidly overwhelmed with plastic products, which were regarded by society to be “cheap and disposable.” In 1979, the plastic production in the USA exceeded that of steel production. Hence, one could conclude that World War II changed the world and started the age of the plastic industry (Beall, 2009; Morris, 1986) .

In 1951, high-density polyethylene (HDPE) and polypropylene (PP) were invented and were employed for use in making water jugs and hula hoops. In 1954, Styrofoam was invented. Styrofoam is a trademark for extruded polystyrene foam and weighs 30-fold less than normal polystyrene foam. Thermoplastic polyester, which is based on polybutylene terephthalate (PBT), was introduced in 1970. This thermoplastic polymer is used as a material for high-quality, highly stressed engineering parts in many industrial sectors as a result of its high strength and good stability at high temperatures (Beall, 2009).

### **Statement of the Problem**

Human activities are responsible for a major decline of the world’s biological diversity, and the problem is so critical that combined human impacts could have accelerated present extinction rates to 1000–10,000 times the natural rate. Plastics have been, slowly,

accumulating in the marine environment since the 1960s, to the point that we now have huge masses of plastics floating in the oceans and other wastes plastics washing up on the once beautifully clean rivers of Port Harcourt (Woji and New Calabar Rivers). Gabriel (2018) in his study on the effect of water quality on the prevalence of gastrointestinal parasites of *Chrysichthys nigrodigitatus* in Woji River, Port Harcourt revealed that no fish was found in the 6 sampled stations of the river. Could this unlikely phenomenon be as a result of plastic waste pollution? Hence, this study will examine the impact of plastic wastes in two major rivers around Port Harcourt namely: the Woji River and the New Calabar River.

### Objectives of the study

- i. Determine the physico-chemical properties of plastics collected at different reaches of the Woji and New Calabar Rivers.
- ii. Determine the physico-chemical properties of water collected at different reaches of the Woji and New Calabar Rivers.

### Methodology

#### Study Area

The study was carried out at two (2) different locations, Woji River and the New Calabar River both in Port Harcourt (*see Fig. 3.1*).

**Woji River** is an estuarine tidal water, a tributary of upper Bonny River located between longitudes 7°00 E and 7°15 N and latitudes 4°28 E and 4°40 N. It rises from the bifurcation to the left of the Okpoka River, which drains into Bonny River. The area has a mean water depth of 4.8 m, which is tidal and gradually transits from fresh to salt water at the head. Woji

River receives industrial effluent discharges from the Nigerian Bottling Company, Schlumberger, Halliburton and Rivers State Vegetable Oil Company and transverses through several communities among which are: Azuabie, Woji, Okuru-ama, Abuloma, Kalio-ama and Oba-ama. The Trans-Amadi slaughter house and market generate wastes and faeces entering the River.

**The New Calabar River** lies between longitude  $06^{\circ}53' 53.086''$ E and latitude  $04^{\circ}53' 19.020''$ N in Choba, Rivers State, Nigeria. The entire river course is situated between longitude  $7^{\circ}60''$ E and latitude  $5^{\circ}45''$ N in the coastal area of the Niger Delta and empties into the Atlantic Ocean. The river is used as a domestic and industrial waste disposal point for companies and people living close to it. The land around the river houses an abattoir, poultry, a fabrication company and a weekly market. A small cluster of houses were seen close to the river bank where toilets and bathrooms are also constructed close to the river bank. Dredging and fishing activities are still ongoing alongside numerous other human activities (such as waste disposal, bathing, washing and so on). All aforementioned activities pollute the water body in varying degrees.

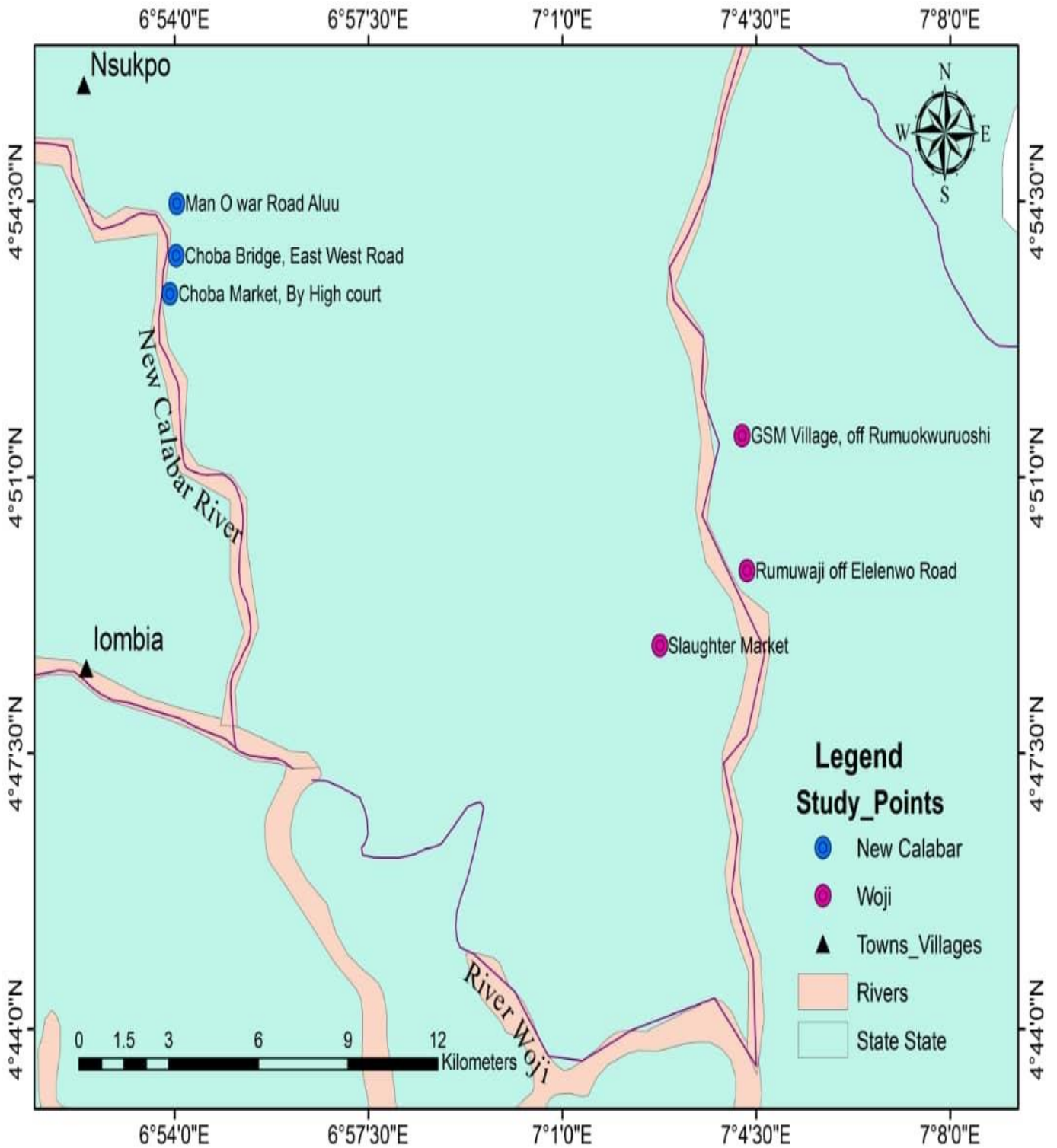


Fig. 1

## **Sample and Sampling Technique**

In a bid to obtain information on measures of stopping plastic waste disposal into the rivers with focus on Sustainable Development Goal (SDG) 14 (Blue economy). The researcher sampled the opinions of respondents (Staff of Rivers State Waste Management Agency) experienced in waste management in Rivers State using the questionnaire. The purposive sampling technique was used in selecting 192 respondents used in this study. The reason for this approach was to focus on the particular population that can provide answers to the research question.

### ***Collection of plastic samples***

In the study, two locations throughout the New Calabar and Woji River were sampled for analysis of plastic debris at Iwofe and Choba. Sampling sites selection was based on a number of criteria including site access and suitability for sampling and most, importantly, the different anthropogenic activities to which they are thought to be exposed.

The methodology of transect determination and selection, quadrant (1 m<sup>2</sup>) placement as well as sampling, sample processing and analysis procedures were based on the existing shoreline monitoring protocols established by the National Oceanic and Atmospheric Administration Marine Debris Program (Lippiatt, 2013).

A survey of 100 m long, 5 m deep area along the study area was taken to quantify density and composition of debris. After selecting a site that ideally allows 100 m of continuous riverside collecting (that is, avoiding walls, private property, or an impenetrable landscape), the site was measured and marked a 100 m length of shoreline with survey flags, starting at the river's edge. Then, 5 m depth landward was measured from the shoreline, marking this distance with flags along the 100 m length, which produced a total collection area of 500 m<sup>2</sup>.

Thereafter, a systematic pattern of walking back and forth from the shoreline to the edge of the 5 m deep area was repeated until the entire area was covered. Everything visible within the project area that was attributable to humans was collected and use for the study.

The materials collected from the site were returned to the laboratory for analysis. It was systematically counted, weighed, and cataloged the constituents in accordance with laboratory standards, which include data sheets for both site data and for cataloging debris, derived and adapted from Opfer *et al.* (2012).

**Table 1:** Physical Properties of the plastics at different reaches along the Woji and New Calabar Rivers, Port Harcourt.

<b>Physical Properties</b>		
	Thickness ( $\mu\text{m}$ )	Density ( $\text{kg}/\text{m}^3$ )
<b>Woji River</b>	$22.21 \pm 4.39$	$0.010 \pm 0.01$
<b>New Calabar River</b>	$28.57 \pm 0.89$	$0.034 \pm 0.02$
<b>P-Value</b>	0.000	0.010

**Note:** Values represents (Mean  $\pm$  S.E.M)

**Table 2:** Chemical Properties of the plastics at different reaches along the New Calabar River and Woji River

**Note :** Values represents (Mean  $\pm$  S.E.M)

		<b>Combustion</b>	<b>Resistivity (Ohms)</b>
<b>New Calabar River</b>		$66.87 \pm 5.42$	$10^{11}$
<b>Woji</b>		$72.87 \pm 3.66$	$10^{11}$
<b>Plastic Technology Handbook</b>		50-75 = Slow- burning 75-200 = Combustible	$> 10^9$ is considered an electrical insulator

## **Physico-chemical properties of water collected at different reaches of the Woji and New Calabar River**

Table 4.4 and 4.5 revealed the mean and individual values of the physicochemical parameters from the different stations compared with the World Health Organisation standard. It was seen that parameters such as pH, temperature, turbidity, salinity, dissolved oxygen, Nitrate and phosphate had mean values within the permissible limit of W.H.O. On the other hand, conductivity, total dissolved solids, BOD, Faecal Coliform Bacteria (FCB), Total Coliform Bacteria (TCB) and Total Heterotrophic Bacteria (THB) were above the permissible limit of W.H.O.

### ***pH***

Results obtained as seen in table 4.4 and 4.5 showed the pH value obtained across the study area ranged between 6.65 and 6.82 with *mean*±*S.E* pH value of  $6.91 \pm 0.00$  at Woji River and  $6.67 \pm 0.00$  at New Calabar River. A p-value of 0.214 was also obtained which indicates no significant variation in pH across sample stations as values were within the W.H.O permissible limit of (6.5-8.5).

### ***Temperature***

Table 4.4 and 4.5 showed that the temperature values obtained across the study area ranged between 26.8°C and 28.0°C with *mean*±*S.E* temperature value of  $27.13 \pm 0.29$  (New Calabar) and  $27.73 \pm 0.25$  (Woji River). A p-value 0.449 was obtained which indicates no significant variation in temperature across sample stations as values were within the W.H.O permissible limit of (26.5 – 32).

### ***Turbidity***

Similarly, the turbidity values shown in table 4.4 and 4.5 showed turbidity values ranging between 0.2NTU and 1.3NTU across the study area with *mean*±*S.E* turbidity value of  $0.20\pm 0.00$  at New Calabar River and  $1.17\pm 0.07$  at Woji River. A p-value of 0.005 was obtained which indicates a significant variation in turbidity across sample stations although values were within the W.H.O permissible limit of 5NTU.

### ***Conductivity***

The conductivity values range between  $5879\mu\text{S}/\text{cm}$  and  $15580\mu\text{S}/\text{cm}$  across the study area with *mean* ± *S.E* conductivity value of  $6183.33\pm 179.01$  at New Calabar River and  $15303.33\pm 307.16$  at Woji River (See table 4.4 and 4.5). A p-value of 0.003 which indicates a significant variation in conductivity across sample stations. Values obtained were above the W.H.O permissible limit of  $500\mu\text{S}/\text{cm}$ .

### ***Salinity (mg/l)***

The salinity values range between  $3.25\text{mg}/\text{l}$  and  $9.07\text{mg}/\text{l}$  across the study area with *mean* ± *S.E* conductivity value of  $3.34\pm 0.05$  at New Calabar River and  $8.72\pm 0.34$  at Woji River. A p-value of 0.000 which indicates a significant variation in salinity across sample stations. Values obtained were below the W.H.O permissible limit of  $5000\text{mg}/\text{l}$ .

### ***Total dissolved solid, TDS (mg/l)***

The total dissolved solid values range between  $3960\text{mg}/\text{l}$  and  $11000\text{mg}/\text{l}$  across the study area with *mean* ± *S.E* conductivity value of  $4586.67\pm 442.02$  at New Calabar River and  $10406.67\pm 398.18$  at Woji River. A p-value of 0.006 which indicates a significant variation in total dissolved solid across sample stations. Values obtained were above the W.H.O permissible limit of (250-500)  $\text{mg}/\text{l}$ .

### ***Dissolved oxygen, DO (mg/l)***

The dissolved oxygen values range between 6.1mg/l and 9.3mg/l across the study area with *mean ± S.E* dissolved oxygen value of  $6.17 \pm 0.07$  at New Calabar River and  $7.16 \pm 0.13$  at Woji River. A p-value of 0.038 which indicates a significant variation in dissolved oxygen across sample stations. Values obtained were within the W.H.O permissible limit of (5-10) mg/l.

### ***BOD<sub>5</sub> (mg/l)***

The BOD<sub>5</sub> (mg/l) ranged between 0.6mg/l and 6.8mg/l across the study area with *mean ± S.E* BOD<sub>5</sub> value of  $0.67 \pm 0.03$  at New Calabar River and  $6.73 \pm 0.07$  at Woji River. A p-value of 0.000 which indicates a significant variation in BOD<sub>5</sub> across sample stations. Value obtained in the New Calabar River was below the W.H.O permissible limit of 4mg/l while at Woji River it was above.

### ***Nitrate (NO<sub>3</sub><sup>-</sup> (mg/l))***

The Nitrate values obtained ranged between 0.12mg/l and 0.18mg/l across the study area with *mean ± S.E* Nitrate value of  $0.16 \pm 0.01$  at New Calabar River and  $0.13 \pm 0.01$  at Woji River. A p-value of 0.035 which indicates a significant variation in NO<sub>3</sub><sup>-</sup> across sample stations. Value obtained were below the W.H.O permissible limit of 10mg/l.

### ***Phosphate (PO<sub>4</sub><sup>3-</sup> (mg/l)***

The Phosphate values obtained were below detectable limit across the study area with *mean ± S.E* phosphate value of  $0.01 \pm 0.00$  at New Calabar River and  $0.03 \pm 0.00$  at Woji River. A p-value of 0.023 which indicates a significant variation in phosphate across sample stations. Value obtained were below the W.H.O permissible limit of 0.5mg/l.

**Table 3** Mean values of physico-chemical parameters of water collected from the different stations compared with WHO Standard (2006)

S/N	Parameters	Permissible Limits by W.H.O	New River	Calabar	Woji River	P-Value
1	pH	6.5 -8.5	6.67±0.00		6.91 ± 0.00	0.214
2	Temperature (°C)	26.5 – 32	27.13± 0.29		27.73± 0.25	0.449
3	Turbidity (NTU)	5	0.20±0.00		1.17±0.07	0.005
4	Conductivity (µS/cm)	500	6183.33±179.01		15303.33±307.16	0.003
5	Salinity (mg/l)	1000-5000	3.34±0.05		8.72±0.34	0.000
6	Total dissolved solid, TDS (mg/l)	250-500	4586.67±442.02		10406.67±398.18	0.006
7	Dissolved oxygen, DO (mg/l)	5-10	6.17±0.07		7.16±0.13	0.038
8	BOD <sub>5</sub> (mg/l)	4	0.67±0.03		6.73±0.07	0.000
9	Nitrate as NO <sub>3</sub> <sup>-</sup> (mg/l)	10	0.16±0.01		0.13±0.01	0.035
10	Phosphate as PO <sub>4</sub> <sup>-3</sup> (mg/l)	0.5	0.01±0.00		0.03±0.00	0.023

Note: <0.05 = Less than detection limit

**Table 4:** Results of physico-chemical parameters at each sampled stations in the Study area

S/ N	Parameters/Sampled Stations	New Calabar River			Woji River			Permissible Limits by WHO,2006
		Choba Market	Choba Bridge	Man O War	Slaughter	Rumuwaji	GSM village	
1	pH	6.67	6.70	6.65	6.91	6.85	6.82	6.5 -8.5
2	Temperature (°C)	27.3	26.8	27.3	28.0	27.5	27.7	26.5 - 32
3	Turbidity (NTU)	0.2	0.2	0.2	1.1	1.3	1.1	5
4	Conductivity (µS/cm)	6190	6490	5870	15640	14690	15580	500
5	Salinity (mg/l‰)	3.42	3.36	3.25	9.07	9.05	8.05	1000-5000
6	Total dissolved solid, TDS (mg/l)	4360	5440	3960	11000	10570	9650	250-500
7	Dissolved oxygen, DO (mg/l)	6.1	6.3	6.1	7.3	6.9	7.3	5



---

<b>8</b>	BOD <sub>5</sub> (mg/l)	0.7	0.7	0.6	6.6	6.8	6.8	4
<b>9</b>	Nitrate as NO <sub>3</sub> <sup>-</sup> (mg/l)	0.14	0.16	0.18	0.12	0.13	0.14	10
<b>10</b>	Phosphate as PO <sub>4</sub> <sup>-3</sup> (mg/l)	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.5

---

**Note:** <0.05 = Less than detection limit

### **Toxic impact of plastic wastes on the marine life at Woji and New Calabar Rivers.**

Table 4.6, Plate 1 and 2 revealed the type of encounter, predominant debris type and impact response of marine life found in the study areas. As previously mentioned in the review that entanglement is very difficult to estimate. Nevertheless, as seen in table 4.6, Plate 1 and Plate 2. Twenty-two fishes (22) were found only in the New Calabar River out of which 10(45.5%) were observed to be entangled with fishing ropes and gears whereas ten 12(54.5%) fishes also in the New Calabar River had their guts perforated with plastic materials such as plastic ropes and pellets. Other marine lives such as lug worms and marine insects were also in abundance and can't be quantified. Nevertheless, the impact of plastic waste as a result of ingestion and interaction were death and increase in population size.

### **Conclusions**

The study concludes that plastic wastes obtained from the study area are characterized by high resistivity values which is as a result of the nature of plastics found. Also, the study concludes that the absence of fishes in Woji River was as a result of the degree of plastic pollution caused by human activities in the river thereby making it uncondusive for survival of fishes as the results revealed very high DO, BOD and TDS.

### **Recommendations**

Following the findings, the study recommends that the following measures should be adopted in stopping plastic waste disposal into the rivers with focus on Sustainable Development Goal (SDG) 14 (Blue economy)

1. Government should introduce anti-litter regulations, set plastic litter innovation funds and set fixed penalties for plastic littering.
2. Develop a baseline and an affordable methodology for assessing and monitoring the extent of plastic litter.
3. There should be awareness of the environmental and economic costs of plastic littering.
4. Relevant agencies should Development of better and more cost-effective systems for collecting, transporting and sorting waste plastics.
5. Baling and shredding equipment should be introduced at the transfer stations.

### **References**

- Alabi O. A, Ologbonjaye K. I, Awosolu O, & Alalade OE (2019). Public and Environmental Health Effects of Plastic Wastes Disposal: A Review. *J Toxicol Risk Assess* 5:021.
- Aliani, S; & Molcard, A. (2003). Hiteh-hiking on floating marine debris: Macrobiotic special in the Western Mediterranean Sea. *Hydrobiol.* 503(11), 59-61.
- Allsopp, M.; Walters, A.; Santillo, D. & Johnston, P. (2006). Plastic debris in the world's ocean. Greenpeace: Auckland, New Zealand. pp. 44.
- Amadi, A., (1993). Urban Waste Management. In Proceedings of the Nigerian Environmental Society Conference. Port Harcourt, Nigeria.
- AMRF (2010) The Algalita Marine Research Foundation. <http://www.algalita.org/>
- Andrady, A. L. (2011). Microplastics in the marine environment. *Mar. Pollut. Bull.* 62, 1596–1605.
- Andrady, A.L. (2003). *Plastics and the Environment*. Wiley: New York, USA, 792pp.

- APHA (1998) Standard Methods for the Examination of Water and Wastewater. 20th Edition, American Public Health Association, American Water Works Association and Water Environmental Federation, Washington DC.
- Avio, C.G., Gorbi, S., Milan, M., Benedetti, M., Fattorini, D., d'Errico, G., Pauletto, M., Bargelloni, L. & Regoli, F. (2016). Pollutants bioavailability and toxicological risk from microplastics to marine mussels. *Environ. Pollut.*, 198: 211-222.
- Bakir, A., Rowland, S. J., & Thompson, R. C. (2014). Transport of persistent organic pollutants by microplastics in estuarine conditions. *Estuarine, Coastal and Shelf Science*, 140, 14–21.
- Barnes DKA, & Milner P (2005) Drifting plastic and its consequences for sessile organism dispersal in the atlantic ocean. *Mar Biol.* 146(4):815–825
- Barnes, D.K.A., Galgani, F., Thompson, R.C., and Barlaz, M. (2009). Accumulation and fragmentation of plastic debris in global environments. *Phil Trans R Soc B*, 364(1526), 1985-1998.
- Beall G (2009) By Design: World War II, Plastics, and Npe. <http://www.plasticstoday.com/imm/articles/design-world-war-ii-plastics-and-npe>
- Beatley, T., (1991). Protecting biodiversity in coastal environments: introduction and overview. *Coastal Management* 19, 1–19.
- Cheshire, A., and Adler, E. (2009). UNEP/IOC Guidelines on Survey and Monitoring of Marine Litter. UNEP Publication.
- Cho D-O (2011) Removing derelict fishing gear from the deep seabed of the East Sea. *Mar Policy* 35(5):610–614
- Claessens M, Meester SD, Landuyt LV, Clerck KD, and Janssen CR (2011). Occurrence and distribution of microplastics in marine sediments along the Belgian Coast. *Mar Pollut Bull* 62(10):2199–2204
- Cliff G, Dudley S, Ryan PG, Singleton N (2002) Large sharks and plastic debris in Kwazulu-Natal, South Africa. *Mar Freshw Res* 53:575–581

- Climate Smart Oceans, (2017): Towards Sustainable Growth of Ocean Economies un Africa Under a Changing Climate, (<http://climatesmartoceans.org/wp-content/uploads/2016/08/Policy-brief-basse-def-en.pdf>), 2016 (accessed 1 August 2017).
- Cole M., Lindeque P., Halsband C., & Galloway T.S. (2011). Microplastics as contaminants in the marine environment: A review. *Marine Pollution Bulletin* 62: 2588-2597.
- Colton, J.B., F.D. Knapp & B.R. Burns. (1974). Plastic particles in surface waters of the northwestern Atlantic. *Science*, 185(4150): 491-497.
- Creel L., (2003). Ripple Effects: population and Coastal Regions, Population Reference Bureau, Washington, DC
- Da Costa J.P., Santos P.S., Duarte A.C., & Rocha-Santos T. (2016). (nano)plastics in the environment – Sources, fate and effects. *Science of the Total Environment* 566-567: 15-26.
- Darnerud PO (2003). Toxic effects of brominated flame retardants in man and in wildlife. *Environ Int* 29(6):841–853
- De Laender F, Hammer J, Hendriks AJ, Soetaert K, Janssen CR (2011). Combining monitoring data and modeling identifies PAHs as emerging contaminants in the Arctic. *Environ Sci Technol* 45(20):9024–9029.
- Lambert S., Christian S., Wagner M. (2017). Ecotoxicity testing of microplastics: considering the heterogeneity of physico-chemical properties. *Integrated Environmental Assessment and Management* 13 (3): 470-475.
- Law KL, Morét-Ferguson S, Maximenko NA, Proskurowski G, Peacock EE, Hafner J, Reddy CM (2010). Plastic accumulation in the North Atlantic Subtropical Gyre. *Science* 329(5996): 1185–1188
- Legler J (2008). New insights into the endocrine disrupting effects of brominated flame retardants. *Chemosphere* 73(2):216–222.
- Liddell HG, Scott R, Jones HS, & Barber EA (1968) A Greek-English Lexicon compiled by Henry George Liddell and Robert Scott. The Clarendon, London.
- Lippiatt S, Opfer S, Arthur C. (2013). Marine Debris Monitoring and Assessment. NOAA Technical Memorandum NOS-OR danR-462005

- Ma Y., Huang A., Cao S., Sun F., Wang L., & Guo H. (2016). Effects of nanoplastics and microplastics on toxicity, bioaccumulation, and environmental fate of phenanthrene in fresh water. *Environmental Pollution* 219: 166-173.
- Macfadyen, G., T. Huntington, & R. Cappell, (2009) Abandoned, lost or otherwise discarded fishing gear, FAO Fisheries and Aquaculture Technical Paper, 523, UNEP regional seas reports and studies, 185.FAO Fisheries and Aquaculture Technical Paper, 523, UNEP regional seas reports and studies, 185.
- Mato Y, Isobe T, Takada H, Kanehiro H, Ohtake C, Kaminuma T (2000). Plastic resin pellets as a transport medium for toxic chemicals in the marine environment. *Environ Sci Technol* 35(2):318–324
- MatWeb (2000). Surface Resistivity Testing of Plastics. <http://www.matweb.com/reference/surface-resistivity.aspx>
- McIlgorm, A.; Campbell, H.F; Rule, M.J. (2011). The economic cost and control of marine debris damage in the Asia-plastic region. *Ocean Coastal Manage.* 54(9), 643-651.
- Moore, C. J., Lattin, G. L., and Zellers, A. F. (2011). Quantity and type of plastic debris flowing from two urban rivers to coastal waters and beaches of Southern California. *Rev. Gestão Costeira Integr.* 11, 65–73.