**Spatial Analysis of the Level of Physico-chemical Properties of Water Quality in the Lower Orashi and Sombriero River Systems of Rivers State, Nigeria**

1Otiasah, C.L., 1Ezekwe C.I., 2Babatunde B.B. and 3Otiasah A.C.

1-Department of Geography and Environmental Management, University of Port Harcourt, Port Harcourt, Nigeria

2- Department of Animal and Environmental Biology, University of Port Harcourt, Port Harcourt, Nigeria

3- Rivers State Ministry of Environment, Port Harcourt, Nigeria

**Abstract**

*The study examined the spatial analysis of the level of physico-chemical properties of water quality in the Lower Orashi and Sombriero River Systems of Rivers State, Nigeria. The study area was divided into ten (10) grids and samples from each of water, sediment and fish was collected from each grid. The sampling sites is the Lower section of Orashi and Sombriero Rivers, specifically, from Mbiama water front to Hulk (Agada)/Degema which is in the transitional zone between the two River systems, and from there down through the Sombriero to the mouth of the Atlantic Ocean. Sampling was done in two seasons (dry and wet/rainy). The surface water samples were collected into sterilized well labeled bottles and taken to the laboratory to test parameters like physico-chemical, heavy metals, polycyclic aromatic hydrocarbons (PAHs), BTEX and polychlorinated biphenyls (PCBs) adopting standard laboratory methods such as the Standard Methods for Examination of Water and Wastewater (APHA) (2012). Descriptive statistics were used for the data analysis. Results showed that the seasonal means for DO of the study is 2.36±3.53mg/L. DO values for the Orashi, TZ and Sombriero sections of the study have significantly different values. The Orashi River values for turbidity ranges from 5.0±20 to 3.2±10.0 JTU while that of the Sombriero River ranges from 18.2±27.0 to 2.0±6.0JTU. , the seasonal concentration**of biochemical oxygen demand (BOD) in the study ranged from 0.38±0.31mg/L to 1.76±1.65mg/L. OR2/OR1 recorded the least while TZ1/SR1 recorded the highest concentrations. The study concluded that most of the heavy metals, physicochemical parameters evaluated were higher than institutional permissible limits and thus implicated in the surface water. The study thus recommended that there is the need for multi-stakeholders articulation of an efficient, all inclusive and sustainable environmental remediation strategies and mitigation measures for the Niger Delta region. To this end, environmental issues should be completely devolved and completely a preserve of the Concurrent and Residual Legislative Lists.*

**Keywords:** Pollutants, Physico-chemical properties, Lower Orashi, Sombriero, APHA

**Introduction**

Increased oil and gas production activities brought about oil spills (both operational and third party interference like theft of crude oil), gas flaring, venting and other unfriendly environmental practices that have polluted and degraded the quality of the natural environment of the Niger Delta soil, water, air, plants, animals and humans For instance, the mangrove forest can only grow and thrive in the Delta mudflats within certain tolerance levels of nutrients and salinity (Kadafa, 2012).. Spills cause insufficient nutrients and impair mangrove respiration, and render them unable to compete favorably with other alien invasive species that harm local economic vegetation. Mangrove vegetation loss causes river bank destabilization and changes in the morphology of the flat mud, sediment re-suspension and biodiversity loss (Ekubo & Abowei, 2011). Georgewill (2012) reported that inhabitants of the Niger Delta become exposed to toxicity from their surrounding waters and mangrove vegetation as a result of the frequent crude oil spilling into the waters, sediments and mangrove wetlands. Inherent xenobiotics in crude oil have negative impacts such as pregnancy miscarriages, secondary pollution and human mortalities, as was the case in Asitubo Gbanraun, Bayelsa State in 1997 (Georgewill, 2012).

Ezekwe et al. (2022) reported Emago-Kugbo Community, Odual District, Abua-Odual Local Government Area of Rivers State being the first oil spill in Nigeria occurred in May 31, 1960. The oil spill occurred from a Shell Petroleum Development Limited (SPDC) failed valve at the Bay. Oil spill has been occurring in this area and for instance, an oil spill happened and lasted for 48hours and involved half of the daily production volume of 4,928 barrels (Akintayo & Oyadongha, 2016). It is thus evident that oil spill occur and reoccur in some pockets in the Niger Delta and it is being reported that space-time trend and pattern of oil spills in the Niger Delta (2006 – 2016) where spatial clustering and increasing frequency and decreasing monthly mean distance (0.29km) of spill occurrence where implicated in some Niger Delta states of Bayelsa, Delta and Rivers (Lawal & Chmenwo 2019; Otiasah, et al, 2021).

Within the period under consideration, 20% of spill was observed to have occurred in 2014, with a monthly average of 500 spill incidences. It further reported a two year steady drop in spill incidences which accounted for a total of 21% between 2015 and 2016. The highest of spill incidences was in May while the lowest was in February respectively. Relatedly, Sundays and Wednesdays recorded the highest spill occurrences. Vandalism and third party interference (sabotage) was implicated for 67% of spill incidences. Raimi et al. (2020) reports that the Niger Delta is the world’s heaviest environmental sink with consequences on species decline, livelihood loss, poverty and unrest.

Nigeria is situated between latitudes 3o and 6o North and longitude 5o and 8o East, a land mass of 923.770km2 of which the Niger Delta covers 70,000km2 of wetland and floodplains formed from sedimentation with different ethnic group and languages, amongst the richest wetland in the world and highest oil and gas producing nation in Africa and 6th in the world; with a mean of 300 spills and an estimated 2,300 cm3 of oil annually getting into the water bodies and land of the Niger Delta, a figure vehemently disputed as insincere by communities, NGOs and the world bank (Ekubo & Abowei, 2011). Otiasah et al. (2021) and Otiasah et al (2020), reports massive daily condensate spill from the Soku gas plant facilities into the Soku general area between March 2002 and November 2009 in millions of barrels. These harmful discharges, unremediated spills and illicit mining activities in the area occasioning spill pollute water, sediment and fish qualities also caused surface fires that burnt to death over 1000 inhabitants (IUCN-NDP, 2013 and Otiasah, Ezekwe & Chukwu-Okeah, 2021). Otiasah et al. (2020), reports that 138 of these persons died on 22nd November, 2008 alone. The fire equally destroyed vast mangrove ecosystems habitats and other economic plants. It is reported by Kadafa (2012) that spill volume in the Niger Delta is between 9 – 13 million or 1.5 million tons over 50 years and contributed 0.7 – 1.7 million tons yearly into the world water bodies. Osuagwu and Olaifa (2018) established consilience on the debilitating impact of gas flare on fish production and decline in fishery resources in their study of effects of spills on fish production in the Niger Delta. Similarly, Uwem and Enobong (2017) agrees with the above position but blames the problem on the absence of specific legal framework in the nation’s body of laws and lack of transparency by regulators, coupled with the fact that government (through the NNPC JVC) cannot be efficient as a producer and a regulator at the same time. DPR (2021) estimates Nigeria’s gas reserve to be in excess of 600.53TCF as at May, 2021. Most of this may be either flared or vented into the environment at the peril of ecosystems and consequential public health. In a study of hydrocarbon-based contamination of drinking water sources and shellfish in the Soku oil and gas fields of South-South, Nigeria. Ezekwe et al (2022) implicated elevated heavy metals and polycyclic aromatic hydrocarbons from non-remediated spills and gas flares in drinking water insecurity and decline in fish, fishery resources and shrinking of the rural economy.

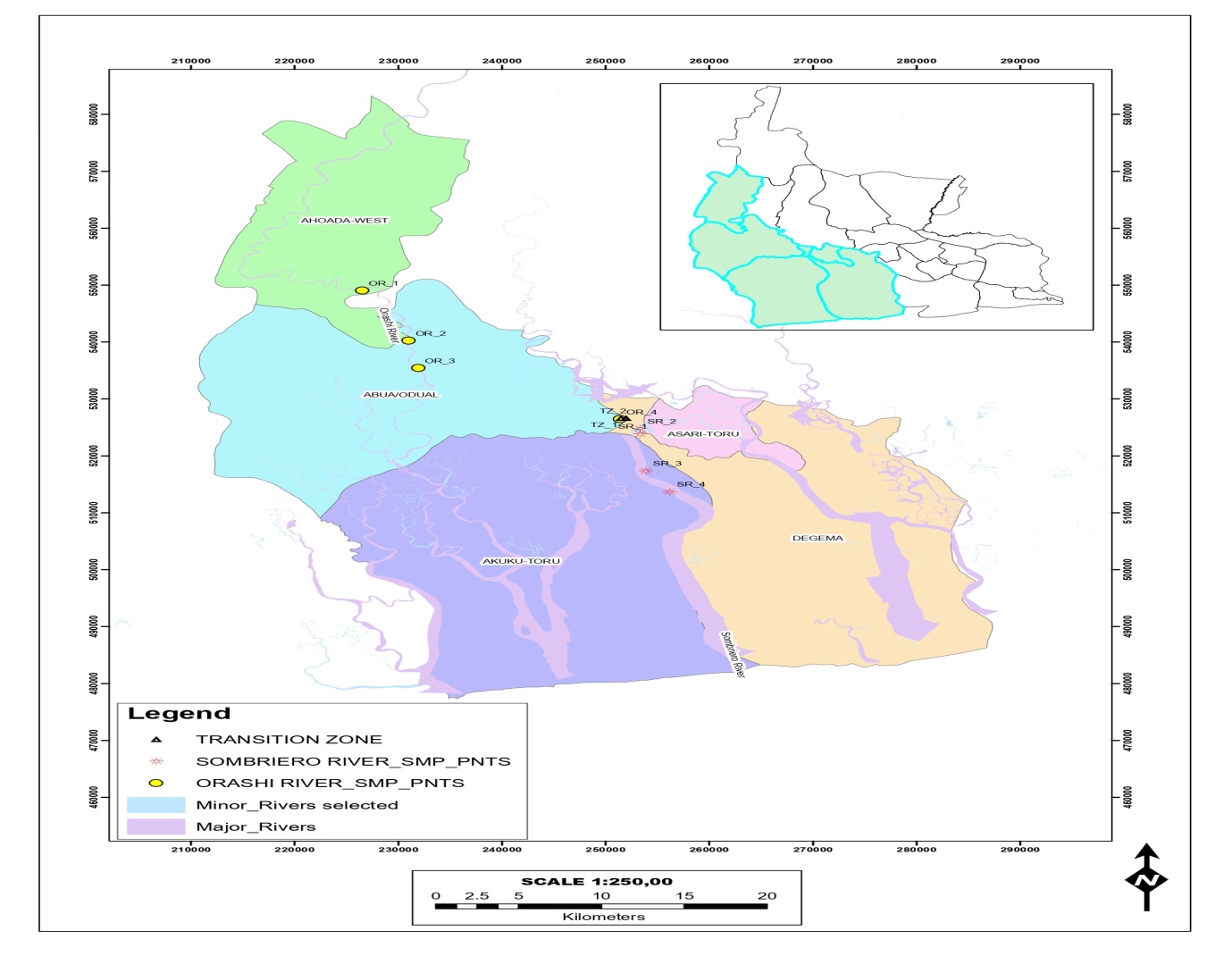
It is trite knowledge from human ecology that man’s survival is entirely dependent on a healthy environment surrounding him, particularly the marine ecosystem which constitutes about two-third (2/3) of the Earth (York & Rosa, 2012). According to the Encyclopedia Britannica (2017 ed.), marine ecosystem habitats are home to diverse organisms including marine mammals, cyanobacteria (blue-green algae) or photosynthetic prokaryotes. USEPA (2014) and Mohan, et al. (2016), noted that, mostly upland unfriendly anthropogenic activities of the benefactor of the marine ecosystem (man) has progressively harmed vital ecosystems and organisms, rendering them incapable of discharging needed ecosystem services to organisms and man sustainably. The deleterious consequences of oil spills and gas flares to ecosystems diversity and public health made it both a local and global issue. Intensive and extensive oil and gas exploration in the Niger Delta has caused serious environmental pollution and degradation, resource depletion, pervasive poverty and tension/stress (Celestine, 2003; Kadafa, 2012, United Nations Environmental Report on Ogoni, 2013). Clinton et al. (2009) argued that gaseous diffusion at the interface of the atmosphere and oil from spills/flares/vents elevates total hydrocarbon content in the marine environment which decreases the quantity of dissolved oxygen due to the formation of sheen on the water surface and endangers aquatic fauna and flora.

Also, oil and grease at flat land mangrove floor are taken-in and bioaccummlate in plants causing mortality to plants seedlings, stunted growth, foliar necrosis, shriveling and defoliation in adult mangrove/economic trees as a result of irregular nutrient supply and respiration (Otiasah et al., 2021). There are many studies that have been deliberating on the surface water quality but very few considered the inclusion of the comparative in-depth effects of pollutants from the oil exploration in the Lower Orashi and Sombriero River Systems of Rivers State in which the present study is focusing at. Against this backdrop, the present study is examining the spatial analysis of the level of physico-chemical properties of water quality in the Lower Orashi and Sombriero River Systems of Rivers State, Nigeria.

**Materials and Methods**

The study area was the Lower Orashi and Sombriero River estuary covering territories of Ahoada West, Abua/Odual, Degema, Akuku-Toru and Asari-Toru Local Government Areas of Rivers State, Nigeria (Figure 1). The area is both freshwater and saline or brackish swamp wetland of tidal and semi tidal flat mud typical of the Niger Delta. The total flow pattern of the study area is influenced by the Orashi and Sombriero. The study area is bounded by Nembe Local Government Area of Bayelsa State on the west, the Atlantic Ocean on the southern of the Sombriero, Emohua Local Government area on the north and Bonny Local Government on the East, all of Rivers State. The transition zones are under the dual influence of the less saline (Oligohaline) Orashi freshwater River and polyhaline Sombriero River brackish waters.

The study area has the typical climate of the Niger Delta region previously described by Oyegun (1997). It is predominantly a humid tropical climate with long annual rainy season spanning March - October, a shorter dry season between November -February, and two characteristic air masses viz South-West Monsoon wind and North East trade wind. The monsoon is dominant during the rainy season while the trade wind dictates activities during the dry season characteristic of the rain forest zone. High annual rainfall up to 2500mm and a mean of 2800, an average temperature of 27oC with seasonal variation of + or – 4oC characterize the study area (Awosika, 1995; Oyegun, 1997). The geology of the study area is a low-lying plain of fresh unconsolidated fluvial sediments of Quaternary Age. Elevation is ≤ 7meters above mean sea level typical of the Niger Delta (Aweto, 2002). Four different vegetation zones characterized the Niger Delta area, viz: coastal inland zone, mangrove swamp zone, freshwater zone and low land rain forest zone (Abam and Okagbue, 1997). The study area is of freshwater and marine forest ecology with fresh and saline water on the Orashi and Sombriero respectively. The Orashi River, particularly from Mbiama to Hulk is fresh water while the Sombriero River from Degema where it beheads the Orashi River (Transition Zone) to Ebemaboko is saline water. The study area is mostly permanent intertidal and waterlogged mud flatlands with rich flora, fauna and complex strata of diverse trees. The ecosystem is highly diverse and support various terrestrial and aquatic fauna and flora, economic trees (predominant among which is P*entaclethra macrophylla, Chrysophyllum albidum and Irvingia gabonenesis*), herb plants, agricultural cultivation (fishery and crop), human livelihoods and enormous hydrocarbons (Ekundayo & Obuekwe, 2001; Nduka, et al., 2011). The economic activities included fishing, farming, crude oil and sand mining.

**Figure 2: Study Area indicating sampling points**

**Research Design**

This study adopted a mixed design consisting of the comparative, longitudinal, analytical and cross-sectional designs. A total of ten (10) sampling sites were used for this study whereby water samples were collected during the dry and wet/rainy seasons (Table 1). Dry season sampling was carried out on the 3rd of February, 2022 while wet/raining season sampling was done on 23rd June, 2022.

**Table 1. Sampling Sites and their GPS Positions**

|  |  |  |  |
| --- | --- | --- | --- |
| S/No | Sampling Sites | Designation | GPS |
| 1 | Ozuochi | OR1 | E006o 32 02.0” N04o57 45.5” |
| 2 | Emesu | OR2 | E006o 34 29.9”N04o53 03.1” |
| 3 | Ogbema Corridor | OR3 | E006o 36 07.0” N04o48 44.3” |
| 4 | Ogonokom | OR4 | E006o 45 06.0” N04o 45.33.0” |
| 5 | Hulk-Transition Zone | TZ1 | E006o 45 31.4” N04o45 46.7” |
| 6 | Atala-Degema Waterfront | TZ2 | E006o 45 51.4” N04o45 40.4” |
| 7 | Opulogoloboko | SR1 | E006o 45 34.1” N04o44 08.3” |
| 8 | Idama Flow Station | SR2 | E006o 46 34.7” N04o44 38 3” |
| 9 | Minjidukiri | SR3 | E006o 46 52.5” N04o40 36.9” |
| 10 | Ebemaboko | SR4 | E006o 48 08.0” N04o38 38.7” |

**Sample and Sampling Techniques**

The study area was divided into ten (10) grids and samples from each of water, sediment and fish was collected from each grid. The sampling sites is the Lower section of Orashi and Sombriero Rivers, specifically, from Mbiama water front to Hulk (Agada)/Degema which is in the transitional zone between the two River systems, and from there down through the Sombriero to the mouth of the Atlantic Ocean. Sampling was done in two seasons (dry and wet/rainy). The surface water samples were collected into sterilized well labeled bottles and taken to the laboratory to test parameters like physico-chemical, heavy metals, polycyclic aromatic hydrocarbons (PAHs), BTEX and polychlorinated biphenyls (PCBs) adopting standard laboratory methods such as the Standard Methods for Examination of Water and Wastewater (APHA) (2012). Descriptive statistics were used for the data analysis. Descriptive statistics were used for the data analysis.

**Results and Discussions**

The physical properties of water quality such as dissolved oxygen, turbidity, total dissolved solids, ORP, pH, salinity, temperature and electrical conductivity are shown in Tables 1 for the dry season and Table 2 for the wet season. From theresults dissolved oxygen concentrations of the different sampling locations of the study ranges from 0.0±6.9 to 0.03±9.10mg/L. The surface waters of Sombriero River (SR) and Transition Zone two (TZ2) (i.e. SR1, SR2, SR3, SR4 and TZ2) uniformly recorded the lowest values of 0.0mg/L in the dry season while OR3, OR2 and OR1 are the least during the wet season. The highest dry season value of DO concentration was recorded in Orashi River 1 (OR1), with a value of 6.9mg/L while the highest for the wet was 9.10mg/L at SR4. Mean DO for the study is 2.36±3.53mg/L. The mean seasonal DO for the three ecologies of the study area are as follows:- Orashi (ORs) = 5.38±0.55mg/L; Transition Zone (TZ1&2) = 1.05±5.18mg/L and Sombriero (SRs) = 0.0±5.68mg/L. The seasonal means for DO of the study is 2.36±3.53mg/L. DO values for the Orashi, TZ and Sombriero sections of the study have significantly different values.

Seasonal turbidity values for the various surface water locations ranges from 5.0±27.0 to 2.0±10.0 JTU as shown in tables 1 and 2 respectively. OR3/SR4 has the lowest turbidity value of 5.0±2.0 JTU while the highest turbidity value of 27.0±10.0 was observed in TZ2/SR1 and OR3 respectively. Turbidity values of Orashi River locations are relatively lower than that of Sombriero River for the dry season except for OR4 at 20 JTU. Similarly, wet season turbidity values for Orashi River system is lower than the Sombriero River system and transition zones except at OR3. The Orashi River values ranges from 5.0±20 to 3.2±10.0 JTU while that of the Sombriero River ranges from 18.2±27.0 to 2.0±6.0JTU. The turbidity values for the Transition Zones 1 and 2 were 24.0±27.0 to 3.2±6.62JTU respectively. The mean turbidity for the locations of the study is 15.94±5.24JTU. The respective ecological turbidity means are as follows:- Orashi River (OR) = 10.40±5.3JTU, Sombriero River (SR) = 21.55±4.9JTU and Transition Zone (TZ) = 25.5±5,35JTU. The WHO permissible value for turbidity is ≤5.00 NTU which is an equivalent of ≤ 10 JTU.

The seasonal values for Oxidation-Reduction Potential (ORP) for the various River water sources of the study area ranges from 0.0±161 to 1.50±35.9mV as shown in tables 1 and 2 respectively. OR1 and OR2 have the uniform lowest ORP values of 0.0mV in dry season, whereas SR4 and SR2 are the lowest during the wet season. The highest ORP value of 161.3mV is observed at OR3 for the dry season whereas TZ2 is the maximum with a value of 35.9mV in the wet season. Mean ORP for the study is 50.49±15.21mV**.** The observed mean ORP for the three ecologies were as follows:- Orashi River (OR) is 65.65±18.68mV, Sombriero River (SR) is 40.15±7.5mV; and Transition Zone (TZ) is 40.85±29.45mV. WHO/USEPA permissible limit for water ORP is 6.6±8.5mV.

Seasonal Potential Hydrogen (pH) ranges from 5.95±87.71 to 8.58±9.41. SR2 and SR1 with pH values of 87.71±9.41 is the highest whereas a pH value of 5.95±8.58 at OR3/OR2 is the lowest of the wet season. The seasonal pH values of the different River water sources for the ecological zones (Orashi, Sombriero & Transition Zone) are fairly the same with little differences. However, both the lowest and highest pH values were observed in the Sombriero polyhaline brackish water ecology of the dry season. In contrary, for the wet season, the lowest and highest pH values were observed at Orashi and Sombriero River systems (OR2 and SR1) respectively. Mean pH for the study area is 7.26±8.97. Mean pH for Sombriero ecosystem (SR1-4) is 27.69±9.21, Orashi ecosystem is 6.66±8.76 while Transition Zone is 7.59±9.1.

Analysis reveals that seasonal Electrical Conductivity values for the various river water sources of the study area ranges from 8.0±50.06µS/cm to 6.0±9055µS/cm. At a value of 8.0±6.0µS/cm, OR1/OR3 recorded the lowest while SR4/SR1 is highest at 50.06±9055µS/cm. Seasonal electrical conductivity values of the Sombriero marine ecological zone are generally higher than those of the freshwater Orashi ecological zone. Mean EC in the study area is 16.21±3335.01µS/cm**,** while the ecological conductivities stood as follows: - Orashi River (OR) is 10.05±1960.88µS/cm, Sombriero River (SR) is 23.07±2273.88µS/cm; and Transition Zone (TZ) is 14.81±8208µS/cm.

Total dissolved solids (TDS) abundance for the various River water sources ranged from 4.0±7727.0ppm to 4.0±9595ppm as shown in tables 1 and 2 respectively. TDS values for Orashi River ranges from 4.0±5118.0ppm to 4.0±24.8ppm while that of the Sombriero ecology ranges from 63110.0±7727.0ppm to 8.32±9595ppm. TZ1 and TZ2 ranges from 7415.0±7316.0ppm to 5112±5710ppm. The highest seasonal TDS values of 7727.0±9595ppm were recorded at SR3. The lowest TDS values of 4.0±4.0ppm were observed at OR1 and OR3 respectively. TDS values of the fresh water Orashi River ecological zone is relatively lower than that of the transition zones (TZ1 & TZ2) and the Sombriero River brackish water ecology except at OR4 with a value of 5118.0±5390ppm. The mean TDS for the study is 4883.6±4130ppm respectively, while the ecological TDS means are as follows:- Orashi River (OR) = 1283.3±1351ppm, Sombriero River (SR) = 7243±6268.0ppm and Transition Zone (TZ) = 7366.0±5411ppm. The WHO permissible value for TDS is 500ppm. 1ppm = 1mg/L.

Temperature values in the waters of the study area ranges from 27.02±28.6oC to 26.69±29.31 oC as shown in Tables 1 and 2 respectively. Temperature was lowest at OR3/OR1 with a value of 27.02±26.69oC. The highest temperature value of 28.6±29.31oC is at TZ2/SR4. Temperatures for all of the River water stations of the three ecological zones are above 27oC of the dry season whereas it was only at locations OR1&2 of the wet season. Mean temperature in the study is 27.60±27.99oC. The ecological mean temperatures are as follows: - Orashi River (OR) is 27.31±27.2oC, Sombriero River (SR) is 27.64±28.44oC; and Transition zone (TZ) is 28.1±28.64oC. The WHO allowable limit for surface water temperature is 27±29oC.

Similarly, seasonal salinity levels of the various River water sources of the study area ranges from 0.01±8.97k/Kg to 0.02±8.7. OR3/OR1&OR2 with salinity values of 0.01±0.02k/Kg has the lowest seasonal observed salinity values. TZ2/SR2 with values of 8.97±8.7g/Kg recorded the highest seasonal salinity values. Salinity values ranges from 0.01±5.74k/Kg to 0.02±8.7g/kg in the study area. OR3/OR1&2 with 0.01±0.02g/Kg are the lowest within the Orashi freshwater and Sombriero ecologies. TZ1 and TZ2 have salinity values of 7.9±8.79g/Kg to 7.12±6.02 respectively, whereas, the values ranges from 6.97±8.71k/Kg to 5.03±8.7 for the Sombriero River ecosystem. The mean salinity for the study is 5.13±4.66 k/Kg. The salinity means for the three River sections of the study are: - Orashi River (OR) = 5.43±1.10k/Kg, Sombriero River (SR) = 7.95±7.27k/Kg and Transition Zone (TZ) = 8.35±6.57 k/Kg respectively. Observed salinity values for the polyhaline Sombriero River system are higher than the oligohaline Orashi River freshwater system in all seasons. The WHO permissible value for salinity is ≤ 6±9k/Kg/600±900mg/L.

On the other hand, the chemical analysis of water quality is displayed in Table 3 for the dry season and Table 4 for the wet season. The analysis reveals that the seasonal quantitative abundance of chloride in the different surface water sources of the study area ranges 8.0±5,120.0mg/L to 6.0±2,855mg/L as shown in tables 4.4a and 4.4b respectively. OR2 and OR3 have a uniform value of 8mg/L, and are the lowest for the dry season while SR2 at 6.0mg/L is the least for the wet season. TZ1/OR3 with Cl values of 5,120.0±2,855mg/L is the highest for the dry and wet season respectively. However, the chloride concentration values are very different from one location to the other. The mean seasonal chloride concentration of the study is 2,918.8±1,534.4mg/L. Sulphates (SO42−)concentration ranges from 0.00±1040mg/L to 0.0±450mg/L. The values of sulphates for sampling locations OR1, 2 and OR3 is the same at 0.0mg/L, and the lowest for the dry season, whereas TZ1 with a value of 1,040mg/L is the highest. For the wet season, with a uniform value of 0.0mg/L, OR2 and OR3 have the lowest observed sulphate concentration while location OR3 at 450mg/L is the highest for the wet season. Observed sulphates concentration in the different surface water sources vary from sampling locations. Mean water sulphates concentration for the study area is 4,995±178.18mg/L. The WHO permissible safe water level for surface water sulphates is 250mg/L.

The relative abundance of nitrates (NO3-)ranges from 0.1±4.5mg/L to 0.3±2.3mg/L. At 0.1±0.3mg/L, OR2&3/SR2&SR3 are the least for the dry and wet seasons respectively. SR1/OR3 with a value of 4.5±2.3mg/L is the highest nitrares concentration. Concentration of nitrates in the different surface water sources of the study area also differ for the different sampling locations. Overall nitrates mean for the waters of the study area is 2.7±1.33mg/L. The WHO permissible safe water level for surface water nitrates is 5mg/L.

Seasonal phosphates (PO43-) concentrations of the waters of the study area ranges from 0.03±1.92mg/L to 0.06±1.24mg/L. OR2/SR2 is the lowest at 0.03±0.06mg/L, while the highest concentration is observed at TZ1/OR3 with a value of 1.92±1.24mg/L. The seasonal concentrations of phosphates at the different surface water sources are however different from each other. Similarly, the seasonal phosphates means for the waters of the study area is 1.09±0.71mg/L respectively. The WHO permissible safe water level for surface water phosphates is 0.1mg/L. The concentration of PAHs in the different river water sources of the study area ranges from 0.001±0.044mg/L to <0.001±0.005mg/L. Lowest PAHs concentrations of ˂0.001mg/L is observed at sampling locations SR3, OR1, OR2, OR3, OR4, TZ1 and TZ2 in the dry season and locations SR2, SR3, SR4, TZ1, TZ2, OR1, OR2, OR3 and OR4 during the wet season. Sampling location SR1 with a value of 0.044mg/L has the highest observed concentration of PAHs in the dry season whereas location SR1 with a PAHs value of 0.005mg/L is the highest in the wet season. PAHs study mean is 0.008±0.002mg/L. Ecological means are Orashi River = 0.001±0.001mg/L. Sombriero River = 0.017±0.002mg/L and Transition Zone = 0.001±0.001mg/L respectively. The seasonal concentrations of BTEX in the different surface water sources of the study range from ˂0.001±˂0.003mg/L to <0.001mg/L. All locations had the least value of ˂0.001 in the dry season except SR1 which has a BTEX concentration of ˂0.003mg/L. In the wet season all locations have an observed concentration of <0.001mg/L. The WHO permissible concentration level for BTEX in marine and freshwater ecologies is B= 0.005mg/L, T= 1mg/L, E= 0.7mg/L, and X[1-4] =10mg/L.

From the results seasonal concentrations of alkalinity in the various surface water locations ranges from 2±30mg/L to 2±45mg/L. Locations OR2, OR3 have the lowest observed value of 2mg/L in the dry season, while locations SR2 &SR3 have the observed lowest alkalinity concentration during the wet season. SR2/OR3 has the highest observed concentration of 30±45mg/L in the respective seasons. Mean seasonal alkalinity concentration for the study area is 18.1±17.3mg/L. Ecological alkalinity means for Sombriero (SRs or SR1-4) is 23.25±5.5mg/L, Orashi River (Ors or OR1-4) is 7.0±25.25mg/L, while the Transition Zone (TZ1 & TZ2) is 30.0±15mg/L.

For the heavy metals,the dry season mean of the various heavy metals concentration showed that Pb, Zn and Cr in the different surface water sources of the study is the same at ˂0.001. However, the wet season mean for Pb is 0.01mg/L, Zn is 0.01mg/L and Cr is 0.006mg/L. Seasonal manganese concentration ranges from 0.243±0.484mg/L to <0.001±0.616mg/L. 0.243±<0.001mg/L are the respective lowest concentrations of Manganese observed at OR1/OR1 while the highest values of 0.484±0.616mg/L observed at OR4/TZ2 respectively. Seasonal concentration of Iron in the surface water sources of the study area ranges from 0.286±0.983mg/L to <0.001±2.84mg/L. The least value of 0.286±<0.001mg/L was observed at SR3/SR4, OR1, OR3 and OR4 while the highest values of 0.983±2.84mg/L were observed at SR4/SR2 respectively. Potassium concentration in the study ranges from 0.518±117.44mg/L to<0.001±51.25mg/L. The lowest values of 0.518±<0.001mg/L were observed at OR3/SR2 while the highest values of 117.44±51.25mg/L were observed at TZ2/TZ1. Similarly, Magnesium concentration in the surface water sources of the study ranges from ˂0.001±138.30mg/L to <0.001±140.7mg/L. OR2/SR2&SR3 recorded uniform lowest values of ˂0.001mg/L. The highest values of 138.30±140.7mg/L were observed at SR2/OR4. Also, Calcium concentrations in the various surface water sources of the study ranges from ˂0.001±108.03mg/L to <0.001±96.16mg/L. At ˂0.001mg/L, OR2&OR3/SR1,SR2&SR3 recorded uniform least values, whereas 108.03±96.16mg/L at locations TZ1/SR3 were the highest observed concentrations of Calcium in the surface water sources of the study area.

Sodium concentration in the river water sources ranges from 2.055±6,653.1mg/L to 0.278±751.59mg/L. OR2/OR1 recorded the least sodium concentration of 2.055±0.278mg/L while the highest value of 6,653±751.59mg/L were the observed highest concentrations at TZ1/SR4. Finally, relative quantitative abundance of Cadmium in the different surface water locations ranges from 0.021±0.146mg/L to <0.001±0.069mg/L. The least and highest values of 0.021±<0.001mg/L and 0.146±0.069mg/L were observed at SR3/OR3&SR1 and SR4/SR3 respectively. Furthermore, the seasonal concentrationof biochemical oxygen demand (BOD) in the study ranged from 0.38±0.31mg/L to 1.76±1.65mg/L. OR2/OR1 recorded the least while TZ1/SR1 recorded the highest concentrations. The seasonal study means stood at 1.06±0.91mg/L, whereas the ecological means stood at 0.06±0.67mg/L, 1.27±1.2mg/L and 1.55±1.41mg/L for Orashi River (OR), Sombriero River (SR) and Transition Zone (TZ) respectively.

**Table 1. Physical Parameters of Water Quality of Orashi and Sombreiro River Sections for dry season**

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Parameters** | **OR1** | **OR2** | **OR3** | **OR4** | **TZ1** | **TZ2** | **SR1** | **SR2** | **SR3** | **SR4** | **Mean** | **USEPA/WHO STANDARDS** |
| DO, mg/L | 6.9 | 5.4 | 3.2 | 6.0 | 2.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2.36 | 6.5±8.0 |
| Turbidity, JTU | 10.0 | 7.0 | 5.0 | 20.0 | 24.0 | 27.0 | 27.0 | 19.2 | 18.2 | 22.0 | 17.94 | <1 |
| TDS, ppm | 4.0 | 6.0 | 5.0 | 5118.0 | 7415.0 | 7316.0 | 6311.0 | 7416.0 | 7727.0 | 7518.0 | 4883.6 | <300 |
| ORP, (Mv) | 0.0 | 0.0 | 161.3 | 101.3 | 65.7 | 16.0 | 27.7 | 56.1 | 50.2 | 26.6 | 50.49 | 300±500 |
| pH | 7.14 | 6.36 | 5.95 | 7.20 | 7.54 | 7.64 | 7.72 | 7.71 | 7.68 | 7.63 | 7.26 | 6.5±8.0 |
| Salinity, ppt | 0.02 | 0.06 | 0.01 | 5.74 | 7.9 | 8.79 | 6.97 | 8.0 | 8.13 | 8.71 | 5.13 | 0.5±1 |
| Temp, oC | 27.30 | 27.35 | 27.02 | 27.56 | 27.6 | 28.6 | 27.42 | 27.14 | 28.2 | 27.78 | 27.60 | 27±29 |
| E/Cond., (µS/cm) | 8.0 | 12.0 | 10.0 | 10.21 | 14.92 | 14.69 | 12.45 | 14.93 | 14.82 | 50.06 | 16.21 | 50 |

**Table 2. Physical Parameters of Water Quality of Orashi and Sombreiro River Sections for wet/rainy season**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Wet/Rainy Season** | | | | | | | | | | | | |
| **Parameters** | | **OR1** | **OR2** | **OR3** | **OR4** | **TZ1** | **TZ2** | **SR1** | **SR2** | **SR3** | **SR4** | **Mean** | **USEPA/WHO STANDARDS** |
| DO, mg/L | | 0.07 | 0.06 | 0.03 | 2.03 | 7.2 | 3.15 | 2.89 | 4.42 | 6.30 | 9.10 | 3.53 | 6.5±8.0 |
| Turbidity, JTU | | 4.1 | 3.9 | 10.0 | 3.2 | 3.2 | 6.62 | 4.0 | 4.40 | 6.00 | 2.0 | 4.74 | <1 |
| TDS, ppm | | 5.0 | 5.0 | 4.0 | 5390 | 5112 | 5710 | 6307 | 8.32 | 9595 | 9164 | 4130.03 | <300 |
| ORP, (Mv) | | 13.1 | 14.3 | 22.5 | 24.8 | 11.5 | 35.9 | 7.2 | 5.0 | 16.3 | 1.50 | 15.21 | 300±500 |
| Ph | | 8.70 | 8.58 | 8.86 | 9.07 | 9.02 | 9.18 | 9.41 | 9.26 | 8.49 | 9.32 | 8.99 | 6.5±8.0 |
| Salinity, ppt | | 0.02 | 0.02 | 0.04 | 4.33 | 7.12 | 6.02 | 5.03 | 8.7 | 7.88 | 7.48 | 4.66 | 0.5±1 |
| Temp, oC | | 26.69 | 26.98 | 27.21 | 27.92 | 28.27 | 29.01 | 27.97 | 28.10 | 28.39 | 29.31 | 28.29 | 27±29 |
| E/Cond., (µS/cm) | | 10.50 | 8.0 | 6.0 | 7819 | 8286 | 8130 | 9055 | 11.72 | 14.61 | 14.18 | 3335.50 | 50 |

**Table 3. Water Quality Chemical Parameters of Orashi and Sombreiro River Sections for dry season**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Dry Season Surface Water** | | | | | | | | | | | | | |
| **S/N** | **Parameter(s)** | **SR01 SW** | **SR02 SW** | **SR 03 SW** | **SR04 SW** | **OR01 SW** | **OR02 SW** | **OR03 SW** | **OR040 SW** | **TZ01 SW** | **TZ02 SW** | **MEAN** | **USEPA/ WHO STD** |
| **1** | **Chloride Cl (mg/l)** | 3,820 | 4,800 | 4,760 | 2,880 | 32 | 8 | 8 | 3,190 | 5,120 | 4,570 | 7.714 | ≤250 |
| **2** | **Sulphate, SO42- (mg/l)** | 660 | 720 | 700 | 540 | 0 | 0 | 0 | 610 | 1,040 | 680 | 495.00 | 250 |
| **3** | **Nitrate, NO3- (mg/l)** | 4.5 | 4.2 | 4.0 | 3.2 | 0.3 | 0.1 | 0.1 | 3.5 | 3.1 | 4.0 | 2.700 | 5 |
| **4** | **Phosphate, PO43- (mg/l)** | 1.25 | 1.76 | 1.56 | 1.20 | 0.53 | 0.03 | 0.04 | 1.15 | 1.92 | 1.45 | 1.089 | 0.1 |
| **5** | **PAH (mg/l)** | 0.044 | 0.003 | <0.001 | <0.021 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | 0.005 | <0.02 |
| **6** | **BTEX (mg/l)** | .003 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | 0.001 | B= 0.005, T= 1, E=0.7, X[1-4] =10**.** |
| **7** | **Alkalimity (mg/l)** | 20 | 30 | 25 | 18 | 4 | 2 | 2 | 20 | 35 | 25 | 18.100 | 200 |
| **8** | **Lead, Pb (mg/l)** | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | 0.001 | 0.01 |
| **9** | **Zinc, Zn (mg/l)** | <0.001 | <0.001 | 0.004 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | 0.001 | 1.0 |
| **10** | **Manganese, Mn (mg/l)** | 0.322 | 0.447 | 0.363 | 0.385 | 0.243 | 0.292 | 0.424 | 0.484 | 0.314 | 0.331 | 0.361 | 0.05 |
| **11** | **Iron, Fe (mg/l)** | 0.507 | 0.788 | 0.286 | 0.983 | 0.678 | 0.554 | 0.533 | 0.725 | 0.465 | 0.439 | 0.596 | 0.03 |
| **12** | **Chromium, Cr (mg/l)** | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | 0.001 | ≤0.05 |
| **13** | **Potassium, K (mg/l)** | 98.520 | 71.188 | 92.514 | 101.96 | 9,752 | 0.591 | 0.518 | 66.388 | 63.789 | 117.44 | 62.266 | 0.01 |
| **14** | **Magnesium, Mg (mg/l)** | 118.60 | 1 38.30 | 123.87 | 128.22 | 6.072 | <0.001 | 0.35 | 117.69 | 118.19 | 117.13 | 86.842 | 0.02 |
| **15** | **Calcium, Ca (mg/l)** | 97.078 | 105.98 | 106.83 | 103.76 | 0.272 | <0.001 | <0.001 | 84.490 | 18.03 | 101.17 | 61.761 | 1.0 |
| **16** | **Sodium, Na (mg/l)** | 680.29 | 635.98 | 372.80 | 634.73 | 18.808 | 2.055 | 12.393 | 619.13 | 6,653.1 | 6,384.7 | 1601.399 | 30-60 |
| **17** | **Cadmium, Cd (mg/l)** | 0.027 | 0.146 | 0.021 | 0.147 | 0.035 | 0.023 | 1.119 | 0.029 | 0.090 | 0.040 | 0.168 | 0.005 |
| **18** | **BOD5 (mg/l)** | 1.27 | 1.48 | 1.36 | 0.98 | 0.47 | 0.38 | 0.04 | 1.16 | 1.76 | 1.33 | 1.023 | 5 |

**Discussion of Findings**

The seasonal dissolved oxygen (DO) means of 2.36±3.53mg/L are far less than the W.H.O limits of 6.5±8.0mg/L. Nirmalendu et al. (2022) identified hypoxia as a condition of low dissolved oxygen in water <2.3mg/L. Therefore, the result indicates that the surface waters of the study area are generally deficient in dissolved oxygen but not necessarily hypoxic. Also, the Sombriero River with seasonal mean of 0.0±5.68mg/L and Transition Zone1 & 2 with means of 1.05±5.18mg/L are chronically hypoxic during the dry season with an improvement during the wet season. Findings showed that seasonal turbidity values were above the WHO permissible level of 5NTU/10JTU in all sampling locations of the study except in OR1, OR2, and OR3. Mean TDS concentrations were above the WHO desirable threshold for surface water in all water sources of the study. However, mean seasonal salinity abundance in the study is within the WHO allowable range of 600-900mg/L in all sampling stations. The totality of the results reveals that the waters of the study are turbid with excessive particle load except in parts of the Orashi River ecology. The results further reveal correlative characteristic between turbidity and TDS in the Orashi ecosystem, particularly in OR1, OR2 and OR3. This implies waters in the various sources are unfit for water quality. The waters in the study has excess dissolved organic and inorganic minerals and salts, hence has undesired taste and diluted color unfit for drinking. The finding disagrees with that of (Soylak et al, 2001) who reported levels of turbidity and TDS within limits in Turkey. From the results, the study ORP means, ecological means and individual location values are less than the WHO standard for surface water in the dry season. However, the wet season means are well above permissible limits for water quality. This is an indication that the water may be highly contaminated with toxic heavy metals, PAHs and PCBs in the dry season and, therefore not suitable for water quality portability. From the various means, it is clear that the waters of the study area is generally alkaline in nature at a mean of 15.26±8.97 except the waters of Orashi and Transition ecologies at 6.63 and 7.59 respectively of the dry season. There is human health risks associated with regular intake of acidic water (low alkalinity) because of the depletion of vital nutrients supportive of balanced health. It supports the osmoregulation of cancer (Gerry, 2012; Tanis and Tian, 2015). The WHO permissible threshold for electrical conductivity is 0.5±3.0/≤400µS/cm. The values for EC in the various water sources of the dry season are less than the WHO value of ≤400µS/cm whereas the values for the wet season are above except at OR1, 2, 3 & SR2. This study, therefore agree with Julian & Katherine (2020) to the effect that pure and saline waters are better conductors electricity than impure and fresh waters. Salinity is the measure of accumulated salts, inextricably linked with water quality parameters as it is affected by climate variability. The mean salinity for the study was 4.90ppt. This is above the USEPA/WHO standard range of 0.5±1. Hoque et al (2016) argued that salinity affects water and soil/sediment/wetland quality, decrease mangrove and plant growth, lowers crop yield, causes erosion, loss of native vegetation, enhances invasive species and is injurious to marine ecosystem.

**Conclusion and Recommendations**

It can be concluded that most of the heavy metals, physicochemical parameters evaluated were higher than institutional permissible limits and thus implicated in the surface water. The study thus recommended that there is the need for multi-stakeholders articulation of an efficient, all inclusive and sustainable environmental remediation strategies and mitigation measures for the Niger Delta region. To this end, environmental issues should be completely devolved and completely a preserve of the Concurrent and Residual Legislative Lists.

**References**

Abam, T.K.S (1999). Modification of Niger Delta Physical Ecology: The Role of Dams and Reservoirs: Hydro-ecology linking Hydrology and Aquatic Ecology (Proceedings of Workshop HWZ held at Birmingham, UK. July 1999.

Anyakora, G & Coker, H. (2006). ‘Determination of Polynuclear Aromatic Hydrocarbons (PAHs) in Selected Water Bodies in the Niger-Delta. A.J. Biotechnology.

APHA (2012) Standard Methods for the Examination of Water and Waste Water, 22nd ed. American Public Health Association, Washington DC, USA.

ASTM (American Standard of Testing Materials) (2003). Test Method for Oil in Water Analysis. Annual Book of ASTM Standards, ASTM International U.S.A.

Ekubo, A.T & Abowei, J. F .N (2011) Review of Some Water Quality Management Principles in Culture Fisheries. Research Journal of Applied Sciences. Engineering and Technology, 3, 1342-1357.

Ekundayo, E. O & Obuekwe, C (2001) Effects of an oil spill on soil physic-chemical properties of a spill site in a typical udipsamment of the Niger Delta Basin of Nigeria. Environment mentoring and assessment.

Ezekwe I. C & Utong I. C (2015) Ecological Risk Levels from Hydrocarbons and Metal Concentrations in the Sediments of an Oil Polluted Coastal River in Andoni, Eastern Niger Delta of Nigeria. A Paper Prepared for Presentation at the 2015 International Conference of Water Resources and Environment, July 25th-28th, Beijing China.

Georgewill, O.A. (2012) “Crude Oil: Sweet and Sour - Effort at Mitigating the Toxic Effects’’. An Inaugural Lecture Series 93, University of Port Harcourt, Port Harcourt.

Kadafa, A. A (2012) Oil Exploration and Spillage in Niger Delta of Nigeria. Civil and Environmental Research. ISSN 2222-1719 (paper) ISSN 2222-2863. Vol. 2, No. 3, 2012.

Nduka J. K & |Orisakwe O. E (2011). Assessment of Pollution Profile of Selected Surface Water in the Niger Delta Region of Nigeria. The Lambert Academic Publishers, Germany.

USEPA (2014a)Dose-Response Assessment for Assessing Health Risks Associated With Exposure to Hazardous Air Pollutants: *Table 1:Prioritized Chronic Dose-Response Values for Screening Risk Assessments (5/9/2014).* https://www.epa.gov/sites/production/files/2014- 05/documents/table1.pdf, accessed March 12, 2018.

USEPA (2014b)Dose-Response Assessment for Assessing Health Risks Associated With Exposure to Hazardous Air Pollutants: *Table 2: Acute Dose-Response Values for Screening Risk Assessments (9/18/2014).* https://www.epa.gov/sites/production/files/2014-05/documents/table2.pdf, accessed April 28, 2018.

USEPA (2017d) Dose-Response Assessment for Assessing Health Risks Associated With Exposure to Hazardous Air Pollutants: *Risk Assessment for Carcinogenic Effects*. https://www.epa.gov/fera/risk-assessment-carcinogenic-effects, accessed June 14, 2018.

USEPA (2017e) Dose-Response Assessment for Assessing Health Risks Associated with Exposure to Hazardous Air Pollutants: *Risk Assessment for Other (noncarcinogenic) Effects*. https://www.epa.gov/fera/risk-assessment-other-effects, accessed April 13, 2018.