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IMPACT OF PETROCHEMICAL ACTIVITIES ON THE PHYSICOCHEMICAL AND MICROBIOLOGICAL QUALITY OF SURFACE WATER, GROUND WATER AND SOIL IN OTU-JEREMI, IWEREHKAN AND OKPARE COMMUNITIES, UGHELLI SOUTH LOCAL GOVERNMENT AREA, DELTA STATE, NIGERIA

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ABSTRACT

The effects of petrochemical activities on the physicochemical and microbiological properties of surface water, ground water and soil from three different communities (Otu-Jeremi, Iwerehkan and Okpare communities) in Ughelli South Local Government Area, Delta State, Nigeria was investigated. A total of 96 samples, were obtained from surface water, ground water as well as soil, and across two seasons (dry and raining). The physicochemical parameters were determined according to the American Public Health Association (APHA) methods, while total heterotrophic bacterial counts and fungal counts were determined by pour plate technique. The results obtained showed that most pH obtained from underground water, surface water and soil were below the acceptable limit, including that of the control. The turbidity level of the surface water samples from all communities (Otu-Jeremi, 4.01 ± 0.3 NTU; Iwerehkan, 3.28 ± 0.89 NTU; Okpare, 3.25 ± 0.89 NTU), including that of the control (3.65 NTU) during the dry season were higher than that of Federal Environmental Protection Agency (FEPA) benchmark (1.0 NTU). Other parameters had varying concentrations, when compared with the FEPA minimum benchmark. Six bacterial genera (*Aeromonas* sp, *Corynebacterium* sp, *Staphylococcus* sp, *Micrococcus* sp, *Bacillus* sp and *Pseudomonas* sp.) and seven fungi genera (*Aspergillus*, *Cladosporium*, *Candida*, *Mucor*, *Rhizopus*, *Trichophyton* and *Geotrichium*) were identified. The result of this study showed that petrochemical activities have negative impact on underground water, surface water and soil from the three communities in Ughelli South Local Government Area of Delta State.

Keywords: Environment; Pollution; Heavy metals; Microbiology; Public Health

INTRODUCTION

Petroleum is a naturally occurring complex mixture found beneath the earth's surface and is made up predominantly of hydrocarbon compounds (Uzoma and Mgbemena, 2015). Prospecting and drilling for petroleum beneath the earth's surface is the major responsibility of petroleum industries globally, and their activities can lead to the destruction, depletion and degeneration of the ecosystems. The Niger Delta area in Nigeria is one of such areas with intensive petroleum exploration, exploitation and production, as well as industrial installations such as pipelines, flow stations, gas clusters as well as gas flaring sites, all of which have adverse impact (directly or indirectly) on food animals, humans, and the environment. According to Ite and Ibok. (2013), every stage of petroleum resources; exploration, development and production, transportation and distribution often results in some considerable environmental impacts.

The high traffic in petrochemical activities has led to environmental degradation, arising principally from oil spills, pipe-line leakages and vandalism (especially in developing countries) amongst others. For example, Chinedu and Chukwuemeka. (2018) reported that approximately 3.1 million barrels of oil was spilled between 1976 and 2014 in the Niger Delta region alone. According to Ordinioha and Brisibe. (2013), an average of 240,000 barrels of crude oil are spilled in the Nigeria's Niger delta region every year and the spillage may be attributed to unknown causes (31.85 %), third party activity (20.74 %), accidental and/or equipment failure (17.04 %).

On the other hand, 102.3 million cubic meters (81.7% of what was generated) of gas produced in Nigeria was flared between 1977 and 1986 (Awosika, 1995). Interestingly, the majority of the gases are flared in the oil rich Nigeria's rich Niger-Delta region. As of 2004, 123 different gas flaring sites were reported in the Niger Delta region alone (Uzoma and Mgbemena, 2015), with approximately 45.8 billion kilowatts of heat being discharged into the atmosphere. Although the quantity of gas being flared in Nigeria has reduced since 2008, due to efforts by the Nigerian Government to stop gas flaring, yet, it is still a major challenge, with 18.971 billion cubic feet of gas reported to be flared in Nigeria in 2019 (Hedley, 2020).

The negative health impact of petrochemical activities is particularly worrisome, and can, therefore, not be over emphasized. Gas flaring for example contributes to global warming and is reported to be toxic to humans, causing respiratory illness, leading to kidney disease, neurological disease and potential death (Ndubisi and Asia, 2007). On the other hand, crude oil spill have been implicated in the destruction of farmlands, soil fauna and flora, as well as aquatic life, poisoning of both surface and ground water etc. (Frank and Boisa, 2018), while long term exposure have been reported to cause DNA damage (Rodriguez-Trigo *et al*. 2007), cancer (San Sebastian *et al*., 2001), as well as respiratory and skin disorders (Ana *et al*., 2009).

The current study, therefore, was aimed at investigating the impact of petrochemical activities on water (surface and ground) and soil quality of Otu-Jeremi and environs, Delta State, Nigeria.

MATERIALS AND METHODS

Study Area

Three study areas were selected for this study that included; Otu-Jeremi (Figure 1), Iwerehkan (Figure 2) and Okpare community (Figure 3). Otu-Jeremi is the headquarters of Ughelli South LGA, and is home to the Nigeria Gas Plant. It is located at latitude 5.438 and longitude 5.878. Iwerehkan community is located in Ughelli South Local Government Area of Delta State, Nigeria. The major occupation in Iwerehkan is farming and fishing. The community also hosts oil wells and flow stations belonging to Shell Petroleum Development Company. Okpare community on the other hand is a neighbouring town to both Otu-jeremi and Iwerehkan, all located in Ughelli South Local Government Area of Delta State.

Figure 1: GPS location of Otu-Jeremi community

Figure 2: GPS location of Iwerehkan community

Figure 3: GPS location of Okpare community

Sample Collection

Surface water samples were collected from rivers at approximately 5 cm depth opposite to the flow direction, while groundwater was taken from taps of boreholes, after the taps were allowed to run for about 10 min. before sample collection. Samples for physico-chemical analyses were collected and stored in appropriately labelled 1 litre plastic bottle while those for heavy metal analysis were collected in 120 ml plastic bottles. Biological Oxygen demand was collected with an amber bottle, while microbiological samples were collected using sterile universal bottle. Water samples for COD and organics were collected in 1 litre wide-mouth glass bottles. A total of 48 water samples (representing 2-lots per community, per month) were collected within a six month period, and across two seasons; May, June and July 2021 representing wet season as well as September, October and November, representing dry season.
Soil samples on the other hand were collected from 48 sites of two-lots each; top (0 – 15 cm) and bottom (15 – 30 cm), using the Dutch Hand Auger. Soil samples for microbiological analyses were collected in sterilized 100 mL McCartney bottles and stored in an ice chest. The samples for organic analyses were collected in glass jars and those for physicochemical analyses in Ziplok bags. All control samples were obtained from Okpare community, which is known not to have any petrochemical activities.

Sample Processing/preparation for Chemical Analysis

Samples for heavy metal analyses were preserved by acidification to pH of ≤ 2 using 1:1 tri-oxonitrate (V) acid (nitric acid) (HNO_3). Samples for COD and organics analyses were, acidified with 1:1 tetra-oxosulphate (VI) acid (Sulphuric acid) (H_2SO_4) to a pH of ≤ 2 (Yusuf *et al.*, 2020). All samples were transported to the laboratory in cold packs containing ice.

Assurance/Control for Laboratory Analysis

For quality assurance, all possible sources of errors, including lack of calibration of equipment, errors in data reporting, lack of sensitivity of instruments, as well as contamination/degradation of reagents were completed avoided.

In-situ Analysis

The following *in-situ* measurements: pH, temperature, dissolved oxygen, dissolved solutes; (TDS), Electrical conductivity and turbidity were carried out using Hanna HI9829 multipara meter (APHA, 1999; Rodier *et al.,* 2009). The pH values ranged from 0 (very acidic) to 14 (very alkaline) with a pH of 7 being neutral. TDS, electrical conductivity, temperature, turbidity and DO were measured using Hanna HI9829 multi-parameter meter which was calibrated using Hanna quick Cal solution (HI9829-27) (APHA, 1999; Rodier *et al.,* 2009). The meter probe was dipped into the water sample and allowed to stabilize before the readings were recorded.

Water Analysis

Water analyses were performed in accordance with the American Public Health Association (APHA, 2017) international reference standards.

Oil and Grease Content

The Infrared method was adopted using INFRACAL-2 for measuring oil and grease, as described by Skoog *et al.* (2015). This involved extraction of the hydrocarbon from the sample with tetrachloroethylene. The concentration of the extract in mg/l was determined using 10 mm unit path length cuvette after blanking.

Heavy Metals

Heavy and alkaline metals were analysed using Varian Spectra A 600 Flame Atomic Absorption Spectrophotometer after acid digestion and filtration by direct aspiration into the flame through the nebulizer, as described by Rodier *et al*. (2009) and Skoog *et al*. (2015). The sample was aspirated into the flame whose high temperature converts the analyte ion into atoms in the vapor state. Absorption occurred when a ground state atom absorbs energy in the form of light of a specific wavelength and is elevated to an excited state. The relationship between the amounts of light absorbed and the concentration of the analyte present in known standards can be used to determine unknown concentrations by measuring the amount of light absorbed.

Soil Analysis

The methodologies employed for soil analysis were in accordance with international reference standards: American Public Health Association (APHA) 1999.

Microbiological Analysis

Sample Preparation and Isolation of Microorganisms

One milliliter each of all water samples were diluted in 9 mL of sterile distilled water in a test tube. This was used to make further dilutions, up to the 10^{th} dilution (Omoruyi *et al*., 2011). For soil samples, 10 g of each soil samples were weighed into a beaker, and 90 mL of sterile distilled water was added and shaken vigorously. Thereafter, 10-fold serial dilution was made and 1 mL of the appropriate dilutions for both water and soil samples were cultured on the respective media.

Total Heterotrophic Bacterial Counts and Total Fungi Counts

The total heterotrophic bacterial and fungi counts were carried out as described by Hounsou *et al*. (2010) Briefly, aliquot amount (1 mL) of the appropriate dilutions were aseptically transferred onto an already prepared nutrient agar plates (Titan biotech ltd India) by the pour plate method, and incubated at 37°C for 24hr. All samples were cultured in triplicate, and the mean heterotrophic count recorded based on the number of colonies on the nutrient agar plates. For fungal counts, 0.1 mL of the appropriate dilution was culture onto potato dextrose agar by the pour plate technique, and incubated at 25°C for 5 – 7 days. All samples were done in triplicates, and the number of isolates recorded as mean ± standard deviation.

Identification of Bacteria and Fungi

The bacterial isolates were identified using their cultural, morphological and biochemical characteristics, while fungal isolates were identified using the atlas of fungi identification. Only pure cultures of the isolates obtained from sub-culturing were further processed for identification.

Statistical Analysis

The mean and standard deviation as well as the regression analysis were obtained using the software Prisma 5.0 (GraphPad Software Inc., San Diego, CA).

RESULTS

Physicochemical Properties of Ground Water from Three Communities in Ughelli South Local Government Area of Delta State, During the Dry Season

The results on the physicochemical properties of ground water from Otu-Jeremi community in Delta State, Nigeria had a pH value of 5.26 ± 0.31, while the pH of Iwerehkan and Okpare communities were 5.58 ± 0.40 and 4.77 ± 0.40 respectively, during the dry season. Interestingly, the pH of the ground water used as control was significantly lower than those obtained from both Otu-Jeremi and Iwerehkan communities. Similarly, the temperature obtained from all 3 communities and the control were within the same range (26.6 ± 0.21 – 26.9 ± 0.14) (Table 1).

The concentration of cadmium, nickel, lead and mercury were below detection limit in ground water samples from all 3 communities, as well as the control, while the concentration of manganese was significantly higher in ground water from Otu-Jeremi and Okpare communities (0.11 ± 0.09 mg/L and 0.14 ± 0.00 mg/L respectively) compared to the control Below Detection Limit (BDL). They were also higher than the WHO limit of 0.10 mg/L but less than the Department of Petroleum Resources, Nigerian Standard for Drinking Water Quality (DPR NSDWQ) benchmark of 0.20 mg/L (Table 1).

Physicochemical Properties of Surface Water from Three Communities in Ughelli South Local Government Area of Delta State, During the Dry Season

Table 2 shows the physicochemical properties of surface water samples from Otu-Jeremi community and environs. All water samples (including controls) were clear in appearance as well as odourless. The values obtained with total dissolved solid, colour, total suspended solid, dissolved oxygen, chloride, sulphate, chromium, zinc, nickel and mercury were below the Federal Environmental Protection Agency (FEPA) acceptable limit (Table 2).

Only Iwerehkan had oil and grease (0.06 ± 0.00 mg/L) above that of FEPA acceptable benchmark of 0.05 mg/L, with all others having values BDL. The concentration of iron was also high in all 3 sample locations when compared with that of the control. Otu-Jeremi had 2.77 ± 0.67 mg/L, almost 2-fold that of FEPA limit, Iwerehkan had 1.79 ± 0.11 mg/L while Okpare had 1.87 ± 0.23 mg/L. Also, lead and manganese were also higher in Otu-Jeremi (0.10 ± 0.01 mg/L and 0.08 ± 0.08 mg/L respectively) and Iwerehkan (0.09 ± 0.04 mg/L and 0.14 ± 0.01

mg/L respectively) when compared with the FEPA minimum benchmark (Table 2).

Physicochemical Properties of Soil Samples from Three Communities in Ughelli South Local Government Area of Delta State, During the Dry Season

Table 3 shows the impact of petrochemical activities on soil from Otu-Jeremi community and environ. The soil pH was all slightly acidic, including that of the control. The concentrations of total organic carbon, chloride, sulphate, total nitrogen, total phosphorus, exchangeable acidity, chromium, zinc, nickel, copper, lead and manganese were all within the DPR EGASPIN target values (Table 3). Meanwhile, the concentration of mercury was below detection limit in all sampling locations, including the controls. Oil and grease was highest at Iwerehkan (793 ± 12.5 mg/kg) at 0 – 15 cm depth and 722 ± 28 mg/kg at 15 – 30 cm depth.

Physicochemical Properties of Ground Water from Three Communities in Ughelli South Local Government Area of Delta State, During the Wet Season

The physicochemical properties of ground water from Otu-Jeremi were generally within the WHO and NSDWQ guidelines except for pH, which was significantly lower. The turbidity, temperature, colour, dissolved oxygen, hardness, alkalinity, ammonia, biological oxygen demand, chemical oxygen demand, chloride, sulphate, nitrate, iron and manganese were within the acceptable limit, while nitrate, phosphate, chromium, cadmium, lead and mercury had concentrations below that of the detection limit (Table 4)

Physicochemical Properties of Surface Water from Three Communities in Ughelli South Local Government Area of Delta State, During the Wet Season

Table 5 shows the impact of petrochemical activities on surface water obtained from three communities in Warri, Delta State, Nigeria, during the wet season. All surface water samples were observed to be clear in appearance as well as odourless. The values obtained for temperature, electrical conductivity, total dissolved solid, total suspended solid, colour, dissolved oxygen, biochemical oxygen demand, chemical oxygen demand, chloride, sulphate, iron and zinc in all three communities were within the FEPA permissible limit (Table 5). Additionally, surface water samples from Otu-Jeremi and Iwerehkan had oil and grease concentration of 0.35 ± 0.00 mg/L and 0.17 ± 0.02 mg/L respectively, a 7- and over 3-fold increase of the recommended benchmark of 0.05 mg/L (Table 5). The concentration of nickel was also higher in Otu-Jeremi (0.51 ± 0.02) and Iwerehkan (0.33 ± 0.06), while Okpare had a concentration below the limit of detection. Lead on the other hand was also only slightly higher that the FEPA limit in surface water obtained from Iwerehkan (0.06 ± 0.01) while surface water from the other communities had concentration below the limit of detection.

Physicochemical Properties of Soil Samples from Three Communities in Ughelli South Local Government Area of Delta State, During the Wet Season

Most of the parameters investigated in soil samples obtained during the wet season were generally within the Environmental Guidelines and Standards for the Petroleum Industry in Nigeria (EGASPIN) target values. Such parameter included electrical conductivity, total organic carbon, chloride, sulphate, total nitrogen, total phosphorus, exchangeable acidity, chromium, zinc, copper, lead and manganese (Table 6), while mercury was below the limit of detection in soil samples obtained from all three communities both at 0 – 15 cm depth and 15 – 30 cm depth. Oil and grease was also below detection limit in soil samples obtained from the control community, while soil from Otu-Jeremi had a concentration of 12.0 ± 1.61 mg/kg at 0 -15 cm depth and 10.9 ± 6.46 mg/kg at 15 – 30 cm depth. Iwerehkan had 30.3 ± 17.8 mg/kg and 17.7 ± 6.46 mg/L at 0 – 15 cm and 15 – 30 cm respectively, while Okpare had a concentration of 15.5 ± 0.00 mg/kg at 0 -15 cm and 18.9 ± 1.62 mg/kg at 15 – 30 cm (Table 6).

Total Bacterial and Fungal Counts Obtained from Ground Water, Surface Water and Soil Samples from Three Communities in Ughelli South Local Government Area of Delta State, During the Dry and Wet Season

Table 7 shows the total heterotrophic bacterial counts (THCs) obtained from all 3 communities. The mean heterotrophic counts obtained during the dry season in Otu-Jeremi was 4.0 ± 1.4 x 10^5 cfu/ml and 18.5 ± 2.12 x 10^5 cfu/ml for surface water and ground water respectively; 74.0 ± 31.0 x 10^5 cfu/ml and 19.3 ± 8.41 x 10^5 cfu/ml for ground water and surface water respectively, during the wet season. Meanwhile, soil samples had fewer THC with depth, except in Okpare community, during the dry season (1.5 ± 0.71 x 10^5 cfu/g and 5.0 ± 5.66 x 10^5 at 0-15 cm depth and 15-30cm depth respectively).

The fungal counts was highest at Otu-Jeremi; 20.5 ± 2.6 x 103 cfu/g and 45.0 ± 14.1 x 103 cfu/g for surface water and ground water respectively, during the dry season (Table 8). At a depth of 0-15cm, soil sample, Iwerehkan had the highest fungal count (7.1 ± 1.9 x 103 cfu/g), while Otu-Jeremi also had the highest count at 15-30cm depth, also during the dry season. During the wet season, Otu-Jeremi had the highest fungal counts for both surface water (12.3 ± 0.71 x 103 cfu/g) and ground water (21.0 ± 3.4 x 103 cfu/g).

Bacteria and Fungi Isolates Obtained from Ground Water, Surface Water and Soil Samples from Three Communities in Ughelli South Local Government Area of Delta State, During the Dry and Wet Season

Six bacterial genera were identified during the study. They included: *Aeromonas* sp, *Corynebacterium* sp, *Staphylococcus* sp, *Micrococcus* sp, *Bacillus* sp and *Pseudomonas* sp. These organisms were identified by their cultural, morphological and biochemical characteristics, and were also present in each of the samples investigated. Similarly, 7 fungal isolates were identified based on the presence and/or absence of a mycelia as well as their cultural morphology. They included; *Aspergillus*, *Cladosporium*, *Candida*, *Mucor*, *Rhizopus*, *Trichophyton* and *Geotrichium*.

DISCUSSION

Environmental pollution arising from increased petrochemical activities is a major challenge in the Niger-Delta region of South-South Nigeria. This region was initially reported to have a well-endowed ecosystem, with one of the highest concentrations of biodiversity. For example, this region was reported to have more species of freshwater fish than any ecosystem in West Africa (Emoyan *et al*., 2008). Unfortunately, this ecosystem is under serious threat from pollution caused majorly by the activities of oil and gas exploration from companies mostly domicile in the region. Otu-Jeremi, a town in Ughelli South Local Government Area of Delta State, Nigeria is home to the Nigeria gas plant and other multinational oil companies, but there are limited studies on the impact of petrochemical and exploration activities in Otu-Jeremi and environs. The current study was, therefore, aimed at investigating the impact of these activities on surface water, ground water and soil in the region, as well as other neighbouring environment.

The results of the current study show that ground water from Otu-Jeremi was in most cases less contaminated in the dry season, when compared with the raining season. This was also the case with the neighbouring communities (Iwerehkan and Okpare), meaning that less pollution happens at ground level, when compared with surface water. The low pH observed in ground water from Otu-Jeremi and environs is an indication of crude oil pollution of ground water aquifers. Njoku *et al*. (2008) reported that pollution caused by crude oil could increase the acidity of ground water, surface water and soil samples, thereby increasing the toxicity of the said sample.

Manganese is an element widely distributed in the earth's crust and is considered the fifth most abundant metal in nature. It is also reported to be present in crude oil, but at substantially lower concentration (WHO, 2011; Bencheng *et al*., 2014). As in the current study, manganese is reported to be more prevalent in ground water when compared with surface water, and could lead to neurological, reproductive and respiratory disorder, especially following chronic exposure. Interestingly, manganese was observed to be higher in water samples (both ground and surface) during the dry season than in the wet season.

Meanwhile, no mercury was observed in all sampling points and location during the wet and dry seasons. This is contrary to the report of Akakuru *et al*. (2017), who reported levels of mercury from different ground water sources around the Nigerian National Petroleum Cooperation oil depot in Aba, South-Eastern Nigeria to be higher than the WHO recommended value.

Also of interest is the high lead content observed in the oil rich exploration community; Otu-Jeremi as well as neighbouring Iwerehkan community, during the dry season, and especially from ground water. Interestingly, the concentration of lead in surface water was even a lot higher in the neighbouring community than in Otu-Jeremi: the community hosting most petrochemical activities. It has been demonstrated quite extensively that dissolved metals from petrochemical activities may become unstable when it propagates in the soil/rock (Zhao *et al*., 2008). The dissolved metals can be transported in the soil/rock through pore-water advection and solute diffusion, thus, contaminating both ground and surface water. The public health impact of drinking heavy metal contaminated water has been studied quite extensively, and is reported to be mutagenic, carcinogenic, teratogenic, oestrogenic etc (Chowdhury *et al*., 2016). Lead for example was majorly used as additives in the petrochemical industries until its use was banned, owing to increased concentration of lead in food, water and air, as well as its potential toxic health effect (Levallois *et al*., 2018).

For soil samples, the majority of samples investigated during the dry season were within the minimum benchmark by the Federal Environmental Protection Agency, except few. There was a somewhat surprising result with the concentration of oil and grease obtained from soil from Otu-Jeremi (both at 0 – 15 cm and 15 - 30 cm), as the concentration was relatively lower than expected. Meanwhile, both neighbouring communities (Iwerehkan and Okpare) had concentrations higher than that of Otu-Jeremi. The concentration of oil and grease was over 45-fold and 58-fold higher in Iwerehkan at 0 - 15 cm and 15 - 30 cm respectively. Also, the concentration of cadmium was higher than FEPA benchmark in all sampling points, while iron was highest from Otu-Jeremi. During the wet season, the concentration of oil and grease was also high, but several folds lower than those obtained during the dry season. Iron, cadmium and nickel were also observed to be greater than the recommended value.

The result obtained in the current study is contrary to those reported by other authors. In a recent study, Muhammad *et al*. (2020) reported water samples from three different communities (Ikpokpo, Atanba and Okpele-Ama) along Escravos River in Warri, South West Local Government Area of Delta state, Nigeria to be highly contaminated by heavy metals such as manganese, mercury, chromium etc. The reason for the high concentrations of heavy metals reported by Muhammad *et al*. (2020) could be attributed to the sample source, as samples were taken directly from crude oil contaminated sources along the Escravos river bank, against the source used in the current study; ground water and surface water. Meanwhile, the results of the pH and temperature values obtained in the current study, is in keeping with that of Emuedo *et al*. (2014) and Akakuru *et al*. (2017). Emuedo *et al*. (2014) reported that there was significant difference in the pH values obtained both in the wet and dry seasons. The values obtained with heavy metals were, however, higher than those reported in the current study. This is also not unexpected, as the samples directly contaminated river sources.

Microorganisms are ubiquitous in nature, and the presence of specific microorganisms in certain environment could be an indication of contamination or as biomarker for the presence of certain contaminants. Some bacterial and fungal isolates observed in the current study (e.g. *Staphylococcus*, *Pseudomonas*, *Bacillus*, *Aspergillus*, *Mucor*, *Rhizopus* spp etc) are similar to those observed in other drinking water sources (Penna *et al*., 2002; Mulamattathil *et al*., 2014; Agu *et al*., 2014; Sirisha *et al*., 2017; Olagoke *et al*., 2018) as well as soil samples (Jasuja *et al*., 2013; Emmanuel *et al*., 2017; Ameh and Kawo, 2017), although, some have been implicated as an ideal candidate in the biodegradation of petroleum hydrocarbon and other chemical contaminant (Zhang *et al*., 2010; Ameh and Kawo, 2017). As reported by Saadoun (2002), the_author reported *Pseudomonas* spp from crude petroleum oil contaminated soil and found the bacterium to have potential to degrade diesel fuel. Spini *et al*. (2018) also reported *Bacillus*, *Pseudomonas* and *Fusarium* species as candidates in the biodegradation of petroleum hydrocarbon. The isolation of these organisms from contaminated soil and water is, therefore, not surprising, and present the organisms as potential candidates in the biodegradation of petroleum hydrocarbon. Kumari *et al*. (2013) had reported that potential oil degraders are best isolated from oil contaminated sites.

CONCLUSION

Surface and drinking water sources as well as soil samples from Otu-Jeremi, Iwerehkan and Okpare communities in Ughelli South, Delta State, Nigeria are contaminated with both heavy metals, bacteria and fungi above FEPA and NSDWQ standards, making it unsuitable for drinking or as use for recreational activities. Also, there were considerable differences between these parameters during the dry and wet seasons. Efforts must, therefore, be made to remediate the already contaminated soil and water, as well as prevent further contamination of such water samples.

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Table 1: Impact of Petrochemical Activities on the Physicochemical Properties of Ground Water from Otu-Jeremi and Environs, Delta State Dry Season

Parameter	Unit	Control	Otu-Jeremi	Iwerehkan	Okpare	WHO Limit	NSDWQ Limit
Appearance	-	Clear	Clear	Clear	Clear	Clear	Clear
Odour	-	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless
pH	-	4.40^{a}	5.26 ± 0.31^{a,b}	5.58 ± 0.40^{a,b}	4.77 ± 0.40^{a,b}	6.5 – 8.5	6.5 – 8.5
Temperature	°C	26.8	26.6 ± 0.21	26.6 ± 0.35	26.9 ± 0.14	< 40	Ambient
EC	µS/cm	71.00	30.5 ± 4.95^{a}	86.5 ± 68.6	53.5 ± 19.1	NG	1000
TDS	mg/L	39.10	16.5 ± 3.53^{a}	48.0 ± 38.3	29.5 ± 10.5	1000	1000
Turbidity	NTU	0.04	0.11 ± 0.04	0.21 ± 0.08	0.12 ± 0.02	5.0	5.0
Colour	TCU	0.00	1.50 ± 0.71^{a}	1.00 ± 0.00^{a}	0.50 ± 0.71^{a}	15.0	15.0
DO	mg/L	9.20	8.65 ± 0.07	8.55 ± 0.35	7.70 ± 1.41	NG	NG
Hardness	mg/L	8.00	11.0 ± 1.41	11.5 ± 3.54	9.00 ± 1.41	500	150
Ammonia	mg/L	0.14	0.15 ± 0.01	0.17 ± 0.02	0.14 ± 0.03	NG	NG
BOD_5	mg/L	1.00	3.25 ± 0.50^{a}	2.20 ± 0.42^{a}	2.40 ± 0.28^{a}	NG	NG
COD	mg/L	7.67	9.54 ± 0.76	11.6 ± 4.91	11.0 ± 1.36	NG	NG
Chloride	mg/L	22.6	9.08 ± 5.32^{a}	30.8 ± 20.7	17.8 ± 9.67	250	250
Sulphate	mg/L	4.15	2.73 ± 1.72	8.45 ± 6.24	3.73 ± 0.15	250	100
Nitrate	mg/L	0.41	0.44 ± 0.01	0.50 ± 0.06	0.42 ± 0.07	20.0	50.0
Nitrite	mg/L	BDL	0.03 ± 0.01	0.02 ± 0.00	0.01 ± 0.00	3.0	0.2
Phosphate	mg/L	BDL	0.02 ± 0.00	0.01 0.00	BDL	NG	NG
Copper	mg/L	BDL	0.05 ± 0.06	0.06 ± 0.05	0.02 ± 0.02	2.0	1.0
Iron	mg/L	0.40	0.27 ± 0.06	0.39 ± 0.30	0.25 ± 0.01	1.0	0.3
Chromium	mg/L	BDL	0.02 ± 0.00	BDL	BDL	0.05	0.05
Zinc	mg/L	0.07	0.05 ± 0.01	0.15 ± 0.15	0.07 ± 0.02	5.0	3.0
Cadmium	mg/L	BDL	BDL	BDL	BDL	0.003	0.003
Nickel	mg/L	BDL	BDL	BDL	BDL	0.07	0.02
Lead	mg/L	BDL	BDL	BDL	BDL	0.01	0.01
Manganese	mg/L	BDL	0.11 ± 0.09^{a,b}	0.09 ± 0.1^{a}	0.14 ± 0.00^{a,b}	0.10	0.20
Mercury	mg/L	BDL	BDL	BDL	BDL	0.006	0.001

Key: BDL: Below Detection Limit; NG: No Guideline; NSDWQ: Nigerian Standard for Drinking Water Quality; DO: Dissolved Oxygen; BOD: Biochemical Oxygen Demand; COD: Chemical Oxygen Demand

Table 2: Impact of Petrochemical Activities on the Physicochemical Properties of Surface Water from Otu-Jeremi and Environs, Delta State Dry Season

Parameter	Unit	Control	Otu-Jeremi	Iwerehkan	Okpare	FEPA Limit
Appearance	-	Clear	Clear	Clear	Clear	Clear
Odour	-	Odourless	Odourless	Odourless	Odourless	Odourless
pH	-	4.76	$5.90 \pm 0.03^{a,b}$	6.62 ± 0.11^{a}	$5.99 \pm 0.13^{a,b}$	6.5 – 8.5
Temperature	°C	31.2	31.7 ± 0.99	31.1 ± 1.34	32.0 ± 0.78	40
EC	µS/cm	70.0	75.5 ± 33.2	36.0 ± 1.41^{a}	104 ± 74.3	NG
TDS	mg/L	38.5	42.3 ± 18.7	104 ± 118.5^{a}	56.9 ± 40.9	500
Turbidity	NTU	3.65^{b}	4.01 ± 0.30^{b}	3.28 ± 0.89^{b}	3.25 ± 0.89^{b}	1.0
Colour	TCU	10.0	9.50 ± 2.12	8.00 ± 1.41	8.50 ± 0.71	15.0
TSS	mg/L	2.28	1.29 ± 0.20	2.28 ± 0.56	2.04 ± 0.10	10
DO	mg/L	8.60	8.35 ± 0.21	8.45 ± 0.21	8.25 ± 0.07	> 7.5
Alkalinity	mg/L	12.0	21.0 ± 9.90	19.0 ± 4.24	25.0 ± 12.7	NG
Oil &Grease	mg/L	BDL	BDL	$0.06 \pm 0.00^{a,b}$	BDL	0.05
BOD_5	mg/L	4.50	9.15 ± 0.21^{a}	7.50 ± 0.42^{a}	8.25 ± 0.21^{a}	NG
COD	mg/L	23.47	32.5 ± 0.76	27.7 ± 3.02	24.3 ± 4.81	NG
Chloride	mg/L	23.00	25.5 ± 9.89	102 ± 9.00^{a}	36.2 ± 27.9	250
Sulphate	mg/L	4.15	9.30 ± 0.37	11.9 ± 9.77	10.8 ± 7.44	500
Copper	mg/L	0.05	0.05 ± 0.00	$0.19 \pm 0.01^{a,b}$	0.05 ± 0.02	0.1
Iron	mg/L	0.27	$2.77 \pm 0.67^{a,b}$	$1.79 \pm 0.11^{a,b}$	$1.87 \pm 0.23^{a,b}$	1.0
Chromium	mg/L	BDL	BDL	0.03 ± 0.00	0.01 ± 0.00	0.05
Zinc	mg/L	0.06	0.08 ± 0.01	0.28 ± 0.01	0.13 ± 0.04	5.0
Cadmium	mg/L	BDL	BDL	$0.02 \pm 0.00^{a,b}$	BDL	0.01
Nickel	mg/L	BDL	BDL	0.04 ± 0.00	BDL	0.05
Lead	mg/L	BDL	$0.10 \pm 0.01^{a,b}$	$0.09 \pm 0.04^{a,b}$	BDL	0.05
Manganese	mg/L	0.05	0.08 ± 0.08^{b}	0.14 ± 0.01^{b}	0.04 ± 0.00	0.05
Mercury	mg/L	BDL	BDL	BDL	BDL	0.01

Key: BDL: Below Detection Limit; NG: No Guideline; EC: Electrical Conductivity; TDS: Total Dissolved Solid; TSS: Total Suspended Solid; DO: Dissolved Oxygen; BOD: Biochemical Oxygen Demand; COD: Chemical Oxygen Demand; FEPA: Federal Environmental Protection Agency

Table 3: Impact of Petrochemical Activities on the Physicochemical Properties of Soil Samples during the Dry Season

Parameters	Unit	Otu-Jeremi 0-15cm	Otu-Jeremi 15-30cm	Iwerehkan 0-15cm	Iwerehkan 15-30cm	Okpare 0-15cm	Okpare 15-30cm	Control 0-15cm	Control 15-30cm
Texture	-	Si,L,S,C	Si,L,S,C	L,S,C,	L,S,C	Si,L,C	Si,L,C	L,S	L,S
pH	-	5.00 ± 0.3[b]	5.16 ± 0.4[b]	4.64 ± 0.3[a,b]	4.52 ± 0.3[a,b]	5.17 ± 0.23[b]	5.47 ± 0.7[b]	5.75[b]	5.44[b]
EC	μS/cm	332 ± 56.0	228 ± 55.0	138 ± 26.2[a]	126 ± 18.4[a]	156 ± 38.0[a]	44 ± 29.7[a]	354.0	211.0
TOC	%	2.73 ± 1.5[a]	2.05 ± 1.4[a]	2.83 ± 1.2[a]	2.29 ± 1.0[a]	3.61 ± 0.8[a]	3.27 ± 0.8[a]	1.17	0.78
Chloride	mg/kg	53.2 ± 25	51.4 ± 2.5[a]	30.1 ± 22.6[a]	40.8 ± 2.5	35.5 ± 35.1[a]	19.5 ± 17[a]	60.27	31.91
Sulphate	mg/kg	73.9 ± 17	54.0 ± 27	36.0 ± 31.9	51.6 ± 11	36.3 ± 30.6	21.3 ± 18	25.49	20.68
Total N	%	0.2 ± 0.07	0.2 ± 0.04	0.21 ± 0.10	0.2 ± 0.08	0.24 ± 0.07	0.2 ± 0.06	0.12	0.10
Total P	%	.003 ± 0.0	.007 ± 0.0	.004 ± 0.00	.003 ± 0.0	.003 ± 0.00	.003 ± 0.0	0.005	0.006
Oil&Grease	mg/kg	17.4 ± 12[a,b]	12.3 ± 9.6[a,b]	793 ± 12.5[a,b]	722 ± 28.0[a,b]	377 ± 174[a,b]	328 ± 148[a,b]	BDL	BDL
Ex. Acidity	Cmol/kg	1.35 ± 0.4	1.43 ± 0.3	1.53 ± 0.2	1.75 ± 0.1	0.85 ± 0.1	0.90 ± 0.1	0.40	0.55
Iron (Fe)	mg/Kg	5,095 ± 26[a,b]	4,073 ± 22[a,b]	2,130 ± 72	2,193 ± 41	1,864 ± 50	2,678 ± 22[a,b]	2,725[b]	1,980[b]
Chromium	mg/kg	3.77 ± 2.27	3.50 ± 0.66	4.25 ± 0.94	4.87 ± 0.2	2.88 ± 0.46	3.63 ± 0.6	2.84	2.21
Zinc	mg/kg	26.2 ± 2.57	24.6 ± 10.2	13.1 ± 7.0	15.4 ± 14	19.2 ± 5.6	10.7 ± 1.0	21.63	11.56
Cadmium	mg/kg	2.26 ± 0.6[a,b]	1.78 ± 0.5[a,b]	2.95 ± 0.2[a,b]	2.15 ± 1.0[a,b]	2.95 ± 2.6[a,b]	3.25 ± 1.2[a,b]	BDL	BDL
Nickel	mg/kg	7.0 ± 5.3[a]	7.0 ± 2.2[a]	11.9 ± 3.3[a]	9.9 ± 5.0[a]	5.1 ± 1.0[a]	5.6 ± 0.8[a]	2.58	1.01
Copper	mg/kg	8.9 ± 1.2[a]	8.8 ± 2.1[a]	12.1 ± 1.2[a]	11.4 ± 3.9[a]	8.1 ± 0.2[a]	7.9 ± 4.1[a]	4.73	3.20
Lead	mg/kg	9.6 ± 4.5[a]	10.9 ± 3.2[a]	11.3 ± 4.4[a]	9.1 ± 1.0[a]	9.0 ± 0.6[a]	7.2 ± 0.3[a]	2.48	4.00
Manganese	mg/kg	90.9 ± 21	79.9 ± 28	64.8 ± 38	65.5 ± 22	64.1 ± 11.7	59.2 ± 2.6	98.30	93.80
Mercury	mg/kg	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL

Key: BDL: Below Detection Limit; EC: Electrical Conductivity; TOC: Total Organic Carbon; Total N: Total Nitrogen; Total P: Total Phosphorus

Table 4: Impact of Petrochemical Activities on the Physicochemical Properties of Ground Water from Otu-Jeremi and Environs, Delta State Wet Season

Parameter	Unit	Control	Otu-Jeremi	Iwerehkan	Okpare	WHO Limit	NSDWQ Limit
Appearance	-	Clear	Clear	Clear	Clear	Clear	Clear
Odour	-	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless
pH	-	4.86^{b}	$5.25 \pm 0.11^{a,b}$	$5.17 \pm 0.06^{a,b}$	$6.08 \pm 1.00^{a,b}$	6.5 - 8.5	6.5 - 8.5
EC	μS/cm	30.00	30.5 ± 4.95	51.5 ± 0.71^{a}	46.0 ± 9.90	NG	1000
TDS	mg/L	15.10	16.0 ± 2.83	26.5 ± 0.71	24.0 ± 5.66	1000	500
Turbidity	NTU	0.08	0.07 ± 0.01	0.22 ± 0.04	0.10 ± 0.01	5.0	5.0
Temperature	°C	29.5	29.1 ± 1.20	28.9 ± 0.14	30.0 ± 0.07	< 40	Ambient
Colour	TCU	0.00	0.50 ± 0.71	0.00 ± 0.0	0.00 ± 0.0	15.0	15.0
DO	mg/L	6.5	6.20 ± 0.28	6.65 ± 0.50	6.75 ± 0.21	NG	NG
Hardness	mg/L	2.00	3.00 ± 1.41	3.00 ± 0.00	5.00 ± 0.00	500	150
Alkalinity	mg/L	8.00	5.00 ± 1.41	4.00 ± 0.00	4.00 ± 0.00	NG	NG
Ammonia	mg/L	0.02	BDL	0.02 ± 0.01	0.05 ± 0.03	NG	NG
BOD_5	mg/L	1.2	1.55 ± 0.07	2.05 ± 0.07	1.50 ± 0.00	NG	NG
COD	mg/L	5.33	7.47 ± 0.00	9.07 ± 0.76	6.94 ± 0.76	NG	NG
Chloride	mg/L	4.00	6.40 ± 0.85	11.2 ± 1.70	9.30 ± 1.84	250	250
Sulphate	mg/L	1.03	1.13 ± 0.28	2.12 ± 0.42	1.97 ± 0.49	250	100
Nitrate	mg/L	0.05	0.05 ± 0.02	0.05 ± 0.04	0.16 ± 0.01	20	50
Nitrite	mg/L	BDL	BDL	BDL	BDL	3.0	0.2
Phosphate	mg/L	BDL	BDL	BDL	BDL	NG	NG
Copper	mg/L	BDL	BDL	0.05 ± 0.01	BDL	2.0	1.0
Iron	mg/L	BDL	0.62 ± 0.14	1.87 ± 0.00	BDL	1.0	0.3
Chromium	mg/L	BDL	BDL	BDL	BDL	0.05	0.5
Zinc	mg/L	BDL	0.01 ± 0.00	0.09 ± 0.09	0.05 ± 0.01	5.0	3.0
Cadmium	mg/L	BDL	BDL	BDL	BDL	0.003	0.003
Nickel	mg/L	BDL	BDL	BDL	BDL	0.07	0.02
Lead	mg/L	BDL	BDL	BDL	BDL	0.1	0.2
Manganese	mg/L	BDL	0.03 ± 0.00	BDL	BDL	0.1	0.2
Mercury	mg/L	BDL	BDL	BDL	BDL	0.006	0.001

Key: BDL: Below Detection Limit; NG: No Guideline; NSDWQ: Nigerian Standard for Drinking Water Quality; EC: Electrical Conductivity; TDS: Total Dissolved Solid; DO: Dissolved Oxygen; BOD: Biochemical Oxygen Demand

Table 5: Impact of Petrochemical Activities on the Physicochemical Properties of Surface Water from Otu-Jeremi and Environs, Delta State Wet Season

Parameter	Unit	Control	Otu-Jeremi	Iwerehkan	Okpare	FEPA Limit
Appearance	-	Clear	Clear	Clear	Clear	Clear
Odour	-	Odourless	Odourless	Odourless	Odourless	Odourless
pH	-	4.76a	5.28 ± 0.05^{a,b}	5.20 ± 0.27^{a,b}	5.23 ± 0.05^{a,b}	6.5 – 8.5
Temperature	°C	31.2	29.3 ± 0.21	29.6 ± 0.00	29.9 ± 0.35	40
EC	µS/cm	30.0	40.5 ± 10.6	39.5 ± 9.19	31.0 ± 1.4	NG
TDS	mg/L	20.5	20.5 ± 4.95	20.0 ± 4.24	15.5 ± 0.71	500
Turbidity	NTU	3.65^{b}	3.70 ± 0.34^{b}	2.69 ± 0.76^{b}	2.57 ± 0.57^{b}	1.0
TSS	mg/L	1.00	1.01 ± 0.11	1.35 ± 0.19	1.47 ± 0.30	10
Colour	TCU	7.28	7.50 ± 2.12	5.50 ± 0.71	6.00 ± 0.00	15
DO	mg/L	8.60	8.15 ± 0.07	8.60 ± 0.28	8.20 ± 0.00	>7.5
BOD	mg/L	4.0	3.30 ± 0.42	4.35 ± 0.21	3.75 ± 0.21	NG
COD	mg/L	10.18	11.2 ± 0.75	14.4 ± 0.75	14.4 ± 0.75	NG
Oil&Grease	mg/L	BDL	0.34 ± 0.00^{a,b}	0.17 ± 0.02^{a,b}	BDL	0.05
Chloride	mg/L	23.19	8.25 ± 1.91	7.90 ± 1.84	6.05 ± 0.50	250
Sulphate	mg/L	1.25	1.72 ± 0.28	1.62 ± 0.28	1.23 ± 0.13	500
Copper	mg/L	BDL	BDL	0.10 ± 0.01^{a}	0.06 ± 0.04	0.1
Iron	mg/L	0.27	0.17 ± 0.00	0.43 ± 0.06	0.37 ± 0.28	1.0
Chromium	mg/L	BDL	BDL	BDL	BDL	0.05
Zinc	mg/L	BDL	BDL	0.10 ± 0.01	0.09 ± 0.00	5.0
Nickel	mg/L	BDL	0.51 ± 0.02^{a,b}	0.33 ± 0.06^{a,b}	BDL	0.05
Lead	mg/L	BDL	BDL	0.06 ± 0.01^{a,b}	BDL	0.05
Manganese	mg/L	BDL	BDL	BDL	BDL	0.05
Mercury	mg/L	BDL	BDL	BDL	BDL	0.001

Key: Below Detection Limit; FEPA: Federal Environmental Protection Agency; NG: No Guideline; EC: Electrical Conductivity; TDS: Total Dissolved Solid; TSS: Total Suspended Solid; DO: Dissolved Oxygen; BOD: Biochemical Oxygen Demand; COD: Chemical Oxygen Demand

Table 6: Impact of Petrochemical Activities on the Physicochemical Properties of Soil Samples Wet Season

		Otu-Jere.		Iwerehkan		Okpare		Control	
Parameters	**Unit**	**0-15cm**	**15-30cm**	**0-15cm**	**15-30cm**	**0-15cm**	**15-30cm**	**0-15cm**	**15-30cm**
Texture	-	Si,L,S,C	Si,L,S,C	L,S,C,	L,S,C	Si,L,C	Si,L,C	L,S	L,S
pH	-	4.58 ± 0.02[b]	4.67 ± 0.18[b]	5.12 ± 0.64[b]	5.31 ± 0.5[b]	4.55 ± 0.06[b]	4.58 ± 0.08[b]	5.58	5.53
EC	µS/cm	61.0 ± 9.90	62.5 ± 13.4	37.5 ± 6.36[a]	48.0 ± 28[a]	141 ± 55.2[a]	87.0 ± 2.83[a]	78.0	56.0
TOC	%	1.74 ± 0.32	1.57 ± 0.35	1.79 ± 1.27	1.67 ± 1.3	2.31 ± 0.21[a]	2.12 ± 0.17[a]	1.48	1.29
Chloride	mg/kg	38.18 ± 3.9	42.4 ± 15.2	25.14 ± 1.4	25.8 ± 9.6	55.0 ± 4.7[a]	40.5 ± 2.25	35.36	30.27
Sulphate	mg/kg	18.95 ± 3.8	15.5 ± 2.42	14.28 ± 2.5	15.2 ± 2.0	28.6 ± 0.81	17.12 ± 0.7	20.04	19.46
Total N	%	0.10 ± 0.00	0.12 ± 0.01	0.10 ± 0.02	0.09 ± 0.02	0.14 ± 0.01	0.11 ± 0.01	0.11	0.10
Total P	%	0.10 ± 0.00[a]	0.01 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.01 ± 0.00	0.01 ± 0.01	0.008	0.008
Oil & Grease	mg/kg	12.0 ± 1.61[a,b]	10.9 ± 6.46[a,b]	30.3 ± 17.8[a,b]	17.7 ± 6.46[a,b]	15.5 ± 0.00[a,b]	18.9 ± 1.62[a,b]	BDL	BDL
Exch. Acid.	Cmol/kg	1.35 ± 0.07[a]	1.20 ± 0.28[a]	1.35 ± 0.64[a]	1.55 ± 0.78[a]	1.85 ± 0.21[a]	1.70 ± 0.28[a]	0.70	0.80
Iron	mg/kg	2368 ± 825[b]	2071 ± 819[a,b]	1792 ± 132[b]	1966 ± 154[a,b]	3857 ± 472[b]	3647 ± 395[a,b]	2855.50	1177.50
Chromium	mg/kg	3.59 ± 1.20	2.91 ± 0.53	3.56 ± 0.93	2.55 ± 1.01	2.95 ± 0.08	2.45 ± 0.41	1.77	1.32
Zinc	mg/kg	13.6 ± 3.99	12.8 ± 3.86	14.7 ± 0.25	12.6 ± 0.80	14.2 ± 1.70	17.5 ± 3.44	16.39	18.93
Cadmium	mg/kg	1.08 ± 0.01[a,b]	2.10 ± 0.00[a,b]	0.99 ± 0.19[a,b]	1.27 ± 0.37[a,b]	2.09 ± 1.08[a,b]	1.90 ± 0.07[a,b]	BDL	BDL
Nickel	mg/kg	48.5 ± 3.57[a,b]	46.3 ± 6.36[a,b]	43.6 ± 0.53[a,b]	44.4 ± 7.18[a,b]	46.6 ± 16.9[a,b]	46.5 ± 4.60[a]	BDL	0.84
Copper	mg/kg	5.50 ± 1.56[a]	4.86 ± 2.06[a]	8.36 ± 1.39[a]	11.24 ± 1.4[a]	8.44 ± 1.16[a]	6.71 ± 1.99[a]	36.0	190.0
Lead	mg/kg	4.48 ± 1.72[a]	5.90 ± 4.10[a]	6.71 ± 2.24[a]	5.68 ± 4.66[a]	5.98 ± 1.59[a]	5.74 ± 1.05[a]	1.50	1.32
Manganese	mg/kg	17.9 ± 11.8[a]	9.93 ± 1.87[a]	19.9 ± 13.8[a]	19.6 ± 11.8[a]	32.3 ± 10.9[a]	38.8 ± 13.9[a]	71.40	53.70
Mercury	mg/kg	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL

Key: BDL: Below Detection Limit; Otu-Jere: Otu-Jeremi; EC: Electrical Conductivity; TOC: Total Organic Carbon; Total N: Total Nitrogen; Total P: Total Phosphorus; Exch. Acid.: Exchangeable Acidity

Table 7: Total heterotrophic bacterial counts obtained from surface water, ground water and soil samples from Otu-Jeremi Community and environ during the wet season

Sample	Dry Season	($x10^5$)	($x10^5$)		Wet Season	($x10^5$)	($x10^5$)	
Location	**SW (cfu/ml)**	**GW (cfu/ml)**	**0–15cm (cfu/g)**	**15–30cm (cfu/g)**	**SW (cfu/ml)**	**GW (cfu/ml)**	**0–15cm (cfu/g)**	**15–30cm (cfu/g)**
Otu-Jeremi	4.0 ± 1.40	18.5 ± 2.12	395.5 ± 135	9.5 ± 2.12	19.3 ± 8.41	74.0 ± 31.0	86.5 ± 30.4	74.0 ± 49.5
Iwerehkan	20.0 ± 2.13	0.00 ± 0.00	40.5 ± 10.6	9.0 ± 5.66	27.5 ± 9.19	16.5 ± 3.54	74.5 ± 10.61	68.0 ± 32.53
Okpare	60.0 ± 11.3	34.5 ± 7.78	1.5 ± 0.71	5.0 ± 5.66	3.0 ± 2.83	13.5 ± 6.36	12.1 ± 5.66	4.0 ± 1.02
Control	1.50 ± 0.71	0.0 0.00	51.0 ± 1.41	304 ± 135.8	5.1 ± 0.17	11.8 ± 2.31	92.0 ± 0.00	49.0 ± 13.40

Key: SW: Surface Water; GW: Ground Water

Table 8: Total fungal counts obtained from surface water, ground water and soil samples from Otu-Jeremi Community and environ during the wet season

Sample	Dry Season	($x10^3$)	($x10^3$)		Wet Season	($x10^3$)	($x10^3$)	
Location	**SW (cfu/ml)**	**GW (cfu/ml)**	**0–15cm (cfu/g)**	**15–30cm (cfu/g)**	**SW (cfu/ml)**	**GW (cfu/ml)**	**0–15cm (cfu/g)**	**15–30cm (cfu/g)**
Otu-Jeremi	20.5 ± 2.6	43.0 ± 14.1	4.3 ± 1.2	11.8 ± 3.33	12.3 ± 0.71	21.0 ± 3.4	33.3 ± 7.2	13.8 ± 4.3
Iwerehkan	15.0 ± 7.07	26.0 ± 16.9	7.1 ± 1.9	7.0 ± 0.00	4.1 ± 2.3	1.9 ± 0.31	23.8 ± 8.8	15.7 ± 9.1
Okpare	11.0 ± 1.4	1.0 ± 0.00	3.4 ± 0.01	4.2 ± 0.28	7.2 ± 3.6	9.8 ± 4.1	9.3 ± 3.21	14.4 ± 1.9
Control	25.5 ± 21.9	12. 3 ± 4.80	2.1 ± .061	1.8 ± 0.90	2.2 ± 0.9	2.2 ± 0.0	4.8 ± 1.7	3.2 ± 0.9

Key: SW: Surface Water; GW: Ground Wate