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ASSESSMENT OF SURFACE AND GROUND WATER QUALITY AROUND ARTISANAL REFINING OPERATION SITES IN OHAJI / EGBEMA LGA, IMO STATE

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Abstract

This study assessed the distribution of water quality for surface and groundwater samples collected within artisanal refining sites in Ohaji/Egbema local government area in Imo state. The sampling technique involved collecting ten groundwater and ten surface water samples around artisanal refining sites within the distances of 0-100m, 100-200m, 200-300m, 300-400m, 400-500m, Four control samples (two each for surface water and groundwater) were also collected at distances of over 10km from the refining sites. Some physicochemical parameters were analyzed, and water quality index were also calculated for difference distances based on measured physicochemical parameters and WHO standards using weighted arithmetic mean methods. The results revealed that the WQI for surface and groundwater samples and their control samples were 4.669, 4.585, 3.742, 3.730. 1.016, 0.2162 and 2.727, 2.672, 2.692, 1.860. 0.905, 0.212 respectively for distance ranges of 0-100m, 100-200m, 200-300m, 300-400m, 400-500m and control sample. The results revealed that surface water sources were more polluted than groundwater sources at all the sampled distance range. The results also revealed that WQI of both surface and groundwater samples decreases with an increase in distance away from the artisanal refining site which is an indication of improvement in water quality at distance farther from artisanal refining sites. However, both the surface and groundwater sources were unfit for drinking except for water sourced beyond 400-500m range and control samples. Therefore, it was concluded that that both ground and surface water sources within distances of less than 500 meters away from the artisanal refining operation are not fit for drinking and must be treated properly before drinking.

Keywords; Surface and groundwater, Water quality index, artisanal refining and Ohaji/Egbema LGA.

1. Introduction

The exploration of crude oil in the Niger Delta region has been analyzed using the resource curse theory and the Dutch disease, and these theories shows the economic, environmental, and social challenges it has brought to Nigeria. Aprioku (2018) argued that the discovery of oil in commercial quantities led to a shift in Nigeria's economic policies, making crude oil the backbone of the economy. However, this has also resulted in socio-economic problems, particularly for local communities that have turned to illicit activities such as oil theft, kidnapping of expatriates, and artisanal refining. Crude oil and gas from the Niger Delta contribute over 95% of Nigeria's export earnings and more than 80% of its total revenue (Adeoye 2018; Okoro 2018). However, this economic dependency has led to severe environmental degradation. The absence of corporate social responsibility and inadequate government intervention have driven local youth into illegal refining activities using crude and unsafe refining techniques and methods (Ajayi & Olutuase, 2020). These methods not only expose operators to risks but also result in poor-quality petroleum products and widespread pollution of land and water resources.

Nigeria struggles with refining its crude oil domestically due to the moribund state of its four state-owned refineries (Bodo, 2019). This deficiency has fueled the proliferation of illegal refineries, which, despite supplying petroleum products to the market, cause significant environmental damage. Reports indicate that these refineries produce PMS, diesel, and kerosene, but their operations heavily pollute the environment, with residues contaminating water bodies, soil, and air (Owei & Owei, 2018). The World Bank identifies soil and water pollution as a primary ecological concern in the region, with high concentrations of heavy metals, TPH, PAHs, and BTEX found in water and soil

The local refining of crude oil has become a lucrative but disturbing business in the Niger Delta region of Nigeria. Deep inside the forests of the Niger Delta camps are built and used for the local refining of crude oil. However, the activities of the 'local crude oil refiners' have severely hit the host communities by farmlands been destroyed and fishing settlements evacuated because of pollution of the rivers and estuaries, with loss of lives and properties (Agnew & Petersen, 2018). Recently the activities of illegal petroleum refining proliferated in the entire Niger Delta Region. Artisanal refining plants are common features of the Niger Delta Region. This is so because it has become a lucrative business providing means of livelihood to the youth of the Niger Delta region. Artisanal refining plant is a non-conventional refining plant setup which involves the use of drums and pipes fitted together and mounted on a heat source to heat or distil the crude inside the drum to a certain temperature to produce some petroleum products (Ajayi & Olutuase, 2020).

Ajayi and Olutuase (2020) described artisanal refining, known as "*Kpo-Fire*" by the locals, as a local way of distilling crude oil to get diesel, kerosene and PMS as refined product. Also "Kpo-Fire", in local parlance in the Niger Delta is a process of burning crude oil by non-state actors at isolated locations to extract refined petroleum products. It is simply a local process of extracting petroleum products by heating the crude in fabricated oven (Ajayi & Olutuase, 2020). Additionally, the amnesty program granted to former militants led to a situation where unemployed and non-violent youths resorted to illegal artisanal refining as a means of survival. Their crude refining methods, which involve boiling crude oil in metal drums, contribute to severe environmental pollution. The impact of these activities includes water and soil degradation, loss of biodiversity, and severe health risks for local communities dependent on these natural resources. There is no uniform procedure, specification in the facilities and quality of products from the artisanal refining camps. Ajayi and Olutuase (2020) contend that the quality of products from the artisanal refining camps do not meet the standard for public consumption, but there is a substantial demand that keep the trade active (Douglas, 2018). However, there is common knowledge that the procedure adopted by non-state actors to refine crude oil involves the heating of crude and collection of resultant fluid before cooling and condensation in tanks.

Bodo (2019) argued that the technology employed by the operators of artisanal refineries is simple and local distillery process to achieve refined products by subjecting the distilleries with crude oil content to heat from open fire. The refining process yields Petrol, Kerosene, and diesel. Materials deployed for the operation are indigenously constructed and acquired, including drilling machines, drums, Cotonou boats, pipes, firewood, crude oil, pumping machines, rubber hose, dried wood, storage facilities, among others (Boniface & Samuel, 2016). Bodo (2019) averred that the operators of the artisanal refineries rely on innate ingenuity without proper training and certification. However, Aprioku (2018) argues that the fund required to set up the artisanal refining camps cannot be provided by many of the locales which raises the question on the ownership of the refining camps. Boniface and Samuel (2016) argued that low capital is required to set up the artisanal refining camps when compared to the humongous investment required to establish modular refineries, however, many of the rural residents have been so impoverished by the destruction of the environment that provide a support system for the local economy and thus cannot fund the fabrication of the materials. Bodo (2019) argued that many of the artisanal refining camps are owned by business and political elites. The operation is conveniently and effectively managed by few personnel. It requires a low capital outlay to set up depending on the choice of processing capacity adopted or entrepreneurial capability. The refinery is simple, efficient, and cheap to set up. Its relatively low cost makes it an easy-going business for local private investors (Ogbuigwe, 2018). This is the situation of the Niger Delta region where over 20,000 artisanal refineries have been setup by private investors who take advantage of the cheap labour and availability of raw materials in the area (Ogbuigwe, 2018).

Hydrocarbon compounds are the main pollutants emitted by the petroleum industry, while other fuel combustion devices emit criteria pollutants [Oxides of Nitrogen (NOx), Carbon Monoxide (CO), Oxides of Sulphur (SO_X), Particulate Matter (PM) and Lead (Pb)] (Ogbuigwe, 2018). Obiefuna and Nwankwoala (2019) in their study unraveled that the flames which emanate from the process of artisanal refining of crude oil increases has the potential to contribute significantly to the carbon footprint with implication of temperature characteristics and the public health of communities close to the operation camps of the non-state actors. Bodo (2019) argued that the operation of artisanal refiners in the Niger Delta region could increase the concentration of heavy metals in surface and groundwater, compromise vegetal cover and deplete the luxuriant mangrove forest in the Niger Delta region. Previous studies have also reported that the enormous earning from oil theft and the operation of artisanal refineries have manifested in increasing dropouts from school, proliferation of arms and abuse of hard substances. Okoro (2018) reported that artisanal refining increased the number of school dropouts, cult rivalry, arms proliferation, among others. These activities also contribute to the contamination of water resources by the non-conventional refining plants. While there is a growing body of literature on the dialectics of artisanal refineries in the Niger Delta region, the case of Ohaji / Egbema communities is conspicuously unreported. Therefore, it has become imperative to carry out this study to assess the effect of artisanal refining activities particularly in water resources in Ohaji / Egbema localities.

2. Materials and Methods

2.1 Study Area

Ohaji / Egbema local government is in Imo state in the southeastern part of Nigeria see Figure 1 Preference for the study area is hinged on the flares of artisanal refining of crude which has assumed a deleterious manifestation and the implication for the environment, the local economy, livelihood and public health. Ohaji / Egbema is located on latitude 5.3138°N and longitude 6.8780°E. The community is one of the oil-producing communities in Imo state in the southern part of Nigeria. The population of Ohaji / Egbema is 254,200 as reported in the 2006 population census.

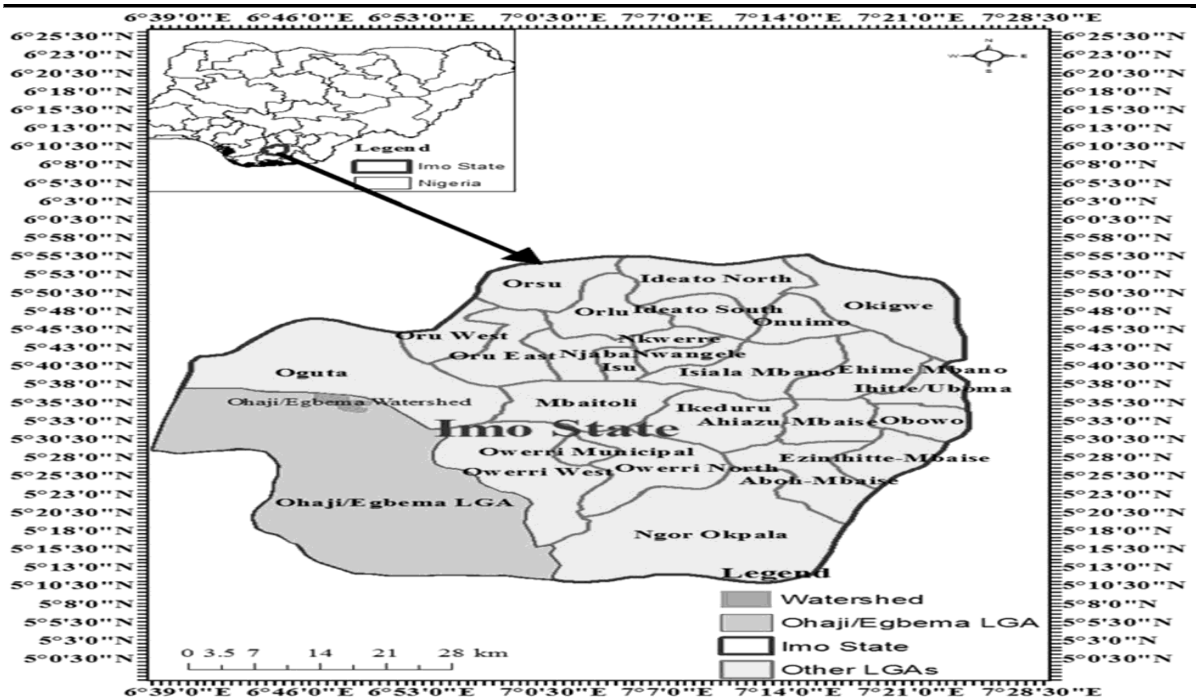

Figure 1: Imo State showing Ohaji / Egbema LGA, Okoro et al. (2021).

2.2 Sampling Techniques

The study deployed the multi-stage sampling technique for the study. In the first stage, areas notorious for artisanal refining were identified using lottery sampling techniques. This was achieved by listing all the affected local government areas (LGAs in Imo state involved in artisanal refining) and denoted them using alphabets. Thereafter, the alphabets were put in a lottery spin, from which the selected LGA was picked. After the selection of the areas, the polluted sites in the study area were identified to reflect places polluted through artisanal refining of crude oil and places polluted through oil spillage after the collection of crude oil to feed to refining camps. After that, a buffer zone of 500 meters radius was created around the artisanal refining sites for the study. This was done to assess environmental vulnerability, itemize the impacts of the refining activities and to take samples. Systematic sampling was adopted to collect surface and groundwater samples at different intervals from the polluted site to show variation. To collect the samples, an interval of 100 meters was calibrated using the distance decay principles. As such, 5 sample stations were determined for the water samples collections based on the 100meter intervals from the artisanal refining sites. In all, five stations were determined for sample collection in Ohaji / Egbema Imo State. To establish whether the water samples are as a result of pollution, a control site was established. This was done to eliminate the assumption that pollution within the artisanal site had occurred by chance and WHO standard limit was also used. Groundwater and surface water samples were collected at intervals of 0-100m, 100-200m, 200-300m, 300-400m and 400-500m from the polluted sites as well as the control. In this study, 10 surface water and 10 groundwater samples as well as 4 control samples (2 control samples for both surface water and groundwater) making a total of 24 samples were collected from the study area. These water samples were sent to the laboratories for analysis.

2.3 Collection of Water samples

The buffer area was graduated 100 meters and a total of 5 intervals were determined in the study area. In all five sample points (stations) were determined. Additionally, a control site was determined about 10 kilometers from the buffer zone. Surface water samples were collected from the water depth of 0-1 feet in rivers while groundwater samples were collected from water wells scattered across the area. Total water samples 12 surface water and 12 groundwater samples making a total of 24 water samples were obtained from the study area.

The water samples from the different surface and ground sources in the study area were collected in 2.5 L pre-treated Winchester bottles. Samples were collected and preserved at 0°C in a chest cooler filled with ice. Upon reaching the laboratory, the samples were transferred to a refrigerator till the time the various analytical procedure were performed on the samples (Wang et al., 2022). The preservation is to retard biological actions, retard hydrolysis of chemical compounds and complexes and to reduce the volatility of the constituents. To prevent contamination, all sampling materials and containers were sterilized and then rinsed with solution of the liquid to be sampled before sampling. Water samples were collected in brown glass bottles pre-washed with detergent, rinsed with water and pure acetone (99.9%) and then dried before samples collection. Samples were taken from 0.1m below the water surface and transported directly to an accredited laboratory in Port Harcourt. Various laboratory tests were performed on the samples collected in order to obtain the level of concentration physicochemical properties such as Phosphate, Sulphate, Nitrate as well as the volatile organic compound (BTEX) in the samples.

2.4 Calculation of Water Quality Index (WQI)

In this study, the water quality index was determined using the weighted Arithmetic water quality index method (Ukah et al 2020). The procedure for calculation of WQI based on this method is expressed as follows;

1. Calculation of weightage of the parameter Wi. The weightage parameter Wi = 1/Si, Where Wi is the unit weightage and Si the recommended standard for the parameter; in this study, the recommended standard is the WHO standards.
2. Calculate the quality rating for each of the parameters Qi. Individual quality rating is given by the expression Qi = Vi/Si, Where Qi is the sub index of the parameter, Vi is the monitored value of the parameter and Si the standard or permissible limit for the parameter.
3. Then WQI is computed using the following equation

$$\text{WQI} = \frac{\sum_{i=1}^{n} WiQi}{\sum_{i=1}^{n} Wi} \quad (1)$$

Decision criteria: WQI range of 0.00-0.25 is very good for drinking, 0.25-0.50 is good for drinking, 0.51-0.75 is fair while 0.76 and above is not good for drinking (Ukah et al 2020).

3. Results and Discussions

33.1 Physicochemical parameters of the surface and ground water samples and control

The results in Table 1 and Table 2 provide an assessment of the physicochemical properties of surface and groundwater in areas impacted by artisanal refining in Ohaji/Egbema. The variation in parameters across different distances highlights the extent of contamination and the potential impact on water quality. Surface water pH ranges from 5.6 to 7**,** while groundwater pH varies between 5.9 and 7.8. Temperature values remain relatively stable, between 25.5°C and 26.5°C for both surface and groundwater, indicating minimal thermal pollution. Surface water turbidity is highest at 0–100 m (13.5 NTU) and decreases with distance, reaching 7.3 NTU at 401–500 m**.** Groundwater follows a similar trend but with lower turbidity levels, indicating sedimentation and filtration as water percolates through soil layers. EC values are highest in surface water (1501.5 µS/cm at 0–100 m) and decrease with distance (1246 µS/cm at 401–500 m)**.** DO levels in surface water range from 3.5 mg/L to 6 mg/L, with lower values at closer distances, indicating oxygen depletion due to organic pollutants from oil contamination. BOD and COD levels follow a similar pattern, with surface water showing a maximum BOD of 4 mg/L and COD of 5.9 mg/L at certain points**,** suggesting organic matter degradation. Groundwater values are generally lower, indicating reduced organic pollution. Surface water has higher TDS levels than groundwater, with a peak of 1201.5 mg/L at 0–100 m, decreasing to 679.5 mg/L at 401–500 m**.** The high TDS values close to refining sites indicate contamination by dissolved pollutants from crude oil residues. Ammonia (NH_3) levels are highest at 0–100 m (2.5 mg/L) in surface water and decrease with distance, indicating contamination from petroleum waste. Groundwater follows a similar pattern but at lower concentrations. Nitrate (NO_3^-) concentrations range from 6.5 to 8.8 mg/L for both surface and groundwater, with no significant variations, suggesting agricultural or industrial contributions. Phosphate (PO_4^{3-}) levels are notably higher at 0–100 m (1.6 mg/L) and drop to 0.1 mg/L at 401–500 m, indicating a dilution effect over distance. Chloride (Cl^-) and sulfate (SO_4^{2-}) concentrations remain relatively high, with surface water Cl^- levels peaking at 459.6 mg/L and SO_4^{2-} at 681.5 mg/L, reflecting industrial contamination. Calcium carbonate ($CaCO_3$) values are relatively stable**,** ranging from 61.8 mg/L to 66.8 mg/L**,** with minor fluctuations between surface and groundwater. The concentrations of benzene, toluene, ethylbenzene, and xylenes (BTEX) in surface and groundwater at varying distances from artisanal refinery sites in Ohaji/Egbema are also presented in Table 1 and Table 2. The results reveal trends in BTEX pollution, with higher concentrations generally observed in surface water compared to groundwater. Surface water shows higher benzene concentrations (0.05 mg/L at 0–100m and 101–200m), which decline with distance, reaching 0.01 mg/L at 401–500m. Groundwater levels are consistently lower, starting at 0.03 mg/L and decreasing to 0.01 mg/L at 401–500m. Surface water has significantly higher toluene concentrations, ranging from 1.31 mg/L at 0–100m to 1.01 mg/L at 401–500m, indicating persistent contamination. Groundwater concentrations are much lower, peaking at 0.51 mg/L at 0–100m and dropping to 0.1 mg/L at 401–500m, showing reduced infiltration into deeper layers. Surface water ethylbenzene levels are generally low, with minor fluctuations (0.03 mg/L at 0–100m, dropping to 0.02 mg/L at most distances). Groundwater levels are significantly lower, with values remaining nearly constant at 0.011 mg/L before dropping to 0.001 mg/L at 301–500m. Surface water concentrations of m.p-xylene start at 0.91 mg/L at 0–100m and decline to 0.5 mg/L at 401–500m, while o-xylene starts at 1.01 mg/L and drops to 0.41 mg/L over the same distance. Groundwater levels are extremely low for both compounds, with most values near or below 0.01 mg/L, indicating minimal penetration

These results aligned with work of Linden and Palsson (2013) who carried out water quality assessment by testing the surface waters, drinking wells, sediment, and biota in Ogoni-land, area in the Niger Delta region which comprised of Eleme, Tai, Gokana, and Khana, and revealed that water samples from Eleme showed extremely high levels of the carcinogenic benzene. The results also aligned with work of Nwankwoala et al (2017) who carried out study to assess the impacts of crude oil pollution due to artisanal refining activities on soil and water quality in some parts of Okrika and Ogu-Bolo areas of Rivers State, Nigeria whose results revealed a high level of pollution in the water samples with respect to WHO recommended limits.

Table 1 Physicochemical properties surface water sampled from the areas and control sample in Ohaji / Egbema

Sn	Parameter	0-100m	101-200m	201-300m	301-400	401-500m	Control	WHO
1	pH	5.6	5.7	5.8	6	7	6.5	65-8.5
2	°C	26.5	25.5	25.5	26	26	26	30.00
3	Turbidity NTU)	13.5	9.5	7.9	7.9	7.3	2	5.0
4	EC (µS/cm)	1501.5	1465.6	1278.9	1264.5	1246	1203	1500
5	DO (mg/L)	3.5	3.5	4.9	6	5	7.1	7.5
6	TDS (mg/L)	1201.5	1195.5	1046.9	1033.8	679.5	428.3	500
7	BOD (mg/L)	3.5	2.5	2.9	4	2	2.1	5.0
8	COD (mg/L)	5.5	4.4	4.8	5.9	5	7.3	10.0
9	NH_3 (mg/L)	2.5	1.5	1.9	3	1	0.5	0.5
10	NO^{3}- (mg/L)	8.8	7.6	7.7	8.8	6.5	6.4	10.00
11	$PO4^{3-}$ (mg/L)	1.6	0.6	1	1	0.1	0.1	1.00
12	Cl^{-} (mg/L)	451.5	459.6	434	458.3	434.5	132.1	250
13	$CaCO_3$ (mg/L)	66.8	64.8	62.3	66.4	64.7	66.3	200
14	$SO4^{2-}$ (mg/L)	681.5	645.5	635.4	621.1	532.1	143.2	250
15	Benzene (mg/l)	0.05	0.05	0.04	0.04	0.01	0.002	0.01
16	Toluene (mg/l)	1.31	1.21	1.11	1.06	1.01	1	0.70
17	Ethylbenzene (mg/l)	0.03	0.02	0.02	0.02	0.1	0.01	0.30
18	m.p-Xylene (mg/l)	0.91	0.81	0.81	0.66	0.5	Trace	0.3
19	o-Xylene (mg/l)	1.01	1.01	1.01	0.61	0.41	0.01	0.3

Table 2 Physicochemical properties groundwater sampled from the study area and control in Ohaji / Egbema

Water	Parameter	0-100m	101-200m	201-300m	301-400	401-500m	Control	WHO
1	pH	5.9	6.8	6.8	6.8	7.8	6.4	65-8.5
2	°C	26.5	25.5	25.5	26	26	25	30.00
3	Turbidity (NTU	10.5	8.5	7.9	7.9	7.1	2	5.0
4	EC (µS/cm)	1237.5	1215.5	1210.9	1196.5	1189	1203	1500
5	DO (mg/L)	5.5	3.5	5.9	7	6	7.2	7.5
6	TDS (mg/L)	975.5	946.5	923.9	910.8	563.5	429.1	500
7	BOD (mg/L)	3.4	2.4	2.8	3.9	1.9	2.1	5.0
8	COD (mg/L)	4.8	3.8	4.5	5.6	5	7.3	10.0
9	NH_3 (mg/L)	2.4	1.4	1.8	2.9	0.9	0.5	0.5
10	NO^{3}- (mg/L)	8.6	7.6	7.6	8.7	6.5	6.3	10.00
11	$PO4^{3-}$ (mg/L)	1.6	0.6	1	1	0.1	0.1	1.00
12	Cl^{-} (mg/L)	415	414.01	410.01	434.21	431.45	130.4	250
13	$CaCO_3$ (mg/L)	64.7	63.7	61.8	65.9	64.5	66.1	200
14	$SO4^{2-}$ (mg/L)	640.5	633.6	620	605.7	445.4	143..2	250
15	Benzene (mg/l)	0.03	0.03	0.03	0.02	0.01	0.002	0.01
16	Toluene (mg/l)	0.51	0.51	0.31	0.2	0.1	1	0.70
17	Ethylbenzene (mg/l)	0.011	0.011	0.011	0.001	0.001	0.001	0.30
18	m.p-Xylene (mg/l)	0.011	0.011	0.01	0.001	0.001	Trace	0.3
19	o-Xylene (mg/l)	0.04	0.04	0.03	0.03	0.02	Trace	0.3

3.2 Water quality index of surface water sampled from study area at different distances as well as control sample

Table 3 present the water quality index of surface water sampled at different distance ranges artisanal refining sites and control sample. The results revealed that the WQI were 4.669, 4.585, 3.742, 3.730. 1.016 and 0.2162 for distance ranges of 0-100m, 100-200m, 200-300m, 300-400m, 400-500m and control sample. These results showed that there is decrease in the WQI with increase in distance away from the artisanal refining site which showed that the water quality improve with increase in distance away of the artisanal refining sites however based on the decision criteria presented in section 2.4, these results implies that the surface water within the entire sampled distance range of 0 to 500 meter from the artisanal refining sites are not good for drinking in Ohaji / Egbema because their WQI is greater than 0.75 threshold for drinking while only the control surface water sample is good for drinking because the WQI is within the 0.75 threshold to good drinking water. See appendix 1 for the calculation tables of the water quality index

Table 3. Summary of the water quality Index of surface water samples at different distance from study area and control

SN	Distance range (m)	Water Quality Index (WQI	Remark
1	0-100	4.669	Not good for drinking
2	100-200	4.585	Not good for drinking
3	200-300	3.742	Not good for drinking
4	300-400	3.730	Not good for drinking
5	400-500	1.016	Not good for drinking
6	Control	0.2160	Very good for drinking

These results aligned with the work of Nwankwoala et al (2017) carried out study to assess the impacts of crude oil pollution due to artisanal refining activities on soil and water quality in some parts of Okrika and Ogu-Bolo areas of Rivers State, Nigeria and their results showed a water Quality index rating greater than 1 which is an indication that the water is very bad. This study results also agreed with the works of Nduka and Orisakwe (2011) who carried out study to investigate the level of pollution due to crude oil contamination in Niger-delta Nigeria and their results revealed that the surface waters of the Delta and Rivers State were more contaminated than those at Bayelsa. These results agreed with the outcome of study by Yerima Kwaya et al., (2019) who carried out investigation on the groundwater quality of Maru town using the pollution indices and multivariate statistical approaches and the calculated water quality index was greater than 1 which consequently translates to high groundwater pollution in the area

3.3 Water quality index of groundwater samples at different distance from artisanal refining sites in Ohaji / Egbema

Table 4 and Figure 2 present the water quality index of groundwater samples collected at different distance ranges from artisanal refining sites and control sample. The results revealed that the WQI were 2.727, 2.672, 2.692, 1.860. 0.905 and 0.2120 for distance ranges of 0-100m, 100-200m, 200-300m, 300-400m, 400-500m and control sample. These results showed that there is decrease in the WQI of the groundwater samples with increase in distance away from the artisanal refining site which showed that the water quality improve with increase in distance away of the artisanal refining sites however based on the decision criteria presented in section 2.4, these results implies that the groundwater within the entire sampled distance range of 0 to 500 meter from the artisanal refining sites are not good for drinking in Ohaji / Egbema because their WQI is greater than 0.75 threshold for drinking while only the control surface water sample is good for drinking because the WQI is within the 0.75 threshold to good drinking water see appendix 2 for the WQI calculation tables

Table 4. Summary of the water quality Index of groundwater samples at different distance from study area and control

SN	Distance range (m)	Water Quality Index (WQI	Remark
1	0-100	2.727	Not good for drinking
2	100-200	2.672	Not good for drinking
3	200-300	2.692	Not good for drinking
4	300-400	1.860	Not good for drinking
5	400-500	0.905	Not good for drinking
6	Control	0.2120	Very good for drinking

These results aligned with the work of Nwankwoala et al (2017) carried out study to assess the impacts of crude oil pollution due to artisanal refining activities on soil and water quality in some parts of Okrika and Ogu-Bolo areas of Rivers State, Nigeria and their results showed a water Quality index rating greater than 1 which is an indication that the water is very bad. This study results also agreed with the works of Nduka and Orisakwe (2011) who carried out study to investigate the level of pollution due to crude oil contamination in Niger-delta Nigeria and their results revealed that the surface waters of the Delta and Rivers State were more contaminated than those at Bayelsa. These results agreed with the outcome of study by Yerima Kwaya et al., (2019) who carried out investigation on the groundwater quality of Maru town using the pollution indices and multivariate statistical approaches and the calculated water quality index was greater than 1 which consequently translates to high groundwater pollution in the area

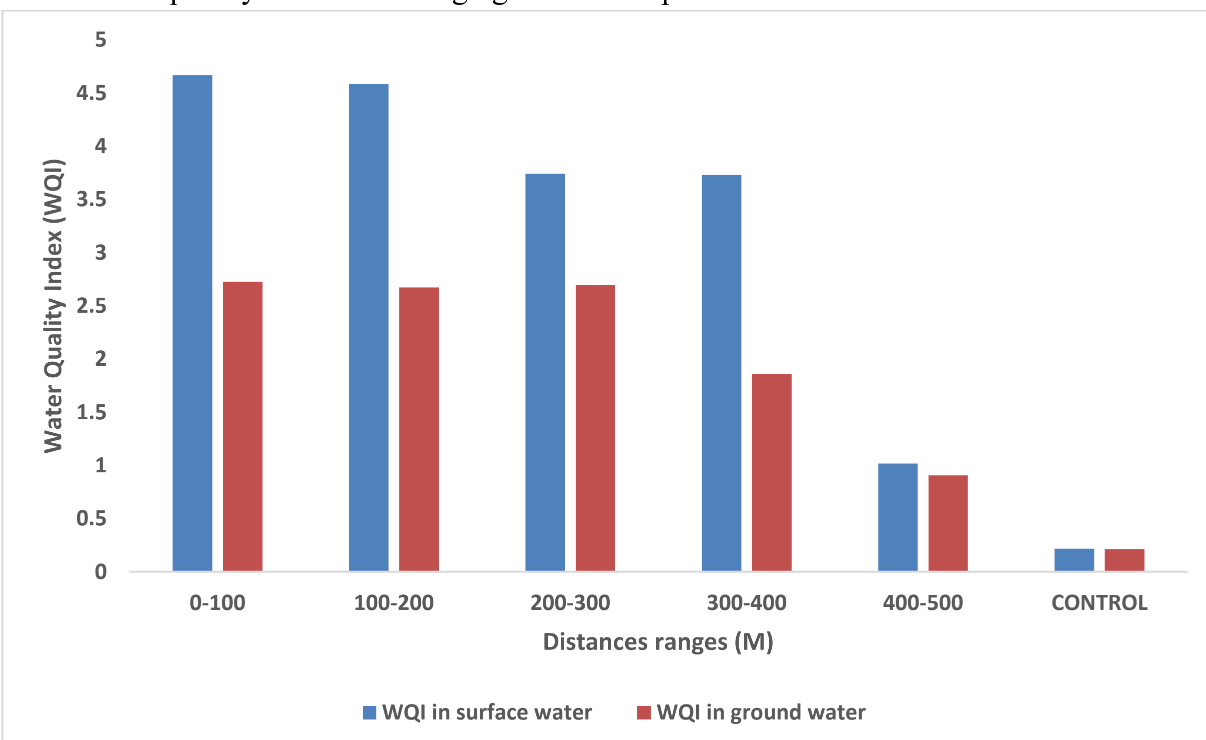

Figure 2 Water quality index and distances ranges for surface and groundwater from artisanal refining sites in Ohaji / Egbema

4.0 Conclusions

From on the results of the contaminations level and water quality index of surface and groundwater around area polluted by activities of artisanal refining activities in Ohaji / Egbema LGA in Imo state, it was concluded that there is high level of contamination in both groundwater and surface water resources around areas within 500 meters from artisanal refining sites. Hence, areas below 500m away from the artisanal refining site could be considered as hot zone to surface and groundwater pollutions. It was also concluded that both ground and surface water resources at distances of less than 500 meters away from the artisanal refining operation are not good for drinking and must be treated properly before drinking. Finally, it was concluded that surface water was more polluted than groundwater samples based on both the concentration of the contaminant and the water quality index. This suggests that groundwater sources are safer than surface water sources.

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Appendix 1. Water quality index calculation table for surface water sample and control sample

Table A. Water quality index of surface water at distance range of 0-100m from polluted site in Ohaji / Egbema

Sn	Parameter	Concentration	WHO Standard	W_1	Q_1	W_1Q_1
1	pH	5.60	8.5	0.118	0.659	0.078
2	°C	26.50	30.00	0.033	0.883	0.029
3	Turbidity NTU)	13.50	5.00	0.200	2.70	0.54
4	EC (µS/cm)	1501.5	1500	0.0007	1.00	0.0007
5	DO (mg/L)	3.50	7.50	0.133	0.467	0.062
6	TDS (mg/L)	1201.5	500	0.002	2.40	0.0048
7	BOD (mg/L)	3.50	5.00	0.200	0.70	0.14
8	COD (mg/L)	5.50	10.00	0.100	0.55	0.055
9	NH_3 (mg/L)	2.50	0.50	2.00	5.00	10.00
10	NO^{3}- (mg/L)	8.80	10.00	0.100	0.80	0.080
11	$PO4^{3-}$ (mg/L)	1.60	1.00	1.00	1,60	1.60
12	Cl^{-} (mg/L)	451.5	250	0.004	1.80	0.0072
13	$CaCO_3$ (mg/L)	66.80	200	0.005	0.327	0.00164
14	$SO4^{2-}$ (mg/L)	681.5	250	0.004	2.72	0.011
15	Benzene (mg/l)	0.05	0.01	100	5.00	500
16	Toluene (mg/l)	1.31	0.70	1.40	1.871	2.62
17	Ethylbenzene (mg/l)	0.03	0.30	3.33	0.10	0.33
18	m.p-Xylene (mg/l)	0.91	0.30	3.33	3.03	10.10
19	o-Xylene (mg/l)	1.01	0.30	3.33	3..37	11.23
				114.96		536.827

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$$WQI = \frac{\sum \boldsymbol{W_1 Q_1}}{\sum \boldsymbol{W_1}}$$

$$WQI = \frac{536.827}{114.96} \qquad = 4.669$$

Table B. Water quality index of surface water at distance range of 100-200m from polluted site in Ohaji / Egbema

Sn	Parameter	Concentration	WHO Standard	W_1	Q_1	W_1Q_1
1	pH	5.70	8.5	0.118	0.682	0.079
2	°C	25.5	30.00	0.033	0.850	0.0280
3	Turbidity NTU)	9.50	5.00	0.200	1.90	0.380
4	EC (µS/cm)	1465.6	1500	0.0007	1.00	0.0068
5	DO (mg/L)	3.50	7.50	0.133	0.40	0.0621
6	TDS (mg/L)	1195.5	500	0.002	2.39	0.048
7	BOD (mg/L)	2.50	5.00	0.200	0.50	0.10
8	COD (mg/L)	4.40	10.00	0.100	0.44	0.044
9	NH_3 (mg/L)	1.50	0.50	2.00	3.00	6.00
10	NO^3- (mg/L)	7.60	10.00	0.100	0.76	0.076
11	$PO4^{3-}$ (mg/L)	0.60	1.00	1.00	0.60	0.60
12	Cl^- (mg/L)	459.6	250	0.004	1.84	0.074
13	$CaCO_3$ (mg/L)	64.80	200	0.005	0.324	0.0061
14	$SO4^{2-}$ (mg/L)	645.5	250	0.004	1.78	0.007
15	Benzene (mg/l)	0.05	0.01	100	5.00	500
16	Toluene (mg/l)	1.21	0.70	1.40	1.714	2.40
17	Ethylbenzene (mg/l)	0.02	0.30	3.33	0.066	0.222
18	m.p-Xylene (mg/l)	0.81	0.30	2.667	2.70	7.201
19	o-Xylene (mg/l)	1.01	0.30	3.33	3.33	9.99
				114.96		425.3727

$$WQI = \frac{\sum \boldsymbol{W_1 Q_1}}{\sum \boldsymbol{W_1}}$$

$$WQI = \frac{527.1739}{114.96} \qquad = 4.585$$

Table C. Water quality index of surface water at distance range of 200-300m from polluted site in Ohaji / Egbema

Sn	Parameter	Concentration	WHO Standard	W_1	Q_1	W_1Q_1
1	pH	5.80	8.5	0.118	0.682	0.081
2	°C	25.5	30.00	0.033	0.85	0.028
3	Turbidity NTU)	7.90	5.00	0.200	1.58	0.316
4	EC (µS/cm)	1278.9	1500	0.0007	0.852	0.00060
5	DO (mg/L)	4.90	7.50	0.133	0.653	0.086
6	TDS (mg/L)	1046.9	500	0.002	2.090	0.0042

7	BOD (mg/L)	2.90	5.00	0.200	0.58	0.116
8	COD (mg/L)	4.80	10.00	0.100	0.48	0.048
9	NH_3 (mg/L)	1.90	0.50	2.00	3,8	7.60
10	NO^{3}- (mg/L)	7.70	10.00	0.100	0.77	0.077
11	$PO4^{3-}$ (mg/L)	1.00	1.00	1.00	1.00	1.00
12	Cl^{-} (mg/L)	434	250	0.004	1.74	0.003
13	$CaCO_3$ (mg/L)	62.3	200	0.005	0.307	0.00154
14	$SO4^{2-}$ (mg/L)	635.4	250	0.004	2.54	0.0102
15	Benzene (mg/l)	0.04	0.01	100	4.00	400
16	Toluene (mg/l)	1.11	0.70	1.40	1.57	2.22
17	Ethylbenzene (mg/l)	0.02	0.30	3.33	0.066	0.22
18	m.p-Xylene (mg/l)	0.81	0.30	2.667	2.7	7.201
19	o-Xylene (mg/l)	1.01	0.30	3.33	3.367	11.211
				114.96		322.795

$WQI = \frac{\sum \boldsymbol{W_1 Q_1}}{\sum \boldsymbol{W_1}}$

$WQI = \frac{430.226}{114.96}$ = 3.742

Table D. Water quality index of surface water at distance range of 300-400m from polluted site in Ohaji / Egbema

Sn	Parameter	Concentration	WHO Standard	W_1	Q_1	W_1Q_1
1	Ph	6.00	8.5	0.118	0.706	0.083
2	°C	26.00	30.00	0.033	0.867	0.0287
3	Turbidity NTU)	7.9	5.00	0.200	1.58	0.316
4	EC (µS/cm)	1264.5	1500	0.0007	0.841	0.00060
5	DO (mg/L)	6.00	7.50	0.133	0.800	0.106
6	TDS (mg/L)	1033.8	500	0.002	2.062	0.0042
7	BOD (mg/L)	4.00	5.00	0.200	0.80	0.18
8	COD (mg/L)	5.90	10.00	0.100	0.59	0.059
9	NH_3 (mg/L)	3.00	0.50	2.00	6.00	12.00
10	NO^{3}- (mg/L)	8.80	10.00	0.100	0.68	0.068
11	$PO4^{3-}$ (mg/L)	1.00	1.00	1.00	1.00	1.00
12	Cl^{-} (mg/L)	458.3	250	0.004	1.83	0.007
13	$CaCO_3$ (mg/L)	66.4	200	0.005	0.33	0.00165
14	$SO4^{2-}$ (mg/L)	621.1	250	0.004	2.48	0.0102
15	Benzene (mg/l)	0.04	0.01	100	4.00	400
16	Toluene (mg/l)	1.06	0.70	1.40	1.54	2.12
17	Ethylbenzene (mg/l)	0.02	0.30	3.33	0.067	0.222
18	m.p-Xylene (mg/l)	0.66	0.30	2.667	2.20	5.867
19	o-Xylene (mg/l)	0.61	0.30	3.33	2.033	6.769
				114.96		318.959

$WQI = \frac{\sum \boldsymbol{W_1 Q_1}}{\sum \boldsymbol{W_1}}$

$WQI = \frac{428.847}{114.96}$ = 3.730

Table E. Water quality index of surface water at distance range of 400-500m from polluted site in Ohaji / Egbema

Sn	Parameter	Concentration	WHO Standard	W_1	Q_1	W_1Q_1
1	pH	7.00	8.5	0.118	0.823	0.084
2	°C	26	30.00	0.033	0.866	0.0286
3	Turbidity NTU)	7.3	5.00	0.200	1.46	0.292
4	EC (μS/cm)	1246	1500	0.0007	0.831	0.00060
5	DO (mg/L)	5	7.50	0.133	0.667	0.071
6	TDS (mg/L)	679.5	500	0.002	1.359	0.0027
7	BOD (mg/L)	2	5.00	0.200	0.40	0.080
8	COD (mg/L)	5	10.00	0.100	0.50	0.05
9	NH_3 (mg/L)	1	0.50	2.00	2.00	4.00
10	NO^{3}- (mg/L)	6.5	10.00	0.100	0.65	0.065
11	$PO4^{3-}$ (mg/L)	0.1	1.00	1.00	0.10	0.1
12	Cl^{-} (mg/L)	434.5	250	0.004	1.74	0.006
13	$CaCO_3$ (mg/L)	64.7	200	0.005	0.322	0.00154
14	$SO4^{2-}$ (mg/L)	532.1	250	0.004	2.128	0.0085
15	Benzene (mg/l)	0.01	0.01	100	1.00	100
16	Toluene (mg/l)	1.01	0.70	1.40	1.44	2.02
17	Ethylbenzene (mg/l)	0.1	0.30	3.33	0.33	1.11
18	m.p-Xylene (mg/l)	0.5	0.30	2.667	1.667	4.445
19	o-Xylene (mg/l)	0.41	0.30	3.33	1.367	4.551
				114.96		116.847

$WQI = \frac{\sum W_1 Q_1}{\sum W_1}$

$WQI = \frac{116.847}{114.96}$ = 1.016

Table F Water quality index of surface water control sample for Ohaji / Egbema

Sn	Parameter	Concentration	WHO Standard	W_1	Q_1	W_1Q_1
1	pH	6.50	8.5	0.118	0.765	0.092
2	°C	26.00	30.00	0.033	0.866	0.0275
3	Turbidity NTU)	2.00	5.00	0.200	0.40	0.08
4	EC (µS/cm)	1203	1500	0.0007	0.802	0.0005
5	DO (mg/L)	7.10	7.50	0.133	0.987	0.121
6	TDS (mg/L)	428.3	500	0.002	0.874	0.001
7	BOD (mg/L)	2.10	5.00	0.200	0.42	0.084
8	COD (mg/L)	7.30	10.00	0.100	0.73	0.073
9	NH_3 (mg/L)	0.50	0.50	2.00	1.00	2.00
10	NO^{3}- (mg/L)	6.40	10.00	0.100	0.64	0.064
11	$PO4^{3-}$ (mg/L)	0.10	1.00	1.00	0.10	0.1
12	Cl^- (mg/L)	132.1	250	0.004	0.528	0.002
13	$CaCO_3$ (mg/L)	66.30	200	0.005	0.322	0.00167
14	$SO4^{2-}$ (mg/L)	143.2	250	0.004	0.573	0.002
15	Benzene (mg/l)	0.002	0.01	100	0.20	20
16	Toluene (mg/l)	1.00	0.70	1.40	1.52	2.000
17	Ethylbenzene (mg/l)	0.01	0.30	3.33	0.033	0.111
18	m.p-Xylene (mg/l)	0.00	0.30	2.667	0.00	0.00
19	o-Xylene (mg/l)	0.01	0.30	3.33	0.033	0.111
				114.96		24.8675

$$WQI = \frac{\sum W_1Q_1}{\sum W_1}$$

$$WQI = \frac{24.8575}{114.96} = 0.2162$$

Appendix 2. Water quality index calculation table for groundwater sample and control sample

Table G. Water quality index of groundwater at distance range of 0-100m from polluted site in Emohua Ohaji / Egbema

Sn	Parameter	Concentration	WHO Standard	W_1	Q_1	W_1Q_1
1	pH	5.90	8.5	0.118	0,694	0.082
2	°C	26.50	30.00	0.033	0.833	0.027
3	Turbidity NTU)	10.50	5.00	0.200	2.1	0.42
4	EC (µS/cm)	1237.5	1500	0.0007	0.824	0.0005
5	DO (mg/L)	5.50	7.50	0.133	0.733	0.097
6	TDS (mg/L)	975.5	500	0.002	1.948	0.0048

7	BOD (mg/L)	3.40	5.00	0.200	0.68	0.008
8	COD (mg/L)	4.80	10.00	0.100	0.48	0.048
9	NH_3 (mg/L)	2.40	0.50	2.00	4,80	9.60
10	NO^3- (mg/L)	8.60	10.00	0.100	0.86	0.086
11	$PO4^{3-}$ (mg/L)	1.60	1.00	1.00	1.60	1.60
12	Cl^- (mg/L)	415	250	0.004	1.66	0.0066
13	$CaCO_3$ (mg/L)	64.7	200	0.005	0.316	0.00165
14	$SO4^{2-}$ (mg/L)	640.5	250	0.004	2.556	0.011
15	Benzene (mg/l)	0.03	0.01	100	3.00	300
16	Toluene (mg/l)	0.51	0.70	1.40	0.728	1.02
17	Ethylbenzene (mg/l)	0.011	0.30	3.33	0.036	0.122
18	m.p-Xylene (mg/l)	0.011	0.30	3.33	0.036	0.122
19	o-Xylene (mg/l)	0.04	0.30	3.33	0.133	0.444
				114.96		313.569

$$WQI = \frac{\sum W_1 Q_1}{\sum W_1}$$

$$WQI = \frac{313.569}{114.96} = 2.727$$

Table H. Water quality index of groundwater at distance range of 100-200m from polluted site in Ohaji / Egbema

Sn	Parameter	Concentration	WHO Standard	W_1	Q_1	W_1Q_1
1	pH	6.8	8.5	0.118	0,80	0.094
2	°C	25.5	30.00	0.033	0.833	0.027
3	Turbidity NTU)	8.5	5.00	0.200	1.70	0.340
4	EC (µS/cm)	1215.5	1500	0.0007	0.824	0.0005
5	DO (mg/L)	3.5	7.50	0.133	0.466	0.06
6	TDS (mg/L)	946.5	500	0.002	1.948	0.0048
7	BOD (mg/L)	2.4	5.00	0.200	0.40	0.008
8	COD (mg/L)	3.8	10.00	0.100	0.38	0.038
9	NH_3 (mg/L)	1.4	0.50	2.00	2.80	5.60
10	NO^3- (mg/L)	7.6	10.00	0.100	0.760	0.076
11	$PO4^{3-}$ (mg/L)	0.6	1.00	1.00	0.60	0.60
12	Cl^- (mg/L)	414.01	250	0.004	1.66	0.0066
13	$CaCO_3$ (mg/L)	63.7	200	0.005	0.316	0.00165
14	$SO4^{2-}$ (mg/L)	633.6	250	0.004	2.532	0.011
15	Benzene (mg/l)	0.03	0.01	100	3.00	300
16	Toluene (mg/l)	0.51	0.70	1.40	0.714	1.02
17	Ethylbenzene (mg/l)	0.011	0.30	3.33	0.036	0.122
18	m.p-Xylene (mg/l)	0.011	0.30	3.33	0.036	0.122
19	o-Xylene (mg/l)	0.04	0.30	3.33	0.133	0.444
				114.96		307.199

$$WQI = \frac{\sum \boldsymbol{W_1 Q_1}}{\sum \boldsymbol{W_1}}$$

$$WQI = \frac{307.911}{114.96} = 2.672$$

Table I. Water quality index of groundwater at distance range of 200-300m from polluted site in Ohaji / Egbema

Sn	Parameter	Concentration	WHO Standard	W_1	Q_1	W_1Q_1
1	pH	6.8	8.5	0.118	0,80	0.094
2	°C	25.5	30.00	0.033	0.833	0.027
3	Turbidity NTU)	7.9	5.00	0.200	1.60	0.320
4	EC (µS/cm)	1210.9	1500	0.0007	0.824	0.0005
5	DO (mg/L)	5.9	7.50	0.133	0.786	0.104
6	TDS (mg/L)	923.9	500	0.002	1.948	0.0036
7	BOD (mg/L)	2.8	5.00	0.200	0.56	0.112
8	COD (mg/L)	4.5	10.00	0.100	0.48	0.038
9	NH_3 (mg/L)	1.8	0.50	2.00	3.60	7.20
10	NO^3- (mg/L)	7.6	10.00	0.100	0.710	0.071
11	$PO4^{3-}$ (mg/L)	1.00	1.00	1.00	1.00	1.00
12	Cl^- (mg/L)	410.01	250	0.004	1.66	0.0066
13	$CaCO_3$ (mg/L)	61.8	200	0.005	0.316	0.00165
14	$SO4^{2-}$ (mg/L)	620	250	0.004	2.532	0.011
15	Benzene (mg/l)	0.03	0.01	100	3.00	300
16	Toluene (mg/l)	0.31	0.70	1.40	0.158	0.222
17	Ethylbenzene (mg/l)	0.011	0.30	3.33	0.003	0.122
18	m.p-Xylene (mg/l)	0.01	0.30	3.33	0.033	0.111
19	o-Xylene (mg/l)	0.03	0.30	3.33	0.1	0.333
				114.96		309.456

$$WQI = \frac{\sum \boldsymbol{W_1 Q_1}}{\sum \boldsymbol{W_1}}$$

$$WQI = \frac{309.456}{114.96} = 2.692$$

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Table J. Water quality index of groundwater at distance range of 300-400m from polluted site in Ohaji / Egbema

Sn	Parameter	Concentration	WHO Standard	W_1	Q_1	W_1Q_1
1	pH	6.8	8.5	0.118	0,916	0.108
2	°C	26	30.00	0.033	0.833	0.027
3	Turbidity NTU)	7.9	5.00	0.200	1.40	0.280
4	EC (µS/cm)	1196.5	1500	0.0007	0.796	0.0005
5	DO (mg/L)	7	7.50	0.133	0.666	0.088
6	TDS (mg/L)	910.8	500	0.002	1.888	0.0036
7	BOD (mg/L)	3.9	5.00	0.200	0.78	0.176
8	COD (mg/L)	5.6	10.00	0.100	0.56	0.058
9	NH_3 (mg/L)	2.9	0.50	2.00	5.80	11.60
10	NO^{3}- (mg/L)	8.7	10.00	0.100	0.670	0.067
11	$PO4^{3-}$ (mg/L)	1	1.00	1.00	1.00	1.00
12	Cl^{-} (mg/L)	434.21	250	0.004	1.736	0.0069
13	$CaCO_3$ (mg/L)	65.9	200	0.005	0.319	0.00159
14	$SO4^{2-}$ (mg/L)	605.7	250	0.004	2.532	0.011
15	Benzene (mg/l)	0.02	0.01	100	2.00	200
16	Toluene (mg/l)	0.20	0.70	1.40	0.14	0.196
17	Ethylbenzene (mg/l)	0.001	0.30	3.33	0.0033	0.0111
18	m.p-Xylene (mg/l)	0.001	0.30	3.33	0.0033	0.011
19	o-Xylene (mg/l)	0.03	0.30	3.33	0.10	0.333
				114.96		213.828

$$WQI = \frac{\sum W_1Q_1}{\sum W_1}$$

$$WQI = \frac{213.828}{114.96} \quad = 1.860$$

Table K Water quality index of groundwater at distance range of 400-500m from polluted site in Ohaji / Egbema

Sn	Parameter	Concentration	WHO Standard	W_1	Q_1	W_1Q_1
1	pH	7.8	8.5	0.118	0,916	0.108
2	°C	26	30.00	0.033	0.833	0.027
3	Turbidity NTU)	7.1	5.00	0.200	1.56	0.312
4	EC (µS/cm)	1189	1500	0.0007	0.793	0.0005
5	DO (mg/L)	6	7.50	0.133	0.800	0.106
6	TDS (mg/L)	563.5	500	0.002	1.126	0.002
7	BOD (mg/L)	1.9	5.00	0.200	0.38	0.076
8	COD (mg/L)	5	10.00	0.100	0.50	0.05
9	NH_3 (mg/L)	0.9	0.50	2.00	1,80	3.60
10	NO^3- (mg/L)	6.5	10.00	0.100	0.650	0.067
11	$PO4^{3-}$ (mg/L)	0.1	1.00	1.00	0.10	0.10
12	Cl^- (mg/L)	431.45	250	0.004	1.736	0.0069
13	$CaCO_3$ (mg/L)	64.5	200	0.005	0.325	0.00169
14	$SO4^{2-}$ (mg/L)	445.4	250	0.004	2.532	0.011
15	Benzene (mg/l)	0.01	0.01	100	1.00	100
16	Toluene (mg/l)	0.1	0.70	1.40	0.14	0.200
17	Ethylbenzene (mg/l)	0.001	0.30	3.33	0.003	0.011
18	m.p-Xylene (mg/l)	0.001	0.30	3.33	0.003	0.011
19	o-Xylene (mg/l)	0.02	0.30	3.33	0.067	0.223
				114.96		104.143

$$WQI = \frac{\sum W_1Q_1}{\sum W_1}$$

$$WQI = \frac{104.143}{114.96} \quad = 0.905$$

Table L. Water quality index of groundwater control water sample for Ohaji / Egbema

Sn	Parameter	Concentration	WHO Standard	W_1	Q_1	W_1Q_1
1	pH	6.4	8.5	0.118	0.776	0.092
2	°C	25	30.00	0.033	0.833	0.0275
3	Turbidity NTU)	2	5.00	0.200	0.40	0.080
4	EC (µS/cm)	1203	1500	0.0007	0.831	0.0005
5	DO (mg/L)	7.2	7.50	0.133	0.987	0.131
6	TDS (mg/L)	429.1	500	0.002	0.874	0.001
7	BOD (mg/L)	2.1	5.00	0.200	0.42	0.084
8	COD (mg/L)	7.3	10.00	0.100	0.73	0.073
9	NH_3 (mg/L)	0.5	0.50	2.00	1.00	2.00
10	NO^3- (mg/L)	6.3	10.00	0.100	0.64	0.065
11	$PO4^{3-}$ (mg/L)	0.1	1.00	1.00	0.10	0.1
12	Cl^- (mg/L)	130.4	250	0.004	1.74	0.006
13	$CaCO_3$ (mg/L)	66.1	200	0.005	0.322	0.00154
14	$SO4^{2-}$ (mg/L)	143..2	250	0.004	2.48	0.0102
15	Benzene (mg/l)	0.002	0.01	100	0.2	20
16	Toluene (mg/l)	1	0.70	1.40	1.50	2.10
17	Ethylbenzene (mg/l)	0.001	0.30	3.33	0.0033	0.011
18	m.p-Xylene (mg/l)	0.00	0.30	2.667	0.00	0.00
19	o-Xylene (mg/l)	0.00	0.30	3.33	0.00	0.00
				114.96		24.376

$$WQI = \frac{\sum W_1Q_1}{\sum W_1}$$

$$WQI = \frac{24.376}{114.96} = 0.212$$