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SPATIAL EVALUATION OF WATER QUALITY OF SURFACE AND GROUNDWATER AROUND ARTISANAL REFINING POLLUTED AREA IN EMOHUA LGA, RIVERS STATE

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ABSTRACT:

This study evaluated the spatial distribution of water quality for surface and groundwater sampled around sites of artisanal refining activities in Emohua local government area in Rivers State. Ten ground and tensurface water samples were collected around artisanal refining operation sites within the distances of 0-100m, 100-200m, 200-300m, 300-400m, 400-500m Two control samples were obtained at distances of over 10km from the refining sites for both the surface and groundwater samples. The water samples were analyzed for some physicochemical parameters. Water quality index were calculated at difference distances based on measured physicochemical and WHO standards using weighted arithmetic mean technique. The results revealed that the WQI for surface water samples and the control sample were 3.719, 3.700, 2.832, 2.775. 0.098 and 0.115 while that of ground water sample and the control were 1.780, 1.410, 1.778, 0.0518. 0.038 and 0.113 for distance ranges of 0-100m, 100-200m, 200-300m, 300-400m, 400-500m and control sample respectively. These results showed that surface water sources were more polluted than the ground water sources at all the sampled distance range. The results also showed that there was 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 but the surface and ground water samples were mostly unfit for drinking except at distances beyond 400 and 300 respectively as well as the control samples. It was therefore concluded that, based on results of water quality index, that both ground and surface water sources within distances of less than 400 and 300 meter respectively away from the artisanal refining operation are not fit for drinking and must be properly and intentionally treated before drinking.

Keywords:

Water quality index, Spatial distribution, surface and ground water, artisanal refining and Emohua LGA

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1. Introduction

Oil exploration in the Niger Delta can be traced to the discovery of commercial quantity of hydrocarbon in Oloibiri in 1956 (Ajayi&Olutuase, 2020). While the exploration of crude oil in the region has improved revenue for government, the Niger Delta where international oil companies and non-state actors are operating is replete with inestimable environmental degradation. Studies such as Douglas (2018) have attempted to estimate the volume of pollution that can be adduced to different activities in the region. Aprioku(2018) argue that one reoccurring gap in the literature is that studies have not been able to account for the quantity of effluent from the activities of artisanal refineries into the environment. The growing body of literature has revealed that all the components of the environment such as surface water, groundwater, soil and vegetal cover are susceptible to oil pollution in the Niger Delta (Adeoye, 2018). However, the localized impact of pollution in the host communities have not been sufficiently estimated.

Several sources have been identified as contributors to this water resource pollution of which include oil spillage, pipeline explosion, gas flaring and venting, improper disposal of large volumes of petroleum–derived hazardous waste streams such as drilling mud, oily and toxic sludge, equipment failure/oil spills associated with ageing facilities, sabotage of petroleum facilities, illegal oil bunkering and artisanal refining (Auty & Haydn, 2012). The activities of artisanal crude oil refiners in Emohua localities is a source of environmental pollution. Sediments are sinks for contaminants in river ecosystems and their physico-chemical properties and response to the chemical dynamics of the hydrological system may enhance subsequent contamination to the ecosystem components to which they are linked.

The local refining of crude oil has become a lucrative but disturbing business in the Niger Delta region of Nigeria. Deep inside the forest 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). For many years, oil production carried out within Niger Delta communities have led to numerous incidents of massive oil spillage which have wreaked enormous havoc on the environment, making the region one of the most polluted in the world (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 “*Kpo-Fire*” by the locals, as a local way of distilling crude oil to get diesel 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 product by heating the crude in fabricated oven (Ajayi &Olutuase, 2020). 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) argue 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 setup, 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).

Petroleum hydrocarbon compounds are the principal 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 soil, 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 has manifested in increasing dropouts from school, proliferation of arms and abuse of hard substances. Okoro et al., (2018) reported that artisanal refining increased the number of school dropouts, cult rivalry, arms proliferation, among others. These activities also contribute to the contamination on 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 Emohua communities is conspicuously unreported. Therefore, it has become imperative to carry out this study to evaluate the spatial effect of artisanal refining activities particularly on water resource in Emohua localities.

2. Materials and Methods

2.1 Study Area

Emohualocal government is in Rivers state in the south-south part of Nigeria see Figure 1. This area was preferred for the study area due to flares of artisanal crude oil refining activities which has assumed a deleterious manifestation and the implication for the environment, the local economy, livelihood and public health. Emohua is an oil rich local government area in Rivers state, Nigeria. The local government area is made of towns and communities which include Omudioga, Egbeda, Ubimini, Elele-Alimini, Rumuji, Ibaa, Itu, Ndele and Odega. Emohua is located on latitude 4.9832ºN and longitude 6.7922ºE. The population of Emohua local government as reported in the 2006 census is 201,901. In terms of landmass, the areal size of Emohua is 831 square kilometers.

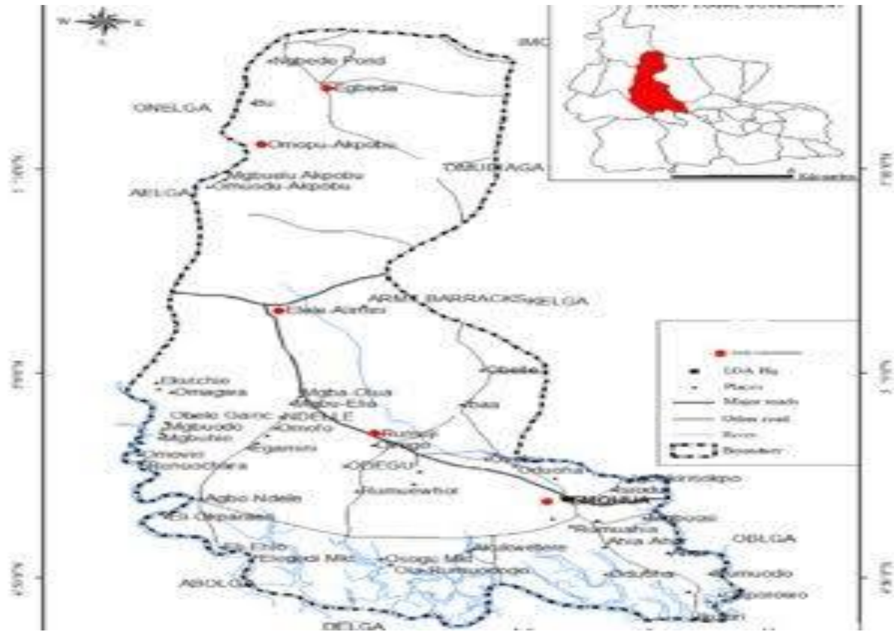

Figure 1: Emohua LGA of Rivers State.

2.2 Sampling Techniques

The study deployed the multi-stage sampling technique for the study. In the first stage, areas notorious for artisanal refining was identified using the lottery sampling techniques. This was achieved by listing all the affected local government areas (LGAs in Rivers 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 also to take samples. Systematic sampling was adopted to collect surface and ground water 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 Emohua Rivers. 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 the 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 all total water samples were 6 surface water samples and 6 groundwater samples. These water samples were sent to the laboratories for analysis.

2.3Collection 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.In the study, 10surface and 10groundwater samples as well as 4 control samples (2 control samples for both surface water and groundwater) making 24 water samples were collected fromthe 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. 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 (HALDEN Laboratory) in Port Harcourt.Various laboratory tests were performed on the samples collected in order to obtain the level of concentration of 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

In this study, the water quality index was determined using the weighted Arithmetic water quality index method. 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

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

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., 2022)

3. Results and discussions

3.1 Physicochemical parameters of the surface and ground water samples

The surface and groundwater characteristics of areas affected by artisanal refineries Emohua were sampled and analyzed. The data in Table 1 and Table 2 present the physicochemical properties of surface and groundwater in areas impacted by artisanal refining activities across varying distances. Surface water shows acidic to neutral conditions, ranging from 5.7 at 0–100 m to 7.0 at 301–500 m. Groundwater is slightly less acidic, starting at 6.8 and reaching 7.8 at farther distances. Both surface and groundwater temperatures remain stable at 25°C across all distances, indicating minimal thermal pollution. Surface water has higher turbidity (12 NTU at 0–100 m) but decreases to 7 NTU beyond 200 m. Groundwater shows lower turbidity, ranging from 9 NTU at 0–100 m to 7.8 NTU at 401–500 m. Surface water EC decreases from 1500 µS/cm at 0–100 m to 1246 µS/cm at 401–500 m. Groundwater EC also declines from 1236 µS/cm to 1189 µS/cm over the same distance.DO in surface water improves with distance from 2 mg/L at 0–100 m to 5 mg/L at 401–500 m. Groundwater follows a similar trend, increasing from 4 mg/L to 6 mg/L. Surface water TDS starts at 1200 mg/L at 0–100 m and drops to 679.5 mg/L at 401–500 m. Groundwater TDS shows a similar decline from 974 mg/L to 563.5 mg/L. Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD). BOD levels are stable at 2 mg/L in surface water and 1.9 mg/L in groundwater. COD remains fairly consistent, with a slight increase at 401–500 m (5 mg/L). Ammonia (NH_3) remains constant at 1 mg/L in surface water and 0.9 mg/L in groundwater. Nitrate (NO_3^-) slightly decreases with distance, from 7.3 mg/L in surface water to 6.5 mg/L. Phosphate (PO_4^{3-}) remains consistently low at 0.1 mg/L in both surface and groundwater. Chloride concentrations fluctuate but remain high, peaking at 459.1 mg/L in surface water. Calcium carbonate ($CaCO_3$) levels remain stable across distances, with minor variations. Sulphate concentrations decrease over distance, from 680 mg/L at 0–100 m to 609.1 mg/L in surface water. Groundwater sulphate levels follow a similar decline from 639 mg/L to 586.4 mg/L.

The concentration of BTEX (benzene, toluene, ethylbenzene, and xylenes) in surface and groundwater at varying distances (0–500 m) in Emohua, an area affected by artisanal refining activities showed that Benzene concentrations in surface water were relatively stable at 0.04 mg/L up to 200 m, then decreased slightly to 0.03 mg/L at 201–400 m, with only trace amounts detected beyond 400 m. In groundwater, benzene levels were lower, with 0.02 mg/L recorded up to 200 m and only trace amounts detected at distances beyond 300 m. This suggests that benzene contamination is more prominent in surface water and diminishes with distance. Surface water exhibited high toluene concentrations, starting at 1.3 mg/L at 0–100 m and gradually decreasing to 1.0 mg/L at 401–500 m. Groundwater concentrations were significantly lower, with 0.5 mg/L recorded up to 200 m and only trace amounts detected beyond 300 m. This pattern indicates that toluene contamination is more persistent in surface water, while groundwater contamination decreases more rapidly with distance. Ethylbenzene was detected at low concentrations in surface water, starting at 0.02 mg/L at 0–100 m and decreasing to trace levels beyond 400 m. In groundwater, ethylbenzene concentrations were even lower, with 0.001 mg/L detected up to 300 m and trace amounts beyond that. This suggests limited groundwater contamination from ethylbenzene. For *m.p-xylene*, surface water concentrations were 0.9 mg/L at 0–100 m, decreasing to 0.65 mg/L at 301–400 m, with only trace amounts detected beyond 400 m. In groundwater, *m.p-xylene* was detected at very low levels (0.001 mg/L) up to 200 m, with only trace amounts beyond that. For *o-xylene*, surface water concentrations remained stable at 1 mg/L up to 300 m but decreased to 0.6 mg/L at 301–400 m and 0.4 mg/L beyond 400 m. In groundwater, *o-xylene* was detected at 0.03 mg/L up to 200 m, decreasing to trace amounts beyond 400 m. However, the BTEX concentration in both surface and ground water samples are higher than WHO limit within buffer zone of 400 meters from the polluted site.

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 1Physicochemical characteristics of surface water sampled from the study areas

Sn	Parameter	0-100m	101-200m	201-300m	301-400	401-500m	Control	WHO
1	pH	5.7	5.8	6.1	7	7	6.6	65-8.5
2	°C	25	25	25	25	25	26	30.00
3	Turbidity NTU)	12	9	7	7	7	2	5.0
4	EC (µS/cm)	1500	1500	1278	1262.5	1246	1212	1500
5	DO (mg/L)	2	3	4	4	5	7.4	7.5
6	TDS (mg/L)	1200	1195	1046	1031.8	679.5	437.5	500
7	BOD (mg/L)	2	2	2	2	2	2.1	5.0
8	COD (mg/L)	4	3.9	3.9	3.9	5	7.3	10.0
9	NH_3 (mg/L)	1	1	1	1	1	0.5	0.5
10	NO^3- (mg/L)	7.3	7.1	6.8	6.8	6.5	6.4	10.00
11	$PO4^{3-}$ (mg/L)	0.1	0.1	0.1	0.1	0.1	0.1	1.00
12	Cl^- (mg/L)	450	459.1	433.1	456.3	434.5	133.4	250
13	$CaCO_3$ (mg/L)	65.3	64.3	61.4	64.4	64.9	66.3	200
14	$SO4^{2-}$ (mg/L)	680	645	634.5	619.1	609.1	123.2	250
15	Benzene (mg/l)	0.04	0.04	0.03	0.03	Trace	0.001	0.01
16	Toluene (mg/l)	1.3	1.2	1.1	1.05	1	1	0.70
17	Ethylbenzene (mg/l)	0.02	0.01	0.01	0.01	Trace	0.01	0.30
18	m.p-Xylene (mg/l)	0.9	0.8	0.8	0.65	Trace	Trace	0.3
19	o-Xylene (mg/l)	1	1	1	0.6	0.4	0.01	0.3

Table 2Physicochemical characteristics of ground water sampled from the study areas

Water	Parameter	0-100m	101-200m	201-300m	301-400	401-500m	Control	WHO
1	pH	6.8	6.9	6.9	7.8	7.8	6.6	65-8.5
2	°C	25	25	25	25	25	26	30.00
3	turbidity (NTU	9	8	7	7	7.8	2	5.0
4	EC (µS/cm)	1236	1215	1210	1194.5	1189	1212	1500
5	DO (mg/L)	4	3	5	5	6	7.4	7.5
6	TDS (mg/L)	974	946	923	908.8	563.5	437.5	500
7	BOD (mg/L)	1.9	1.9	1.9	1.9	1.9	2.1	5.0
8	COD (mg/L)	3.3	3.3	3.6	3.6	5	7.3	10.0
9	NH_3 (mg/L)	0.9	0.9	0.9	0.9	0.9	0.5	0.5
10	NO^3- (mg/L)	7.1	7.1	6.7	6.7	6.5	6.4	10.00
11	$PO4^{3-}$ (mg/L)	0.1	0.1	0.1	0.1	0.1	0.1	1.00

12	Cl^- (mg/L)	415	414.01	410.01	434.21	431.45	133.4	250
13	$CaCO_3$ (mg/L)	63.2	63.2	60.9	63.9	65.5	66.3	200
14	$SO4^{2-}$ (mg/L)	639	633.1	619.1	603.7	586.4	123.2	250
15	Benzene (mg/l)	0.02	0.02	0.02	Trace	Trace	0.001	0.01
16	Toluene (mg/l)	0.5	0.5	0.3	Trace	Trace	1	0.70
17	Ethylbenzene (mg/l)	0.001	0.001	0.001	Trace	Trace	Trace	0.30
18	m.p-Xylene (mg/l)	0.001	0.001	Trace	Trace	Trace	Trace	0.3
19	o-Xylene (mg/l)	0.03	0.03	0.02	0.02	Trace	Trace	0.3

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

Table 3 present the summary of the water quality index of surface water sampled at difference distance ranges artisanal refining sites and control sample. The results revealed that the WQI were 3.719, 3.700, 2.832, 2.775. 0.098 and 0.115 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. Based on the decision criteria presented in section 2.4, these results implies that the surface water between 0 to 400 meter are not good for drinking because their WQI is greater than 0.75 threshold for drinking while surface water sampled beyond 400m as well as the control surface water sample are good for drinking because their WQI is within the 0.75 threshold to good drinking water. See appendix 1 for the WQI calculation Tables

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	3.719	Not good for drinking
2	100-200	3.700	Not good for drinking
3	200-300	2.832	Not good for drinking
4	300-400	2.775	Not good for drinking
5	400-500	0.098	Very good for drinking
6	Control	0.115	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 the water Quality index rating obtained weregreater than 1within this study area 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 the results revealed that the surface waters of the Delta and Rivers State were more contaminatedthan those at Bayelsa.

3.3 Water quality index of ground water sample from the Study area within different distancesand control sample

Table 4 present the water quality index of ground water sampled at difference distance ranges artisanal refining sites and control sample area in Emohua. The results revealed that the WQI were 1.780, 1.410, 1.778, 0.0518. 0.038 and 0.113 fordistance 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 ground water samples with increase in distance away from the artisanal refining site which showed that the water quality of the ground water samples improve with increase in distance away of the artisanal refining sites. Based on the decision criteria presented in section 3.6.11, these results implies that the ground water between 0 to 300 meter are not good for drinking because their WQI is greater than 0.75 threshold for drinking while surface water sampled beyond 300m as well as the control surface water sample are good for drinking because their WQI is within the 0.75 threshold to good drinking water

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	1.780	Not good for drinking
2	100-200	1.410	Not good for drinking
3	200-300	1.778	Not good for drinking
4	300-400	0.052	Very good for drinking
5	400-500	0.038	Very good for drinking
6	Control	0.113	Very good for drinking

These results agreed with outcome ofstudy by Yerima Kwaya et al., (2019) who carried out investigation on the groundwater quality of Maru town using the pollution indices and multivariatestatistical approaches. 29 groundwater samples were taken from dug wells and oneBorehole in the area and analyzed for the presence of pollutants, Temperature and PH. The concentration of the analyzed pollutant in groundwater were above the WHO recommended limits. Calculated water quality index was greater than one which consequently translates to high groundwater pollution in the area. The results also concurred 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. They adopted standard sampling technique using sixteen (16) sampling points selected random for the water points in Ogu-Bolo and Okrika using weighted arithmetic mean technique. Water were analyzed in the laboratory using standard methods. A water Quality index rating greater than 1 were measured in water sampled within this study area which is an indication that the water is very bad

4. Conclusions

Based on the results of the spatial distribution of contaminations and water quality index of surface and groundwater around area polluted by activities of artisanal refining activities in Emohua LGA in Rivers state, it was concluded that artisanal refining activities substantially contribute to contamination of both ground and surface water sources in the sampled areas. Therefore, areas below 400m away from the artisanal refining operation could be considered as hot zone for surface water pollutions while areas below 300m could also be considered as hot zone forground water pollutions. It can also be concluded, based on results of water quality index, that both ground and surface water sampled collected at distances of less than 400 and 300 meterrespectively away from the artisanal refining operation is not fit for drinking and must be properly in intentionally treated before drinking.

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Appendix 1Water 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 Emohua

Sn	Parameter	Concentration	WHO Standard	W_1	Q_1	W_1Q_1
1	pH	5.70	8.5	0.118	0.671	0.079
2	°C	25.00	30.00	0.033	0.833	0.027
3	Turbidity NTU)	12.00	5.00	0.200	2.40	0.480
4	EC (µS/cm)	1500	1500	0.0007	1.00	0.0007
5	DO (mg/L)	2.00	7.50	0.133	0.267	0.0355
6	TDS (mg/L)	1200	500	0.002	2.40	0.0048
7	BOD (mg/L)	2.00	5.00	0.200	0.40	0.08
8	COD (mg/L)	4.00	10.00	0.100	0.40	0.04
9	NH_3 (mg/L)	1.00	0.50	2.00	2.00	4.00
10	NO^3- (mg/L)	7.30	10.00	0.100	0.73	0.073
11	$PO4^{3-}$ (mg/L)	0.10	1.00	1.00	0.10	0.10
12	Cl^- (mg/L)	450	250	0.004	1.80	0.0072
13	$CaCO_3$ (mg/L)	65.30	200	0.005	0.327	0.00164

14	$SO4^{2-}$ (mg/L)	680	250	0.004	2.72	0.011
15	Benzene (mg/l)	0.04	0.01	100	4.00	400
16	Toluene (mg/l)	1.30	0.70	1.40	1.871	2.62
17	Ethylbenzene (mg/l)	0.02	0.30	3.33	0.067	0.022
18	m.p-Xylene (mg/l)	0.90	0.30	3.33	3.00	9.99
19	o-Xylene (mg/l)	1.00	0.30	3.00	3.33	9.99
				114.96		427.555

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

$$WQI = \frac{427.555}{114.96} = 3.719$$

Table B Water quality index of surface water at distance range of 100-200m from polluted site in Emohua

Sn	Parameter	Concentration	WHO Standard	W_1	Q_1	W_1Q_1
1	pH	5.80	8.5	0.118	0.682	0.080
2	°C	25.00	30.00	0.033	0.833	0.0275
3	Turbidity NTU)	9.00	5.00	0.200	1.80	0.360
4	EC (µS/cm)	1500	1500	0.0007	1.00	0.0007
5	DO (mg/L)	3.00	7.50	0.133	0.40	0.0532
6	TDS (mg/L)	1195	500	0.002	2.39	0.048
7	BOD (mg/L)	2.00	5.00	0.200	0.40	0.080
8	COD (mg/L)	3.90	10.00	0.100	0.39	0.039
9	NH_3 (mg/L)	1.00	0.50	2.00	2.00	4.00
10	NO^3- (mg/L)	7.10	10.00	0.100	0.71	0.071
11	$PO4^{3-}$ (mg/L)	0.10	1.00	1.00	0.10	0.1
12	Cl^- (mg/L)	459.1	250	0.004	1.84	0.074
13	$CaCO_3$ (mg/L)	64.30	200	0.005	0.322	0.0061
14	$SO4^{2-}$ (mg/L)	645	250	0.004	2.58	0.0103
15	Benzene (mg/l)	0.04	0.01	100	4.00	400
16	Toluene (mg/l)	1.20	0.70	1.40	1.714	2.399
17	Ethylbenzene (mg/l)	0.01	0.30	3.33	0.033	0.109
18	m.p-Xylene (mg/l)	0.8	0.30	2.667	3.00	8.001

19	o-Xylene (mg/l)	1.00	0.30	3.33	3.33	9.99
				114.96		425.3727

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

$$WQI = \frac{425.37}{114.96} = 3.70$$

Table C Water quality index of surface water at distance range of 200-300m from polluted site in Emohua

Sn	Parameter	Concentration	WHO Standard	W_1	Q_1	W_1Q_1
1	pH	6.10	8.5	0.118	0.717	0.084
2	°C	25.0	30.00	0.033	0.833	0.0275
3	Turbidity NTU)	7.0	5.00	0.200	1.40	0.280
4	EC (µS/cm)	1278	1500	0.0007	0.852	0.00060
5	DO (mg/L)	4.0	7.50	0.133	0.533	0.071
6	TDS (mg/L)	1046	500	0.002	2.090	0.0042
7	BOD (mg/L)	2.0	5.00	0.200	0.40	0.080
8	COD (mg/L)	3.90	10.00	0.100	0.39	0.039
9	NH_3 (mg/L)	1.0	0.50	2.00	2.00	4.00
10	NO^3- (mg/L)	6.80	10.00	0.100	0.68	0.068
11	$PO4^{3-}$ (mg/L)	0.10	1.00	1.00	0.10	0.1
12	Cl^- (mg/L)	433.10	250	0.004	1.71	0.007
13	$CaCO_3$ (mg/L)	61.40	200	0.005	0.307	0.00154
14	$SO4^{2-}$ (mg/L)	634.5	250	0.004	2.54	0.0102
15	Benzene (mg/l)	0.030	0.01	100	3.00	300
16	Toluene (mg/l)	1.1	0.70	1.40	1.57	2.198
17	Ethylbenzene (mg/l)	0.01	0.30	3.33	0.033	0.109
18	m.p-Xylene (mg/l)	0.80	0.30	2.667	3.00	8.001
19	o-Xylene (mg/l)	1.0	0.30	3.33	3.33	9.99
				114.96		322.795

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

$WQI = \frac{322.795}{114.96}$ = 2.832

Table D Water quality index of surface water at distance range of 300-400m from polluted site in Emohua

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	25.00	30.00	0.033	0.833	0.0275
3	Turbidity NTU)	7.00	5.00	0.200	1.40	0.280
4	EC (µS/cm)	1262.5	1500	0.0007	0.841	0.00060
5	DO (mg/L)	4.00	7.50	0.133	0.533	0.071
6	TDS (mg/L)	1031.8	500	0.002	2.062	0.0042
7	BOD (mg/L)	2.00	5.00	0.200	0.40	0.080
8	COD (mg/L)	3.90	10.00	0.100	0.39	0.039
9	NH_3 (mg/L)	1.00	0.50	2.00	2.00	4.00
10	NO^3- (mg/L)	6.80	10.00	0.100	0.68	0.068
11	$PO4^{3-}$ (mg/L)	0.10	1.00	1.00	0.10	0.1
12	Cl^- (mg/L)	456.3	250	0.004	1.82	0.007
13	$CaCO_3$ (mg/L)	64.4	200	0.005	0.322	0.00154
14	$SO4^{2-}$ (mg/L)	619.1	250	0.004	2.48	0.0102
15	Benzene (mg/l)	0.03	0.01	100	3.00	300
16	Toluene (mg/l)	1.05	0.70	1.40	1.50	2.100
17	Ethylbenzene (mg/l)	0.01	0.30	3.33	0.033	0.109
18	m.p-Xylene (mg/l)	0.65	0.30	2.667	2.167	5.779
19	o-Xylene (mg/l)	0.6	0.30	3.33	2.00	6.66
				114.96		318.959

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

$WQI = \frac{318.969}{114.96}$ = 2.775

Table E Water quality index of surface water at distance range of 400-500m from polluted site in Emohua

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	25.00	30.00	0.033	0.833	0.0275
3	Turbidity NTU)	7.00	5.00	0.200	1.40	0.280
4	EC (µS/cm)	1246	1500	0.0007	0.831	0.00060
5	DO (mg/L)	5.00	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)	2.00	5.00	0.200	0.40	0.080
8	COD (mg/L)	5.00	10.00	0.100	0.50	0.05
9	NH_3 (mg/L)	1.00	0.50	2.00	2.00	4.00
10	NO^3- (mg/L)	6.50	10.00	0.100	0.65	0.065
11	$PO4^{3-}$ (mg/L)	0.10	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)	64.9	200	0.005	0.322	0.00154
14	$SO4^{2-}$ (mg/L)	609.1	250	0.004	2.48	0.0102
15	Benzene (mg/l)	0.00	0.01	100	0.00	0.00
16	Toluene (mg/l)	1.00	0.70	1.40	1.50	2.000
17	Ethylbenzene (mg/l)	0.00	0.30	3.33	0.00	0.109
18	m.p-Xylene (mg/l)	0.00	0.30	2.667	0.00	0.00
19	o-Xylene (mg/l)	0.40	0.30	3.33	1.33	4.43
				114.96		11.297

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

$$WQI = \frac{11.297}{114.96} = 0.098$$

Table F Water quality index of control water sample for Emohua

Sn	Parameter	Concentration	WHO Standard	W_1	Q_1	W_1Q_1
1	pH	6.6	8.5	0.118	0.776	0.092
2	°C	26	30.00	0.033	0.833	0.0275
3	Turbidity NTU)	2	5.00	0.200	1.40	0.280
4	EC (µS/cm)	1212	1500	0.0007	0.831	0.0005
5	DO (mg/L)	7.4	7.50	0.133	0.987	0.131
6	TDS (mg/L)	437.5	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)	6.4	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)	133.4	250	0.004	1.74	0.006
13	$CaCO_3$ (mg/L)	66.3	200	0.005	0.322	0.00154
14	$SO4^{2-}$ (mg/L)	123.2	250	0.004	2.48	0.0102
15	Benzene (mg/l)	0.001	0.01	100	0.1	10
16	Toluene (mg/l)	1	0.70	1.40	1.50	2.000
17	Ethylbenzene (mg/l)	0.01	0.30	3.33	0.00	0.109
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	0.11
				114.96		13,17

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

$$WQI = \frac{13.176}{114.96} = 0.115$$

Appendix 2 Water quality index Calculation table for ground water sample and control sample

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

Sn	Parameter	Concentration	WHO Standard	W_1	Q_1	W_1Q_1
1	pH	6.80	8.5	0.118	0,80	0.094
2	°C	25.00	30.00	0.033	0.833	0.027
3	Turbidity NTU)	9.00	5.00	0.200	1.80	0.360
4	EC (µS/cm)	1236	1500	0.0007	0.824	0.0005
5	DO (mg/L)	4.00	7.50	0.133	0.533	0.071
6	TDS (mg/L)	974	500	0.002	1.948	0.0048
7	BOD (mg/L)	1.90	5.00	0.200	0.40	0.008
8	COD (mg/L)	3.30	10.00	0.100	0.38	0.038
9	NH_3 (mg/L)	0.90	0.50	2.00	1,80	3.60
10	NO^3- (mg/L)	7.10	10.00	0.100	0.710	0.071
11	$PO4^{3-}$ (mg/L)	0.10	1.00	1.00	0.10	0.10
12	Cl^- (mg/L)	415	250	0.004	1.66	0.0066
13	$CaCO_3$ (mg/L)	63.20	200	0.005	0.316	0.00165
14	$SO4^{2-}$ (mg/L)	639	250	0.004	2.556	0.011
15	Benzene (mg/l)	0.02	0.01	100	2.00	200
16	Toluene (mg/l)	0.50	0.70	1.40	0.714	0.997
17	Ethylbenzene (mg/l)	0.001	0.30	3.33	0.003	0.01
18	m.p-Xylene (mg/l)	0.001	0.30	3.33	0.003	0.01
19	o-Xylene (mg/l)	0.03	0.30	3.33	0.1	0.33
				114.96		205.7393

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

$$WQI = \frac{205.739}{114.96} = 1.78$$

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

Sn	Parameter	Concentration	WHO Standard	W_1	Q_1	W_1Q_1
1	pH	6.90	8.5	0.118	0,80	0.094
2	°C	25.00	30.00	0.033	0.833	0.027
3	Turbidity NTU)	8.00	5.00	0.200	1.60	0.320
4	EC (µS/cm)	1215	1500	0.0007	0.824	0.0005
5	DO (mg/L)	3.00	7.50	0.133	0.533	0.071
6	TDS (mg/L)	946	500	0.002	1.948	0.0048
7	BOD (mg/L)	1.90	5.00	0.200	0.40	0.008
8	COD (mg/L)	3.30	10.00	0.100	0.38	0.038
9	NH_3 (mg/L)	0.90	0.50	2.00	1,80	3.60
10	NO^3- (mg/L)	7.10	10.00	0.100	0.710	0.071
11	$PO4^{3-}$ (mg/L)	0.10	1.00	1.00	0.10	0.10
12	Cl^- (mg/L)	414.01	250	0.004	1.66	0.0066
13	$CaCO_3$ (mg/L)	63.20	200	0.005	0.316	0.00165
14	$SO4^{2-}$ (mg/L)	633.1	250	0.004	2.532	0.011
15	Benzene (mg/l)	0.02	0.01	100	2.00	200
16	Toluene (mg/l)	0.50	0.70	1.40	0.714	0.997
17	Ethylbenzene (mg/l)	0.001	0.30	3.33	0.003	0.01
18	m.p-Xylene (mg/l)	0.001	0.30	3.33	0.003	0.01
19	o-Xylene (mg/l)	0.03	0.30	3.33	0.1	0.33
				114.96		203.9393

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

$$WQI = \frac{203.9393}{114.96} = 1.41$$

Table I Water quality index of groundwater at distance range of 200-300m from polluted site in Emohua

Sn	Parameter	Concentration	WHO Standard	W_1	Q_1	W_1Q_1
1	pH	6.90	8.5	0.118	0,80	0.094
2	°C	25.0	30.00	0.033	0.833	0.027
3	Turbidity NTU)	7.00	5.00	0.200	1.60	0.320
4	EC (µS/cm)	1210	1500	0.0007	0.824	0.0005
5	DO (mg/L)	5.00	7.50	0.133	0.533	0.071
6	TDS (mg/L)	923	500	0.002	1.948	0.0036
7	BOD (mg/L)	1.90	5.00	0.200	0.38	0.076
8	COD (mg/L)	3.60	10.00	0.100	0.38	0.038
9	NH_3 (mg/L)	0.90	0.50	2.00	1,80	3.60
10	NO^3- (mg/L)	6.70	10.00	0.100	0.710	0.071
11	$PO4^{3-}$ (mg/L)	0.10	1.00	1.00	0.10	0.10
12	Cl^- (mg/L)	410.01	250	0.004	1.66	0.0066
13	$CaCO_3$ (mg/L)	60.90	200	0.005	0.316	0.00165
14	$SO4^{2-}$ (mg/L)	619.1	250	0.004	2.532	0.011
15	Benzene (mg/l)	0.02	0.01	100	2.00	200
16	Toluene (mg/l)	0.30	0.70	1.40	0.428	0.60
17	Ethylbenzene (mg/l)	0.001	0.30	3.33	0.003	0.01
18	m.p-Xylene (mg/l)	000	0.30	3.33	0.003	0.00
19	o-Xylene (mg/l)	0.02	0.30	3.33	0.1	0.33
				114.96		204.4573

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

$$WQI = \frac{204.4573}{114.96} = 1.778$$

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

Sn	Parameter	Concentration	WHO Standard	W_1	Q_1	W_1Q_1
1	pH	7.80	8.5	0.118	0,916	0.108
2	°C	25	30.00	0.033	0.833	0.027
3	Turbidity NTU)	7.00	5.00	0.200	1.40	0.280
4	EC (µS/cm)	1194.5	1500	0.0007	0.796	0.0005
5	DO (mg/L)	5.00	7.50	0.133	0.666	0.088
6	TDS (mg/L)	908.8	500	0.002	1.888	0.0036
7	BOD (mg/L)	1.90	5.00	0.200	0.38	0.076
8	COD (mg/L)	3.60	10.00	0.100	0.36	0.038
9	NH_3 (mg/L)	0.90	0.50	2.00	1,80	3.60
10	NO^3- (mg/L)	6.70	10.00	0.100	0.670	0.067
11	$PO4^{3-}$ (mg/L)	0.10	1.00	1.00	0.10	0.10
12	Cl^- (mg/L)	434.21	250	0.004	1.736	0.0069
13	$CaCO_3$ (mg/L)	63.9	200	0.005	0.319	0.00159
14	$SO4^{2-}$ (mg/L)	603.7	250	0.004	2.532	0.011
15	Benzene (mg/l)	0.00	0.01	100	0.00	0.00
16	Toluene (mg/l)	0.00	0.70	1.40	0.00	0.00
17	Ethylbenzene (mg/l)	0.00	0.30	3.33	0.00	0.00
18	m.p-Xylene (mg/l)	0.00	0.30	3.33	0.000	0.00
19	o-Xylene (mg/l)	0.02	0.30	3.33	0.067	0.22
				114.96		5.9573

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

$$WQI = \frac{5.957}{114.96} \quad = 0.0518$$

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

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	25	30.00	0.033	0.833	0.027
3	Turbidity NTU)	7.8	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)	65.5	200	0.005	0.325	0.00169
14	$SO4^{2-}$ (mg/L)	586.4	250	0.004	2.532	0.011
15	Benzene (mg/l)	0.00	0.01	100	0.00	0.00
16	Toluene (mg/l)	0.00	0.70	1.40	0.428	0.00
17	Ethylbenzene (mg/l)	0.00	0.30	3.33	0.000	0.00
18	m.p-Xylene (mg/l)	0.00	0.30	3.33	0.000	0.00
19	o-Xylene (mg/l)	0.00	0.30	3.33	0.000	0.00
				114.96		4.441

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

$$WQI = \frac{4.441}{114.96} = 0.038$$

Table L Water quality index of ground water control water sample for Emohua

Sn	Parameter	Concentration	WHO Standard	W_1	Q_1	W_1Q_1
1	pH	6.6	8.5	0.118	0.776	0.092
2	°C	26	30.00	0.033	0.833	0.0275
3	Turbidity NTU)	2	5.00	0.200	1.40	0.280
4	EC (µS/cm)	1212	1500	0.0007	0.831	0.0005
5	DO (mg/L)	7.4	7.50	0.133	0.987	0.131
6	TDS (mg/L)	437.5	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)	6.4	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)	133.4	250	0.004	1.74	0.006
13	$CaCO_3$ (mg/L)	66.3	200	0.005	0.322	0.00154
14	$SO4^{2-}$ (mg/L)	123.2	250	0.004	2.48	0.0102
15	Benzene (mg/l)	0.001	0.01	100	0.1	10
16	Toluene (mg/l)	1	0.70	1.40	1.50	2.10
17	Ethylbenzene (mg/l)	0.00	0.30	3.33	0.00	0.109
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		13,06

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

$$WQI = \frac{13.06}{114.96} = 0.113$$