

ASSESSMENT AND ESTIMATION OF THE IMPACTS OF THE PETROLEUM TANK FARM OPERATIONS ON THE WATER QUALITY OF THE CALABAR RIVER, CROSS RIVER STATE, NIGERIA

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Abstract

The Calabar River frequently becomes the site of accidental discharges and spills from tank farms nearby. This causes the Calabar River to become contaminated, which has various negative effects on human health. Due to this ongoing issue with anthropogenic activity, the study aims to determine how tank farm operations affect the Calabar river. The experimental research design method was employed in the study. Water samples were taken at four different locations, including the control point, higher course, middle course, and lower course. Adopting the independent test and the water pollution index for the assessment of water pollution allowed the study's hypotheses to be put to the test. The study's findings indicated that sites 1, 2, and 3 had relatively low water quality indices, with values of 86.46, 77.64, and 91.03, respectively. This suggests that the water quality at these three sites is very close to the operations of tank farms. Nevertheless, the control point's water quality got a rating value of 11.19, suggesting that it is of outstanding quality. Additionally, the independent t-test result for the impact of tank farm activities on water quality shows that at $t(8.23) = 15$, the level of significance $(p) = 0.033 < 0.05$ for the levene's test of equality, while the independent statistical result provided a level of significance $(p) = 0.034 < 0.05$, indicating that the impact of the tank farm's activities on water quality was significant. Also, the test of the second hypothesis, which sought to understand the variation in the water pollution index between the control site and the polluted site, the independent t-test revealed that at $t(0.23) = 15$, the level of significance $(p) = 0.023 < 0.05$ for the levene's test of equality, while the independent statistical result availed a level of significance $(p) = 0.022 < 0.05$, which means that there was a significant variation in water quality index between the control site and the polluted site. The establishment of a structured management plan that specifies the conditions, practices, and roles required for the system's operation and administration, in the opinion of the experts, is the best way to lessen the risk of adverse effects from petroleum storage tank farms.

Keywords: Calabar River, Tank Farms, Petroleum spills and Water Quality Index (WQI)

ÉVALUATION ET ESTIMATION DES IMPACTS DES OPÉRATIONS DE RÉSERVOIRS PÉTROLIERS SUR LA QUALITÉ DE L'EAU DE LA RIVIÈRE CALABAR, ÉTAT DE CROSS RIVER, NIGERIA

Resume

La rivière Calabar devient fréquemment le site de rejets accidentels et de déversements des parcs de stockage à proximité. Cela provoque la contamination de la rivière Calabar, ce qui a divers effets négatifs sur la santé humaine. En raison de ce problème persistant lié à l'activité anthropique, l'étude vise à déterminer comment les opérations des parcs de stockage affectent la rivière Calabar. La méthode de conception de recherche expérimentale a été utilisée dans l'étude. Des échantillons d'eau ont été prélevés à quatre endroits différents, y compris le point de contrôle, le parcours supérieur, le parcours intermédiaire et le parcours inférieur. L'adoption du test indépendant et de l'indice de pollution de l'eau pour l'évaluation de la pollution de l'eau a permis de tester les hypothèses de l'étude. Les résultats de l'étude ont indiqué que les sites 1, 2 et 3 avaient des indices de qualité de l'eau relativement faibles, avec des valeurs de 86,46, 77,64 et 91,03, respectivement. Cela suggère que la qualité de l'eau à ces trois sites est très proche des opérations des parcs de stockage. Néanmoins, la qualité de l'eau du point de contrôle a obtenu une cote de 11,19, suggérant qu'elle est d'une qualité exceptionnelle. De

plus, le résultat du t-test indépendant pour l'impact des activités du parc de stockage sur la qualité de l'eau montre qu'à $t(8,23) = 15$, le niveau de signification $(p) = 0,033 < 0,05$ pour le test d'égalité de Levene, tandis que le test statistique indépendant fournit un niveau de signification $(p) = 0,034 < 0,05$, indiquant que l'impact des activités du parc de réservoirs sur la qualité de l'eau était significatif. Aussi, le test de la deuxième hypothèse, qui cherchait à comprendre la variation de l'indice de pollution de l'eau entre le site témoin et le site pollué, le t-test indépendant a révélé qu'à $t(0,23) = 15$, le niveau de signification $(p) = 0,023 < 0,05$ pour le test d'égalité de Levene, alors que le résultat statistique indépendant a un niveau de signification $(p) = 0,022 < 0,05$, ce qui signifie qu'il y avait une variation significative de l'indice de qualité de l'eau entre le site témoin et le site pollué. L'établissement d'un plan de gestion structuré qui précise les conditions, les pratiques et les rôles requis pour le fonctionnement et l'administration du système est, de l'avis des experts, la meilleure façon de réduire les risques d'effets néfastes des parcs de stockage pétrolier.

Mots-clés : rivière Calabar, parcs de stockage, déversements de pétrole et indice de la qualité de l'eau (IQE)

تقييم وتقدير آثار عمليات مزرعة خزانات البترول على جودة مياه نهر كالابار ، ولاية كروس ريفر ، نيجيريا

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غالبًا ما يصبح نهر كالابار موقعًا للتصريفات والانسكابات العرضية من مزارع الصهاريج القريبة. هذا يتسبب في تلوث نهر كالابار ، مما يؤدي إلى آثار سلبية مختلفة على صحة الإنسان. بسبب هذه المشكلة المستمرة مع النشاط البشري ، تهدف الدراسة إلى تحديد كيفية تأثير عمليات مزرعة الخزانات على نهر كالابار. تم استخدام أسلوب تصميم البحث التجريبي في الدراسة. تم أخذ عينات المياه في أربعة مواقع مختلفة ، بما في ذلك نقطة التحكم ، والمسار الأعلى ، والمقرر المتوسط ، والمقرر السفلي. سمح اعتماد الاختبار المستقل ومؤشر تلوث المياه لتقييم تلوث المياه بوضع فرضيات الدراسة على المحك. أشارت نتائج الدراسة إلى أن المواقع 1 و 2 و 3 بها مؤشرات جودة مياه منخفضة نسبيًا ، بقيمة 77.64 و 91.03 على التوالي. يشير هذا إلى أن جودة المياه في هذه المواقع الثلاثة قريبة جدًا من عمليات مزارع الصهاريج. ومع ذلك ، حصلت جودة المياه في نقطة المراقبة على تصنيف 11.19 ، مما يشير إلى أنها ذات جودة عالية. بالإضافة إلى ذلك ، تُظهر نتيجة اختبار t المستقل لتأثير أنشطة مزرعة الخزانات على جودة المياه أنه عند $t(8,23) = 15$ ، مستوى المعنوية $(p) = 0.033 < 0.05$ لاختبار ليفين للمساواة ، في حين أن الإحصاء المستقل أعطت النتيجة مستوى معنوية $(p) = 0.034 < 0.05$ ، مما يشير إلى أن تأثير أنشطة مزرعة الخزانات على جودة المياه كان معنويًا. كما أن اختبار الفرضية الثنائية ، والذي سعى إلى فهم التباين في مؤشر تلوث المياه بين موقع التحكم والموقع الملوث ، أظهر اختبار t المستقل أنه عند $t(0,23) = 15$ ، فإن مستوى الأهمية $(p) = 0.023 < 0.05$ لاختبار ليفين للمساواة ، بينما استقادت النتيجة الإحصائية المستقلة من مستوى دلالة $(p) = 0.022 < 0.05$ ، مما يعني وجود تباين كبير في مؤشر جودة المياه بين موقع التحكم والموقع الملوث. يعتبر وضع خطة إدارة منظمة تحدد الشروط والممارسات والأدوار المطلوبة لتشغيل النظام وإدارته ، في رأي الخبراء ، أفضل طريقة لتقليل مخاطر الآثار السلبية من مزارع صهاريج تخزين البترول.

الكلمات الرئيسية: نهر كالابار ، مزارع الخزانات ، الانسكابات البترولية ومؤشر جودة المياه (WQI)

Introduction

The operation department of the crude oil production chain includes the tank farm section where the intermediate and finished products are stored in storage tanks [Cigolini & Rossi, 2010]. In other words, a tank farm also referred to as an operation terminal can be broadly defined as a storage area where petroleum or chemical products are received through pipelines, barges and rail wagons, and stored in large tanks. These products are then transferred to trucks, wagons and ships and sent to the end-user. Modern petrochemical refineries comprise large storage facilities, which contain, among others, significant amounts of

flammable hydrocarbon fuels and chemicals in large storage tanks [Nivolianitou et al 2012]. The usefulness of tank farms cannot be overemphasized. They have assumed a very strategic position in the storage of petroleum, chemical and hazardous flammable liquid [Alaba & Agbalajobi, 2014]. The main function of tank farms is to store transported petroleum and chemical products from pipelines, ships and refineries in a cost-effective manner. Petroleum and chemical products are primary resources in our life and are considered one of the most important basic building blocks for sustainable development. The growing demand, installation and operation of tank farms' hazardous chemical content

have brought a significant increase in risk to man and his environment where the rivers are worst hit [Ibrahim & Syed, 2018]. Rivers in most cases are affected given the low lane position which is always at the receiving end of a spillage incidence [Eni & Ikona, 2019]. The importance of water is globally acknowledged especially due to its usefulness and application in all facets of life. Based on this an important safety consideration in the tank farm operation and containment of the spill is required to prevent the tank contents from escaping into the waterways. Amongst the best practices in advanced Nations is the location of storage tanks within a containment area surrounded by a dike wall or bunds, for proper control and recovery from spillages [Krausmann & Mushtaq, 2008]. Emissions from tank farms and their environmental problems have continued to attract the attention of environmental experts amongst others. In most cases, nearby rivers are usually the points of wastes (such as Carbondioxide, Sulphate compounds, Nitrate, oily waste water, metal scraps etc) for many tank farm facilities, stationed close to water bodies [Frank & Boisa, 2018]. The river usually serves as a cheap alternative compared to other forms of waste disposal for tank farm operators. However, disposal of chemical or petroleum products into nearby water bodies usually or may result in water pollution, which creates several environmental problems for both man and the environment. In Nigeria for example, crude oil spill on the ecosystem of the Niger Delta area has been on the front burner for over three decades [Frank & Boisa, 2018]. Oil spill pollution has remained a source of several international litigations in the Niger Delta region of Nigeria [Ifelebuegu *et al.*, 2017]. When an oil spill occurs, many parameters of the environment may be affected. The water quality index assessment is important in understanding the degree of impact of the contamination. The water quality index (WQI) is a single number that shows water quality at a certain location and time based on several water quality parameters [Kumar & Dua, 2009]. The goal of WQI is to turn complex water quality data into information that is understandable and usable by the public [Etim *et al.*, 2013]. Several indices have been developed to summarize water quality data in an easily expressible and easily understood format. The WQI which was first developed by Horton in the early 1970s as a mathematical means of calculating

a single value from multiple test results [Miller *et al.*, 1986]. The index result represents the level of water quality in a given water basin, such as a lake, river or stream. Numerous tank farms have poised at developing cleaner production and distribution technologies to reduce ecological damages. A total of 242 tank farm incidents worldwide have been reported from the period of 1960 to 2003 [Hartoyo & Suprpto, 2017]. Analysis of these incidents revealed that the most frequent cause was the result of lightning strikes, followed by poor maintenance practices, sabotage, crack, leak or line ruptures [Kannan *et al.*, 2016].

Between January and August 2015, Oboh and Osuala, (2017) evaluated the physical and chemical characteristics of groundwater near a Petroleum Tank Farm to determine whether the water from the borehole was suitable for drinking and other residential applications. The results show that pH of the water was acidic with values ranging from 4.62 to 6.87, Electrical Conductivity (EC) (33.00–206.00 $\mu\text{s}/\text{cm}$), Total Dissolve Solid (TDS) (15.00–115.00mg/L), Dissolve Oxygen (DO) (2.13–7.10mg/L), and Biochemical Oxygen Demand (BOD) (0.71–2.28mg/L). Water Quality Index (WQI) revealed very poor water, suggesting that the heavy vehicular movements and gas flaring at the Petroleum Tank Farm impacted negatively on its surrounding groundwater with increased levels of pH, DO and BOD. Based on their findings in the study, the quality of the borehole water was unsuitable for drinking without adequate treatment. A comparative study on the impact of oil pollution on water quality in both the oil and non-oil bearing communities of Ibeno and Mbo respectively was conducted. The mean concentration of Pb, (0.20mg/L) Cd (0.1mg/L), Cr (0.10mg/L) and Ni (<0.10mg/L) were above the WHO recommended limits of 0.05mg/L, (Pb) 0.005mg/L (Cd), 0.05mg/L (Cr) and 0.02mg/L (Ni) for drinking and domestic water quality. The physicochemical properties in both oil (incident zone and non-oil (control zone) trailed below standards. The mean pH (5.41) for the incident zone and pH (4.73) for the control zone were below the recommended range of 6.5–8.5. BOD varied between 0.5 to 20mg/L in the incident zone and 0.50mg/L in the control zone. The DO ranged from 2.7mg/L to 11.6 mg/L in the incident zone and a mean concentration of 6.4mg/L in the control zone whereas the WHO (1993)

recommended level is 5mg/L. The mean values for hydrocarbons (range between <0.003-0.004mg/L for BTEX were generally below some local and international standards (0.01mg/L for benzene, 0.7mg/L for toluene) [Ekpenyong & Udofia, 2015]. Kumar and Dua, [2019] evaluated the water quality index for assessment of water quality of river Ravi at Madhopur (India). The WQI values for the River Ravi ranged from 54.8 to 97.88. The values of WQI showed that the water was free of any impurities at the sampling site except for 2-3 months where its values were less than 70. Whenever there are human activities e.g., dam operations, water gets polluted to some extent, so the value of WQI decreases. They found out that the parameter which is required in the least amount contributes a high statistical value to the index; and concluded that WQI can be used as a tool in comparing the water quality of different sources, as it gives the public a general idea of the possible problems with water in a particular region. In a work carried out by Madilonga et al., [2021] in assessing the water quality characteristics of Mutangwi River. Physicochemical parameters (pH, temperature, total dissolved solids (TDS), salinity, electrical conductivity (EC), and turbidity) were determined in situ using an Extech multimeter and turbidity meter. The concentrations of the selected metals (Mg, Cr, Fe, Cd, Mn, Pb, Ca, and Na) were analyzed using an Atomic Absorption Spectrophotometer. The physicochemical water quality parameters as well as basic anions (fluoride, phosphate, sulfate, nitrate, and chloride) determined complied with the regulatory guideline of the World Health Organization (WHO) and the South Africa National Standards (SANS). Some of the trace metals (Mn, Ca, Fe, and Mg) were found below the guideline values, while others (Pb and Cd) exceeded the threshold limit. The water quality status using the water quality index (WQI) indicated that on average, the water quality from Mutangwi River is poor (WQI > 100). They advised that water from the river should be adequately treated before domestic and agricultural use.

Calabar tank is located in the Export Processing Zone (EPZ) of Calabar free trade zone, Calabar, Cross River state and comprises five tanks. A reconnaissance survey revealed that the tank farm staff are responsible for the operation of the facility and in most cases that there is an observed number of spills; is as a result of no-spill prevention and

response program [Johnson, 1979]. Spills are permitted to drain into the nearest water body, in this case, the Calabar River which adds to waste products already existing in the river. Spills occur because the dosing and tank filling operations are performed manually, often resulting in overfilling incidents with little or no emphasis placed on the automation of tank farms. Loading and unloading of products is the most important stage of the operation process of a tank farm. Contaminated water has a profound influence on humans due to its impacts on health and well-being. Issues such as the quantity and quality of the water supplied are important in determining the health of individuals and whole communities. In recent times, the population explosion alongside human activities in so many parts of Cross River State and Nigeria with relatively no increase in the supply of potable water [Utsev & Aho, 2012] implies that many communities along the Calabar River depend on the river for their source of drinking and other domestic use. The Calabar Industrial Layout at Esuk Utan was selected for the study because of the location of the tank farm by the Calabar River. Hence the need for continuous review and assessment of the safety of tank farm operations, evidenced by various major accidents that have occurred [Eni et al., 2017]. Therefore the aim of this study was to investigate the environmental implication of petroleum spills from the Calabar Industrial Layout tank farm on the nearest river—the Calabar River. This was to unravel the effects and present a clear picture of the interaction between the river and the petroleum terminal to both scholars and decision-makers and not just awareness alone. To achieve the aim of the study, two specific objectives were carried out; to assess the impact of tank farm activities on the water quality of the Calabar River and to estimate the water quality index of the Calabar River.

Materials and methods

The research adopted the experimental research design, and which is the most familiar type of design for physical science research involving scientific experiments together with Questionnaires [Teegavarapu et al., 2008]. The types of Data used were: locational data (coordinates) of features under study (tank farm, river, water sample collection points, etc.), attribute data on the Calabar River and Esuk Utan Tank farm (area coverage of tank farm, a

distance of tank farm to the river, width of the river, length of the river, etc.) and Water analysis data (physio-chemical characteristics of the water) were the different types of data implored in this work [Kaliraj et al., 2015 & Chiniko, 2019]. The sources of data were obtained from both primary and secondary data sources; the primary data were sourced from surface water sample acquisition and analysis which aided in answering questions on the influence of the tank farm on the quality of the Calabar River and the secondary source of data considered was the National Population Commission (NPC), which was used to collect data on the Population of the study area. The Smith formula for the finite population was employed to statistically determine the minimum sample size for the questionnaire survey aspect of this study, thus; Necessary sample size =

$$(Z\text{-score})^2 \times \text{StdDev} (1\text{-StdDev}) / (\text{margin of error})^2 \dots \text{(Equation 1)}$$

Where:

$$Z\text{-SCORE (confidence level -95\% = (1.96)^2}$$

$$\text{Standard Deviation (StdDev) = 0.5}$$

$$\text{Margin of error} = 0.05.$$

The sample size can be determined thus:

$$((1.98)^2 \times 5(.5)) / (.05)^2$$

$$(3.8416 \times .25) / .0025$$

$$.9604 / .0025$$

$$384.16 = 384$$

Based on this derivation, a total of 384 samples were selected for questionnaire administration within the study area.

To effectively distribute the selected sample size for the questionnaire survey within the study area, the population within a radius of 3km of the Calabar Industrial layout tank farms was determined. The study population was estimated using the triangulation method using satellite imagery and it formed the basis for the sampling. This was done through an enumeration of the buildings within the sample radius and an estimation of the household size and population within the radius. For example, if there were x number of buildings within the radius, and a given average of 6 persons in a household), the estimated population would be x multiplied by 6 [Noori et al., 2010]. The population was made up of the staff of the tank farm, and residents who use the river for their livelihoods (such as fishermen, fisherwomen, boat operators and

commuters on the river, etc). Using the random sampling technique, samples would be distributed to households randomly within the sampling radius. In addition,

Experimental analysis

Water samples were collected from four different points; Adiabo(upper course), Calcemco Jetty (Middle course), Marina resorts (lower course) and Akim-Akim model school (control sites) labeled as Point 1, Point 2, Point 3 and Point 4 respectively. Sterilized 75Cl polyethylene bottles were used to collect water samples from the river sources. The collection process was carried out using the grab sample method in the middle of the river at about 5m in depth. The bottles were duly labeled with masking tape and an indelible pen with the spatial references and location noted with attribute data of the water sample points. In-situ measurements were carried out on the water and for the River, the Lutron PDO-520 Dissolved Oxygen (DO) meter equipment was used to determine dissolved oxygen and water temperature values. The equipment was calibrated properly before dipping it directly into the flowing river. The other physico-chemical analyses were carried out at the Cross-River State Water Board Limited Laboratory. The collected samples were preserved in ice-block filled coolers at temperature of about 4.0°C before being transferred to the laboratory for analysis. Samples were analyzed in the laboratory with the use of atomic absorption spectrophotometer (AAS – model: UNICAM 939) for nitrate, manganese, iron, calcium and chloride, then Brucine and Gravimetric method was used in sulphate/phosphate ions, While pH, temperature, total dissolve solid, salinity, electrical conductivity and turbidity were determined in situ using an Extech multimeter and turbidity meter.

Data analysis technique

Both descriptive and inferential statistical techniques were used to analyze data [Dirisu et al., 2016]. The use of simple averages, percentage, tables, maps and charts to summarize data formed the descriptive techniques, while the hypothesis was tested by inferential statistical techniques such as the independent t-test. Also, the water arithmetic model was adopted in estimating the water quality or pollution index of the water sample.

Water arithmetic model for pollution index of the water sample

The weighted arithmetic index method was used to calculate the water quality index. The most suitable parameters for drinking water were used and compared with the allowable values for drinking water quality as recommended by the World Health Organization (WHO). To calculate a WQI as given in the following steps:

i. Calculation of unit weight factor $W_i = \frac{K}{\sum K}$ (1)

Where:

W_i represents the weighting for the i th determinant and this value varies from (0 to 1) and $\sum W_i = 1$; and

K : is a proportional constant

- ii. Calculation of the quality rating scale (q_i), which reflects the comparative value of this determinant in the contaminated water

concerning its standard permitted value as follows:

$$q_i = \frac{(V_i - V_d)}{(S_i - V_d)} \times 100 \tag{2}$$

where;

q_i represents the rating for the i th determinant, and this value varies from 0 to 100

V_i is the observed value of the i th determinant

V_d is the ideal value of the i th determinant in pure water; and

S_i is the standard value of the i th determinant.

Zero is the ideal value for all determinants except pH, where $V_d = 7$

3- Calculation of water quality index using the following equation:

Overall WOI = total sum of $w_i * q_i$

The water quality index rating scale is shown in Table 2. The index rating scale helps in assessing the degree of water quality.

Table 2: Water Quality Index rating scale (Source: Brown, McClelland, Deininger and. O'Connor (1972))

No	WQI Range	Water Type
1	0-25	Excellent
2	26-50	Good Water
3	51-75	Poor Water
4	76-100	Very Poor Water
5	>100	Unfit for human consumption

Test of Hypotheses

Hypothesis one

The independent sample t test was used to test hypothesis one. The independent sample t-test compares the means between two unrelated groups on the same continuous, independent variable. The independent sample t test sought to assess the impact of the tank farm activities on the water quality of the Calabar River. The null and alternate hypothesis was stated thus:

H_0 : There is no significant impact of the tank farm activities on water quality of the Calabar River.

H_1 : There is a significant impact of the tank farm activities on the water quality of the Calabar River.

The variables considered for the study were the water quality of water samples at the four sample points.

The independent t test formula was given thus

$$t = \frac{(X_1 - X_2)}{(Sp \sqrt{\frac{1}{n_1} + \frac{1}{n_2}})^{1/2}}$$

with

$$Sp = \frac{(n_1 - 1)s^2_1 + (n_2 - 1)s^2_2}{(n_1 + n_2 - 2)^{1/2}}$$

Where

\bar{x}_1 = Mean of the first sample

\bar{x}_2 = Mean of the second sample

n_1 = Sample size (i.e., number of observations) of the first sample

n_2 = Sample size (i.e., number of observations) of the second sample

s_1 = Standard deviation of the first sample

s_2 = Standard deviation of the second sample

sp = Pooled standard deviation

Hypothesis two

Also, the independent sample t test was used to test hypothesis two which sought to assess the difference in the water quality index of the control site and the polluted sites. The null and alternate hypothesis was stated thus:

H_0 : there is no significant difference between the water quality index at the control site and the polluted site.

H_1 : there is a significant difference between the water quality index at the control site and the polluted site.

The variable considered for this hypothesis was the water quality index at the four points.

spsp = Pooled standard deviation

$$t = \frac{(X_1 - X_2)}{(Sp(\frac{1}{n_1} + \frac{1}{n_2})^{1/2}}$$

with

$$sp = \frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{(n_1 + n_2 - 2)^{1/2}}$$

Where

\bar{x}_1 \bar{x}_2 = Mean of the first sample

\bar{x}_2 \bar{x}_2 = Mean of the second sample

n_1 n_1 = Sample size (i.e., number of observations) of the first sample

n_2 n_2 = Sample size (i.e., number of observations) of the second sample

s_1 s_1 = Standard deviation of the first sample

Result and Discussions

Assessment of the Impact of Tank Farm Activities on Water Quality of the Calabar River

The first objective of the study sought to address the impact of the activities of tank farms located at Calabar industrial Layout on the Calabar river. To assess the impacts, a water analysis test was conducted on water samples collected at three points on the Calabar river (Adiabo, Calcemco Jetty and Marina), which made up the polluted sites and one control point (Akim-Akim). Table 3&4 shows the in-situ data collected from the polluted and control sites.

Table 3: In situ Measurement (Morning)

Long	Lat	Time	Period	Dissolve Oxygen (%)	Temperature (o C)	Direction
Adiabo (Upper Course)						
558892	423119	9:50am	Morning	87.6	31.1	South
Calcemco Jetty (Middle Course)						
550826	424921	10:35am	Morning	43.4	31.5	South
Marina (Lower Course)						
548881	424317	11:35am	Morning	68.8	33	South
Control Point						
562892	422419	8:22am	Morning	91.2	30.1	South

Table 4: In situ Measurement (Afternoon)

Long	Lat	Time	Period	Dissolve Oxygen (%)	Temperature (° C)	Direction
Adiabo (Upper Course)						
558892	423119	1:30pm	Afternoon	76.2	32.1	South
Calcemco Jetty (Middle Course)						
550826	424921	10:35am	Morning	56.0	33.2	South
Marina (Lower Course)						
548881	424317	11:35am	Morning	45.3	34.4	South
Akim Akim (Control Point)						
562892	422419	12:02am	Afternoon	81.2	31.2	South

Table 5 shows water test analysis with 15 parameters which were water pH level, temperature, electric conductivity, total hardness, total dissolved solids, turbidity, sulphate ion, phosphate ion, nitrate, manganese, iron, calcium, chloride, total coliform and faecal coliform. The first parameter assessed was the pH level of the polluted river. The pH of water is the level of acidity and alkalinity of water [Dirisu et al 2016]. The pH level ranges from 1 (very acidic H⁺ ion) to 14 (very alkaline OH⁻ ion), with deionized water being 7 [David, 2014]. The WHO

standard for safe drinking water is 6.20 to 8.50. Hence any value lower or higher than the assigned value would pose danger such as development of unpleasant, smell, increase acid deposition in human body, as well as respiratory impact [Dodds & Butler, 2019]. According to the results of the water test, the mean pH value for the water sample at site one was 6.80, lower than deionized water, at site two it was 7.27, higher than deionized water, and at site three it was 7.1, only a little higher than deionized water. The pH level at the control location is 7.01, which is

somewhat higher than that of deionized water. The pH composition of the river is within the WHO limit, thus the water pH value is better, according to a comparison of the pH values at the four sites with the WHO norm. In line with this finding, Ifelebuegbu et al [2017] observed that oil spillage on water surface results in the deterioration of water quality due to changes in physicochemical component of water such as change in temperature.

The second water quality parameter considered was the temperature of the water samples which is still captured in table 5. Water temperature is a physical property expressing how hot or cold water is [Daniels & Koutsougeras, 2021]. As hot and cold are both arbitrary terms, temperature can further be defined as a measurement of the average thermal energy of a substance and it is measured in degree Celsius (°C). Temperature is an important factor to consider when assessing water quality, as it has the potential to affect the absorption of chemical contaminant and physical water quality. The temperature of water can be altered by nature and anthropogenic factor, with the latter of greater concern. One-way anthropogenic activities can affect the temperature of water is through oil spillage. The temperature of the Calabar River at the sampled point showed that at site one and two the temperature was 26.6°C, and at site three the temperature was 26.9°C. Lastly, the temperature of the river at the control point was 24.83°C. The stipulated WHO standard was 25°C, so the temperature at site one, two and three are above the recommended value. Hence, it was thus concluded that oil spillage from the activities of tank farms at the Calabar industrial layout affect the temperature of the Calabar River. In line with this finding, Ifelebuegbu et al [2017] observed that oil spillage on water surface results in the deterioration of water quality due to changes in physicochemical component of water such as change in temperature.

The third parameter considered was the Electric Conductivity (EC). Electrical Conductivity (EC) of water is its ability to conduct an electric current [Kaewthong & Wattanachant, 2018]. The result showed that the mean value of the EC at site one was 5.47, at site two was 4.90, at site three the mean value was 6.26. In addition, the electric conductivity at the control site was 4.34. Comparing with the WHO standard of 2500, it was thus noted that the electric conductivity of the all sites is below the WHO

standard. Although, the EC was less than the stipulated WHO standard, there was however an observable difference in the EC between the control site (4.14) and the contaminated sites (5.47, 4.90 and 6.26 for the three sites). Hence it can be categorically stated that the difference in EC is because of activities from the tank farm. In line with the study, Oufline, *et al* [2012] and Muhammad *et al* [2020] noted that human activities such as oil spillage can affect the EC composition of water. The fourth parameter considered was the total hardness (mg/L) of the river, which assesses the amount of calcium and magnesium in the water [Panaskar et al 2016]. The WHO stand for total hardness is 250mg/L. However, it was observed that at site one the total hardness was 45.6mg/L, at site two the total hardness was 58.5mg/L and at site three the total hardness, was 84.8mg/L. However, it was observed that at the control site the total hardness was 248mg/L which was higher than the contaminated sites. The total hardness from all sites except the control less than the assigned WHO value, the obvious difference between the polluted sites and the control site avails that the impact of tank farm activities compromises the quality of water from the Calabar River. This finding supported the findings of Mogborukor [2014] who noted that oil pollution can lower the hardness of water.

The fifth parameter assess was turbidity of the river. Turbidity is the measure of relative clarity of a liquid, and it is measured in Nephelometric Turbidity Units (NTU). Based on the result of the test, it was thus observed that the turbidity at site one was 0.10, turbidity at site two was 0.53 and the turbidity at site three was 0.76. It was observed that at the control site, the turbidity was 0.10 as seen in Table 5. Due to the low turbidity of the river, it can be thus concluded that the activities of the tank farm do not affect the turbidity of river, while the turbidity at the control site was within the limit of the WHO standard. The finding refute the findings of Nwachukwu and Osuagwu [2014] who concluded that oil pollution affects water turbidity. The sixth parameter assessed was the total dissolved solid TDS (mg/L) (Table 5). The TDS represents the total concentration of dissolved substances in water. The result of water test on TDS showed that at site one the TDS was 34.8mg/L, at site two the TDS was 15.4mg/L and site three the TDS was 12.1mg/L. At the control site, the TDS was

500mg/L. It was observed that the values of TDS at the polluted site was lesser than the assigned WHO values but the value of TDS at the control site was same with the WHO standard. In line with the finding, Nwachukwu and Osuagwu [2014] noted that oil spillage can distort the total dissolve substance of water, hence reducing the quality.

The seventh parameter tested was the sulphate ion of the water as visible in Table 5. The result of the analysis showed that the sulphate content of the water was 6.20mg/L, 6.80mg/L and 5.90mg/L for site one, two and three respectively. However, at the control site the sulphate level was 0.018mg/L. Hence, it was thus noted that the sulphate composition at the contaminated site was higher than the stipulated WHO amount of 0.10mg/L. The implication of the increased sulphate ion may be as a result of other parameters that were meant to be equal to WHO standard but are observed to be highly below the WHO guideline. This agrees with the findings of Devalsam et al 2016 and Oshinye 2000 who attributed water contamination to industrial waste. Finally, the eleventh parameter tested was the iron content of water (mg/L) as visible in Table 5. It was thus observed that at site one the iron content of the water sample was 2.30mg/L, at site two the iron content of the water sample was 0.20 mg/L and at site three the iron content was 0.40 mg/L. However, at the control point, the iron content was 0.03 mg/L. It was observed that the value of the iron content of water at control site was lower than the WHO assigned value, while the value at the contaminated site was higher than the WHO assigned value of 0.20 mg/L, hence, it was concluded that the activities of the tank farms affect the quality of water. This finding correlated with the findings of Muhammad *et al* [2020]. In summary, the test of the 15 parameters showed that petroleum tank farm activities slightly affects the water quality of the river at the contaminated sites. Furthermore, the test of hypothesis one design for the objective showed that that is there is a significant impact of the activities of the tank farm on water quality. This finding is similar to the finding of Dirisu *et al*[41] who concluded that anthropogenic activities such as oil spillages can result in decreased water quality.

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Table 5: Assessment of the water quality of the river

Parameter	Control Point				Site One				Site Two				Site Three				WHO Standard
	Morning	Afternoon	Evening	Average	Morning	Afternoon	Evening	Average	Morning	Afternoon	Evening	Average	Morning	Afternoon	Evening	Average	
pH	7.03	6.98	7	7.01	7.2	6.8	6.4	6.8	6.9	8.6	6.3	7.27	6.5	6.8	7.9	7.06	6.2 -8.5
Temperature (°C)	20.2	26.5	27.8	24.8	25.6	26.5	27.8	26.6	24.8	26.5	28.5	26.6	29.5	26	25.6	26.9	25
Electric Conductivity	2.43	5.44	4.55	4.14	6.43	5.44	4.55	5.47	4.8	4.5	5.4	4.9	6.4	8.6	3.8	6.26	2500
Total Hardness (mg/L)	250	251	243	248	37.5	40.5	58.9	45.6	26.5	64.6	84.6	58.5	95.6	77	82.3	84.8	250
Total Dissolved Solids (mg/L)	521	508	443	500	28.5	30.6	45.3	34.8	19.4	10.5	16.5	15.4	10.3	12	14.5	12.1	500
Turbidity (NTU)	1.5	1.5	1.6	1.5	0.07	0.08	0.15	0.1	0.01	1	0.6	0.53	0.9	0.7	0.7	0.76	1.5
Sulphate ion (mg/L)	0.1	0.1	0.1	0.1	0.1	6.3	7.8	6.2	2	9	9.6	6.86	4.6	7.8	5.4	5.93	0.1
Phosphate ion (mg/L)	0.03	0.08	0.2	0.1	0.06	0.08	0.2	0.11	0.01	0.1	0.04	0.05	1.5	2.6	0.6	1.56	0.1
Nitrate (mg/L)	1.01	1.02	1.4	1.14	1.08	1.02	1.4	1.16	0.02	140	150	96.6	160	200	170	176.	50
Mangnese (mg/L)	0.02	0.06	0.02	0.03	0.05	0.06	0.02	0.04	0.02	0.04	0.05	0.04	0.06	0.1	0.25	0.14	0.05
Iron (mg/L)	0.02	0.06	0.02	0.03	1.5	2.4	3.05	2.32	0.06	0.2	0.6	0.28	0.3	0.4	0.5	0.4	0.2
Calcium (mg/L)	0.05	0.09	0.04	0.06	0.08	0.09	0.04	0.07	0.02	0.07	0.9	0.33	0.8	0.1	0.6	0.5	0.05
Chloride(mg/L)	1.1	2.1	3.15	2.12	1.8	2.1	3.15	2.35	0.05	215	150	121.	160	180	110	150	250
Total Coliform (cfu/100m)	5	30	20	18.3	10	30	20	20	16	10	15	13.6	20	46	25	30.3	0
Faecal coliform (cfu/100ml)	12	40	14	22	30	40	14	28	10	15	6	10.3	17	8	15	13.3	0

More so, independent sample t test was conducted to observe the impact of tank farm activities on water quality of Calabar River as shown below in table 6-8. The null and alternate hypotheses are stated below;

H₀: There is no significant impact of the activities of the tank farm on water quality

H₁: There is a significant impact of the activities of the tank farm on water quality

To test the hypothesis the water quality displayed in table 5 was adopted. The result obtained from the statistical test showed that at $t(8.23) = 15$, the level of

significance (p) = $0.033 < 0.05$ for the levene's test of equality, while the independent statistical result availed a level of significance (p) = $0.034 < 0.05$. Hence, the null hypothesis was rejected against the alternative hypothesis, that is there is a significant impact of the activities of the tank farm on water quality.

Assessment of the water quality index of the river

Large volumes of water quality data can be categorized using the Water Quality Index (WQI) into

Table 6: Independent Test Result for Hypothesis One

Group Statistics					
	Sites	N	Mean	Std. Deviation	Std. Error Mean
Pollution	Control Site	15	11.2	9.12	8.56
	Pollution Site	15	12.2	11.2	2.35

Table 7: Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means	
		F	Sig.	T	Df
Pollution	Equal variances assumed	8.02	-.033	8.23	15
	Equal variances not assumed			9.67	13.4

Table 8: Independent Samples Test

		t-test for Equality of Means				
		Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference Lower	95% Confidence Interval of the Difference Upper
WQI	Equal variances assumed	.003	-7.67	8.23	12.0	-12.0
	Equal variances not assumed	.002	-6.67	8.45	-12.4	-12.4

straightforward categories (such as excellent, good, poor, etc.) for consistent reporting to management and the general public [Ediagbonya, et al 2015]. The weighted arithmetic index approach, which was utilized in the study, assessed the overall quality of the water using a criterion set by Brown et al. [1972] and further predicted whether the quality of the water poses a possible risk to various uses, particularly for human consumption. Based on the evaluation of the four sites' water quality index calculations, specifically the controlled site and the polluted sites shown in Tables 9–12, Table 13 presents the results of the water quality index. The results of the WQI study showed that the WQI of site one was 86.4, indicating that the water quality was contaminated, the

rating at site two was 74.6, indicating that the water was contaminated, and the WQI at site three was 91.0, indicating that the water is once again extremely contaminated. However, the controlled site's water index was 11.1 and was deemed to be outstanding. The findings of Eljaiek-Urzola et al [2019] were supported by this finding, which showed that the water quality index is a crucial instrument for assessing the overall quality of water. Additionally, the outcome of the statistical test for the variation in water quality index revealed a substantial difference in the index of water pollution between the control site and contaminated site. This result was comparable to that of Eljaiek-Urzola et al [2019].

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Table 9: Water Quality Index(WQI) at Control Site

Parameter	WHO (Sn)	1/Sn	$\sum 1/sn$	$K=1/\sum 1/sn$	$Wn=k/Sn$	Ideal Value	Mean Conc. (vn)	vn/sn	$(vn/sn)*100=(Qn)$	$WnQn$ (WQI)
Ph	7	0.142857	65.8	0.015198	0.002171	7	7.066667	0.97	97	0.210595
Temperature (°C)	25	0.04	65.8	0.015198	0.000608	0	26.9	1.076	107.	0.06541
Electric Conductivity	2500	0.0004	65.8	0.015198	6.08E-06	0	6.266667	0.002507	0.25	1.52E-06
Total Hardness (mg/L)	250	0.004	65.8	0.015198	6.08E-05	0	84.8	0.3392	33.9	0.002062
Total Dissolved Solids (mg/L)	500	0.002	65.8	0.015198	3.04E-05	0	12.13333	0.024267	2.42	7.38E-05
Turbidity (NTU)	1.5	0.666667	65.8	0.015198	0.010132	0	0.766667	0.511111	51.1	0.517843
Phosphate ion (mg/L)	0.1	10	65.8	0.015198	0.151976	0	0.003	0.34	34	5.167173
Nitrate (mg/L)	50	0.02	65.8	0.015198	0.000304	0	0.034	0.00068	0.06	2.07E-05
Manganese (mg/L)	0.05	20	65.8	0.015198	0.303951	0	0.0043	0.086	8.6	2.613982
Calcium (mg/L)	0.05	20	65.8	0.015198	0.303951	0	0.0043	0.086	8.6	2.613982
Chloride(mg/L)	250	0.004	65.8	0.015198	6.08E-05	0	150	0.6	60	0.003647
Total Coliform (cfu/100m)	0	0	65.8	0.015198	0	0	30.33333	0	0	0
Faecal coliform (cfu/100ml)	0	0	65.8	0.015198	0	0	13.33333	0	0	0
		65.8			1					11.194

Table 10: Water Quality Index (WQI) at Site 1

Parameter	WHO (Sn)	1/Sn	$\sum 1/sn$	$K=1/\sum 1/sn$	$Wn=k/Sn$	Ideal Value	Mean Conc. (vn)	vn/sn	$(vn/sn)*100=(Qn)$	$WnQn$ (WQI)
PH	7	0.142857	65.8	0.015198	0.002171	7	6.8	0.97	97	0.210595
Temperature (°C)	25	0.04	65.8	0.015198	0.000608	0	26.63333	1.065333	106	0.064762
Electric Conductivity	2500	0.0004	65.8	0.015198	6.08E-06	0	5.473333	0.002189	0.21	1.33E-06
Total Hardness (mg/L)	250	0.004	65.8	0.015198	6.08E-05	0	45.63333	0.182533	18.2	0.00111
Total Dissolved Solids (mg/L)	500	0.002	65.8	0.015198	3.04E-05	0	34.8	0.0696	6.96	0.000212
Turbidity (NTU)	1.5	0.666667	65.8	0.015198	0.010132	0	0.1	0.066667	6.66	0.067545
Phosphate ion (mg/L)	0.1	10	65.8	0.015198	0.151976	0	0.113333	1.133333	113	17.22391
Nitrate (mg/L)	50	0.02	65.8	0.015198	0.000304	0	1.166667	0.023333	2.33	0.000709
Manganese (mg/L)	0.05	20	65.8	0.015198	0.303951	0	0.043333	0.866667	86.6	26.34245
Calcium (mg/L)	0.05	20	65.8	0.015198	0.303951	0	0.07	1.4	140	42.55319
Chloride(mg/L)	250	0.004	65.8	0.015198	6.08E-05	0	2.35	0.0094	0.94	5.71E-05
Total Coliform (cfu/100m)	0	0	65.8	0.015198	0	0	20	0	0	0
Faecal coliform (cfu/100ml)	0	0	65.8	0.015198	0	0	28	0	0	0
		65.8			1					86.46

Table 11: Water Quality Index (WQI) at Site 2

Parameter	WHO (Sn)	1/Sn	$\sum 1/sn$	$K=1/\sum 1/sn$	$Wn=k/Sn$	Ideal Value	Mean Conc (vn)	vn/sn	$(vn/sn)*100=(Qn)$	$WnQn$ (WQI)
PH	7	0.142857	65.8	0.015198	0.002171	7	7.266667	0.97	97	0.210595
Temperature (°C)	25	0.04	65.8	0.015198	0.000608	0	26.6	1.064	106	0.064681
Electric Conductivity	2500	0.0004	65.8	0.015198	6.08E-06	0	4.9	0.00196	0.19	1.19E-06
Total Hardness (mg/L)	250	0.004	65.8	0.015198	6.08E-05	0	58.56667	0.234267	23.4	0.001424
Total Dissolved Solids (mg/L)	500	0.002	65.8	0.015198	3.04E-05	0	15.46667	0.030933	3.09	9.4E-05
Turbidity (NTU)	1.5	0.666667	65.8	0.015198	0.010132	0	0.536667	0.357778	35.7	0.36249
Phosphate ion (mg/L)	0.1	10	65.8	0.015198	0.151976	0	0.05	0.5	50	7.598784
Nitrate (mg/L)	50	0.02	65.8	0.015198	0.000304	0	96.67333	1.933467	193	0.058768
Manganese (mg/L)	0.05	20	65.8	0.015198	0.303951	0	0.036667	0.733333	73.3	22.28977
Calcium (mg/L)	0.05	20	65.8	0.015198	0.303951	0	0.286667	1.45	145	44.07295
Chloride(mg/L)	250	0.004	65.8	0.015198	6.08E-05	0	121.6833	0.486733	48.6	0.002959
Total Coliform (cfu/100m)	0	0	65.8	0.015198	0	0	13.66667	0	0	0
Faecal coliform (cfu/100ml)	0	0	65.8	0.015198	0	0	10.33333	0	0	0
		65.8			1					74.66

Table 12: Water Quality Index (WQI) at Site 3

Parameter	WHO (Sn)	1/Sn	$\sum 1/sn$	$K=1/\sum 1/sn$	$Wn=k/Sn$	Ideal Value	Mean Conc. (vn)	vn/sn	$(vn/sn)*100=(Qn)$	$WnQn$ (WQI)
PH	7	0.142857	65.8	0.015198	0.002171	7	7.066667	0.97	97	0.210595
Temperature (°C)	25	0.04	65.8	0.015198	0.000608	0	26.9	1.076	107	0.06541
Electric Conductivity	2500	0.0004	65.8	0.015198	6.08E-06	0	6.266667	0.002507	0.25	1.52E-06
Total Hardness (mg/L)	250	0.004	65.8	0.015198	6.08E-05	0	84.8	0.3392	33.9	0.002062
Total Dissolved Solids (mg/L)	500	0.002	65.8	0.015198	3.04E-05	0	12.13333	0.024267	2.42	7.38E-05
Turbidity (NTU)	1.5	0.666667	65.8	0.015198	0.010132	0	8.53	10.45	104	10.58764
Phosphate ion (mg/L)	0.1	10	65.8	0.015198	0.151976	0	10.45	1.76	176	26.74772
Nitrate (mg/L)	50	0.02	65.8	0.015198	0.000304	0	176.6667	4.56	456	0.138602
Manganese (mg/L)	0.05	20	65.8	0.015198	0.303951	0	0.136667	0.893	89.3	27.14286
Calcium (mg/L)	0.05	20	65.8	0.015198	0.303951	0	0.023	0.86	86	26.13982
Chloride(mg/L)	250	0.004	65.8	0.015198	6.08E-05	0	150	0.6	60	0.003647
Total Coliform (cfu/100m)	0	0	65.8	0.015198	0	0	30.33333	0	0	0
Faecal coliform (cfu/100ml)	0	0	65.8	0.015198	0	0	13.33333	0	0	0
		65.8			1					91.03

Table 13: Water Quality Index Result

Site	WQI	Water Quality
Site One	86.4	Very poor water
Site Two	74.6	Very poor water
Site Three	91.0	Very poor water
Control Site	11.1	Excellent

In addition, an independent sample t test statistic was adopted in examining the differences in water quality index between control point and the polluted sites as displayed in table 13-15. The null and alternate hypotheses were stated below:

H₀: There is no significant variation in water pollution index between the control site and polluted site

H₁: There is a significant variation in water pollution index between the control site and polluted site

The result obtained from the statistical test showed that at $t(0.23) = 15$, the level of significance $(p) = 0.023 < 0.05$ for the levene's test of equality, while the independent statistical result availed a level of significance $(p) = 0.022 < 0.05$. Hence, the null hypothesis was rejected against the alternative hypothesis, which is there was a significant variation in water pollution index between the control site and polluted site.

Table 13: Independent Test Result for Hypothesis One

Group Statistics					
	Sites	N	Mean	Std. Deviation	Std. Error Mean
WQI	WQI of Control Site	1	0.78	0.65	1.1
	WQI Pollution Site	1	0.88	0.78	0.86

Table 14: Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means	
		F	Sig.	T	df
WQI	Equal variances assumed	8.02	.023	0.23	2
	Equal variances not assumed			0.67	1.78

Table 15: Independent Samples Test

		t-test for Equality of Means				
		Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference Lower	95% Confidence Interval of the Difference Upper
WQI	Equal variances assumed	-.002	-0.98	0.45	-1.08	-1.08
	Equal variances not assumed	-.002	-0.78	0.55	-1.01	-1.01

Conclusion

Over the years, oil leaks from petroleum tank farms have contaminated and degraded the potential utility of fresh water sources, changing the way some locals live and causing the extinction of indigenous species in the studied region. The study's conclusions showed that the Calabar river's water quality was impacted by

the operations of a petroleum tank farm. The majority of the 15 criteria used to evaluate the impact of water quality came within or below WHO standards, while the sulfate level was much higher than the WHO threshold. Additionally, some metrics like as EC, hardness, TDS, and temperature varied between the controlled and contaminated sites. Except for the

control site, which was excellent, the estimation of the Water quality index result showed that all three sites were very contaminated. The T-test result demonstrates that the activities associated with the petroleum tank farm have a considerable impact on the water quality, and the second objective verifies yet another significant difference in the water quality index between the control site and contaminated site. According to the experts, the best way to reduce the

danger of negative effects from petroleum storage tank farms is to put in place a structured management plan that outlines the conditions, procedures, and roles necessary for the system's operation and administration. To clean the water's surface and remove the oil films that cover the river's surface, tank farms should implement the usage of bio-remediation techniques.

Declaration of Competing Interest

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Authors' Contributions

Alexander Oko: Project conceptualization, design, writing, analysis and results extraction.

Lucy Emmanuel Afahanam: Writing, editing and manuscript first draft.

Imoke D. Eni: Resources, review and supervision.

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