

ENVIRONMENTAL IMPACTS OF OIL SPILLS ON MARINE ECOSYSTEMS: A CASE STUDY OF THE NIGER-DELTA ENVIRONMENT.

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ABSTRACT

This work documented the effects of oil spills on the aquatic environment by analyzing changes in oil density, water chemistry and species abundance for 15 days in two locations in the Niger Delta. The main rationale was to assess the oil spill's environmental implications and determine the measures that should be implemented. Samples collected daily enabled measurements of the oil content, pH, and dissolved oxygen (DO) on the water surface. Key equipment included spectrophotometers for oil concentration analysis and multiparameter water quality tools for pH and DO measurements. Statistical tools such as regression analysis and ANOVA were employed to evaluate the data. Results indicate a significant decline in oil concentration at both sites. The results of Site A were reduced from 250 µg/L to 170 µg/L, having a regression slope of -5.33 µg/L per day ($p < 0.01$). Site B's concentration dropped from 320 µg/L to 250 µg/L, with a slope of -4.67 µg/L per day ($p < 0.01$). Water quality also deteriorated, with Site A's pH dropping from 7.8 to 6.4 and DO from 8.5 mg/L to 7.1 mg/L. Site B exhibited similar trends, with pH decreasing from 7.9 to 6.5 and DO from 8.6 mg/L to 7.2 mg/L. The results of the ANOVA analysis indicated that the fish population significantly declined at both sites and to this extent, Site A lost eight kinds of fish while Site B lost only 10 ($p < 0.01$). Therefore, the study found that the oil spill adversely impacts water quality and the nature of various organisms. These discoveries would help in the current state of knowledge by quantifying the effects of oil spillage and proposing an improved approach to environmental management, which includes but is not limited to effectively mitigating the effects of oil spillage by increasing the monitoring of the effects and rendering timely remediation solutions, and engaging various stakeholders, enforcing strict measures and constantly monitoring the environment.

Keywords: *Environmental impacts, Marine Ecosystems, Niger Delta, Nigeria, Oil spills*

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INTRODUCTION

This research strived to extensively assess oil spills' impacts on the provision of marine ecosystems, especially in the Nigerian setting. Specifically, this research aimed to proactively synthesize the potential interactions of oil spills with the marine ecosystem in Nigeria. Oil spills have been described as major environmental threats that have a devastating inimical impact on vast marine habitats. The incidents indicate a prolonged and extensive impact, disrupting both ecological systems and the financial stability of communities residing in the affected regions. Nigeria is widely acknowledged globally for its considerable oil reserves (Osunmuyiwa and Kalfagianni, 2017; Olayungbo, 2019).

Nevertheless, the nation has faced recurring oil spills in the Niger Delta area, resulting in significant consequences. The Niger Delta, which functions as the central hub for oil production in Nigeria, has witnessed a notably more significant occurrence of oil spill incidents than other African regions (Ordinioha and Brisibe, 2013; Chinedu and Chukwuemeka, 2018). Hence, one cannot fail to conclude that this region is among the most affected in the whole of the continent. Oil spills are one of the most well-known and widespread forms of marine pollution, significantly harming the marine environment globally (Martínez-Gómez *et al.*, 2010; Nordborg *et al.*, 2018). One of them is the pollution of the world's oceans, which is extensive and well-known, and this problem significantly affects all aquatic habitats. Oil extraction has significant and persistent implications for the environment, economy, and long-term outcomes. The repercussions of oil spills encompass the degradation of ecosystems, such as coral reefs, and the impoverishment of biodiversity (Johannes *et al.*, 1972; Johansson *et al.*, 2016).

Moreover, this environmental pollution carries significant health implications for the African continent, given its status as the foremost oil producer. Crude oil exports, as well as natural gas exports, remain the primary source of the export revenue. The Niger Delta, which is the seventh largest delta-marginal by land size, is located in the southern part of Nigeria, covering about 70,000 square kilometres, and is naturally endowed with magnificent ecological qualities. The wetland ecosystem is marked by predominance and elaborateness; hence, it is considered one of the most productive and diverse ecosystems globally.

This study area is characterized by a vast network of channels of creeks, which are inlets of the sea and extensive mangrove swamps (Green, 2022; Ikeke, 2020). Situated in the south-south region of Nigeria, the Niger Delta, which is the largest basin in Africa, provides a central area of Nigeria's oil and gas production, contributing well over 80 % of Nigeria's oil production (Akpan and Akpabio, 2003). Despite the economic benefits of the oil sector, Nigeria has experienced numerous oil spills, which have had significant repercussions on the marine ecosystem, public health, and the welfare of indigenous communities. On the negative side, the impacts of oil have been articulated in different facets of literature, especially the effects on the marine environment (Arnber *et al.*, 2018). Some of the various cases of oil spills that have occurred, which can be attributed to the operational factors and the sabotaging features, have raised many questions about the impacts of such disasters on environmental destruction, whereby the sensitive marine life in the area of focus is affected. The occurrence of oil spills, whether of large quantity or consistently over time, presents complex and diverse conducive threats to the marine environment in the area affected in the Niger Delta. This is not just limited to water pollution due to undesirable sedimentation but also affects the health of aquatic life, including fish, birds, and mammals in the water body. This would make it rather easy to conclude that in order to achieve proper protection and

management for the exceptionally fragile ecosystem of the region, greater effort has to be put into comprehending the impacts and the details of these impacts to define the best strategy that should be employed to mitigate and eradicate these impacts effectively. This study undertakes an analysis of the effects of oil spills with a focus on the ecological impacts in the Niger Delta with the use of analytical frameworks. This research on the effects of oil spills explores the impact in several aspects, namely, Oil distribution in water samples, Sediment Total petroleum hydrocarbon (TPH), Water quality pH and DO, and the effect on fish and bird populations. Thus, initiating this study will significantly contribute toward understanding the intricate relationship between the effects of hydrocarbon contaminations and the welfare of the marine environment in the strategically important area.

Furthermore, the ecological splendour of the Niger Delta has been overshadowed by a persistent and formidable issue - occurrences of oil spills. Nigeria has experienced numerous oil spills from industrial operations and illicit activities, leading to an estimated annual release of 240,000 barrels of oil into the surrounding ecosystem (Olujobi *et al.*, 2018). The presence of these spills leads to the pollution of aquatic environments, the saturation of sediment, and the entry into the food chain, thereby endangering the ecosystem and the welfare and economic stability of the communities inhabiting the delta region. It also causes fluctuations in the oil concentrations found in water samples. It disrupts the integrity of sediment, leading to long-term effects on water quality parameters, particularly pH and Dissolved Oxygen (DO) levels (Bruederle and Hodler, 2019). Equally concerning is the notable influence on the region's biodiversity, as demonstrated by the decrease in fish and bird populations, which are indicators of ecological adversity.

Oil spills can cause major environmental consequences on marine ecosystems. These spillages harm marine organisms, destroy natural habitats, and pollute aquatic environments. Oil released due to spills can infiltrate sediment and harm marine organisms, such as fish and other fauna that reside in the benthic zone (Powers *et al.*, 2013). Oil-producing communities have experienced substantial ecological degradation, negatively impacting their cultural practices and livelihoods, specifically in agriculture and fishing activities (Brussaard *et al.*, 2016).

Furthermore, the study unveiled that oil spills can influence fishing activities, leading to economic consequences for fishermen and their households. Oil pollution in Ogoni Land, Nigeria, impacts microbial diversity with worrisome levels of total petroleum hydrocarbon, polyaromatic aromatic hydrocarbon, iron, chromium, and nickel (Ediae *et al.*, 2020). Extremely relevant to the ecological state, there is a calm necessity for major changes in the approach to address this issue, with importance to the pollution of the soil and water bodies due to the oil leakages and further exposure to toxic agents (Madu *et al.*, 2018).

STUDY AREA: THE NIGER DELTA REGION

This research focuses on the Niger Delta region as a 70 000 square kilometres geographical area in Nigeria, characterized by wetlands and other fauna and flora resources. This area is densely endowed with Nigeria's oil activities, companies, and structures. At the same time, the area has also been experiencing the devastating effects of oil spillage and loss of trees through some effects like erosion control, loss of water resources, etc. The region's ecosystem, comprising freshwater bodies, mangrove forests, and low-lying tablelands, supports varieties of fisheries and avian migrations. It also gives the region some socio-

economic importance based on its culture and dependency on the natural region. The research is centred on certain sampling locations across the place called the Niger Delta region in a bid to properly analyze and evaluate the effects of oil spills on marine life as well as water quality in the long run.

Objectives of the study: Given the challenges above, the current study seeks to establish the following: - the effects of oil spills on the ecosystem of the Niger Delta. It is for this reason that the primary aim of this research is to gain a better understanding of such involved processes through a detailed analysis of the pattern in the concentration of oil in water samples, TPH in the sediment, relationships between water quality parameters and changes in the fish and birds population. Oil spills further threaten our environment in various ways, and looking at the quantity means ensuring that better policies are developed to address such issues and that general information on effective conservation practices is enhanced. This approach allows the continuous economic development of the region during the probable future and reiterates such importance due to its status as an extraordinary geophysical formation.

MATERIALS AND METHODS

This study, which was conducted for fifteen days, involved an environmental survey to examine the impact of oil on certain ecological factors at sites A and B. The ongoing study first involved the selection of sites and sampling. Consequently, two research sites with different oil pollution levels were chosen, as demonstrated by site inspection research studies. Water, sediments, and biological samples were collected daily through periodical collections to check up on changes in these subjects in these areas.

Water samples were collected in clean and non-corroding bottles at the same depths and time as each day's temperature and salinity measurements. These samples were analyzed using gas chromatography, and the concentration of hydrocarbons was determined and presented in $\mu\text{g/L}$, as indicated in Figure 1 below. In addition, the second aspect of water quality includes the physical characteristics such as pH and DO, which were established from the portable pH meters and DO meters, respectively, which were calibrated during the sampling and shown in Table 2 below.

A grab sampler was used to ensure that the sediment samples collected were of the same depth and volume. The TPH concentration in the collected sediment samples was analyzed using the Infrared spectroscopy technique, which shows the level of hydrocarbon in mg kg^{-1} , as provided in Figure 2.

As with the fish and birds, data were collected daily concerning their presence in the river and the total number of such species. Fish population density, species richness, and the quantity of fish per unit volume of water were obtained using a net placed in the water, and the identification of the type of fish present in the water was based on the number of fish found in the water every day as seen in figure 3. The bird population was estimated from their documented counts and a minimum number of identified species at the observation stations; results are presented in Figure 4.

The researchers' schedules were also alike for both sites and contained standardized protocols. Water and sediments were sampled early in the morning to retain the samples' integrity in the laboratory; otherwise, they may degrade or be contaminated. These routine parameters include pH and dissolved oxygen (DO), which were done alongside collecting pollution samples. Fish and birds were examined during the different periods to capture the species in their active states since the surveys were done in the morning and the evening.

The water samples were analyzed in the laboratory within 24 hours to avoid quality loss. Each collected sediment sample was treated to obtain hydrocarbons and spectrophotometrically measure the concentration of TPH. Water quality parameters and biological indices data taken from the field were compiled and analyzed statistically to determine the trend in 15 days.

The results, depicted in Tables 1-2 and Figures 1-4, illustrate a clear trend of declining oil concentrations and TPH levels over the study period, indicating a gradual natural attenuation of contaminants. Other water quality factors, like the pH of water and dissolved oxygen, were not drastically affected. However, they also preserved a constant but small negative variation, denoting that oil pollution affects aquatic life. The total abundance of fish and birds also reduced over time, thus exhibiting the impact of oil pollution on the region's biological diversity.

Statistical analysis: In the field, the results of measurements and biological assessment collected over the 15 days were documented, compiled, and quantitatively analyzed using descriptive statistics to make valid conclusions about oil contamination at Site A and Site B. Tests such as analysis of variance (ANOVA) were used to assess the ecological effects of the oil spillage on the fish stock. Regression analyses were used to determine TPH concentration levels.

RESULTS

The results of the study are presented in Figures 1, 2, 3, 4 and Tables 1 and 2

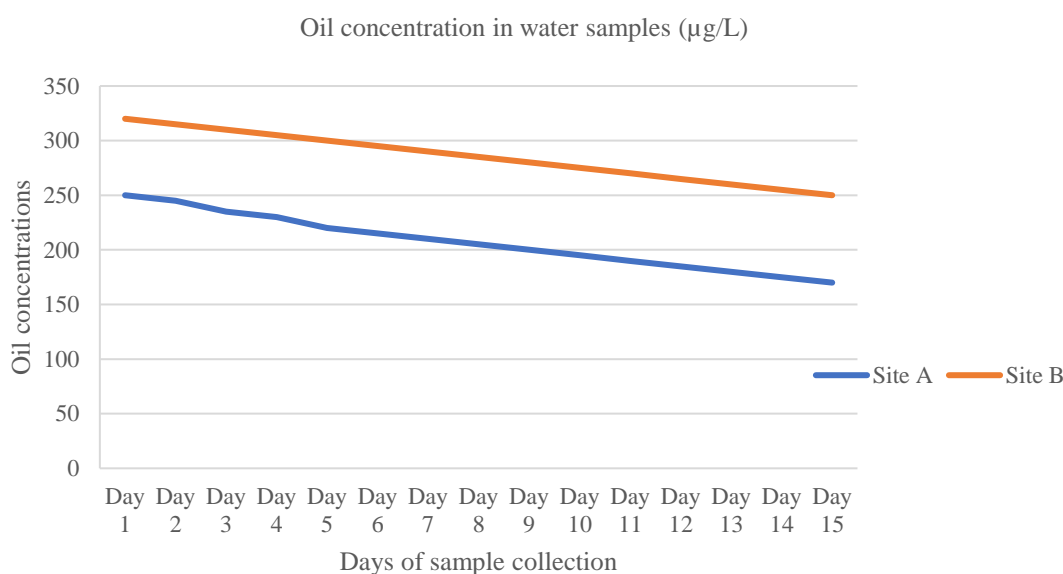


Figure 1: Oil concentration in water samples (µg/L)

Figure 1 shows the oil concentration in water samples, measured in micrograms per liter (µg/L), over 15 days for Site A and Site B. Site A recorded an oil concentration of 250 µg/L on day one. The concentration decreased gradually over the next 14 days, finally measuring 170 µg/L on the last day.

Similarly, the initial oil concentration in Site B was 320 µg/L on day 1. It gradually decreased to 5 µg/L per day, reaching 315 µg/L on day 1, and decreased gradually to 250 µg/L on the 15th. In summary, both sites showed a steady day-to-day decrease in oil content, suggesting a gradual natural decline in the oil content of the water in both areas.

Total petroleum hydrocarbon (TPH) in sediment samples

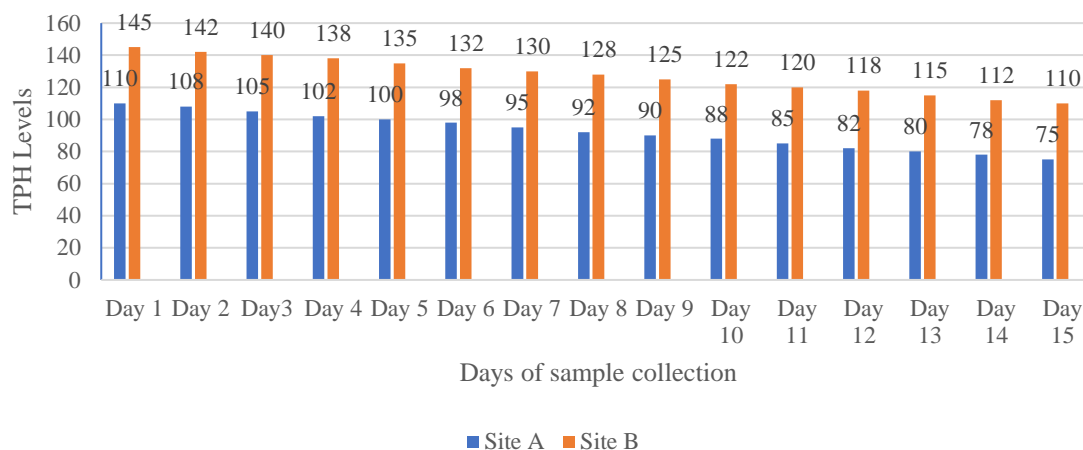


Figure 2: Total petroleum hydrocarbon (TPH) levels in sediment samples (mg/kg)

In Figure 2, the TPH levels in sediment samples in milligrams per kilogram (mg/kg) recorded over 15 days for Site A and Site B were shown, starting from 110 mg/kg and 145 mg/kg on day 1, decreasing to 75. mg/kg and 110 mg/kg on the 15th day for Sites A and B, respectively. Similarly, Site B measured an initial TPH level of 145 mg/kg on the first day. However, the value persistently decreased throughout the study, reducing to 110 mg/kg on the 15th day.

In summary, both sites showed a clear decreasing trend in TPH levels over the 15 days. Site A showed a total decrease of 35 mg/kg, while Site B recorded a total reduction of 35 mg/kg. These consistent reductions suggest effective natural attenuation processes are at work in reducing the TPH contamination in the sediment over time at both sites. Also, the level of total petroleum hydrocarbon in sediment samples was estimated, as shown in Table 1.

Table 1: Regression analysis for TPH Levels in sediment samples (Site A and Site B)

| Site A | | Site B | |
|-------------------------|--------|-------------------------|--------|
| Statistic | Value | Statistic | Value |
| Intercept (β_0) | 111.57 | Intercept (β_0) | 146.57 |
| Slope (β_1) | -2.33 | Slope (β_1) | -2.33 |
| Standard Error of Slope | 0.15 | Standard Error of Slope | 0.16 |
| R-squared (R^2) | 0.98 | R-squared (R^2) | 0.97 |
| F Value | 240.23 | F Value | 213.76 |
| P Value | < 0.01 | P Value | < 0.01 |

The regression analysis (Table 1) offers a detailed understanding of the trends in TPH levels in sediment samples over the 15 days for both sites. The intercept (β_0) for Site A (111.57) and Site B (146.57) represent the estimated TPH level at Day 0, slightly above the actual starting value due to the regression line fitting process. The F value, which indicates the overall significance of the regression model, was 240.23 for Site A and 213.76 for Site B, which affirms that the regression model is statistically significant. Also, the P value for both sites was less than 0.01, indicating that the slope is significantly different from zero and that the decline in TPH levels over time was statistically significant.

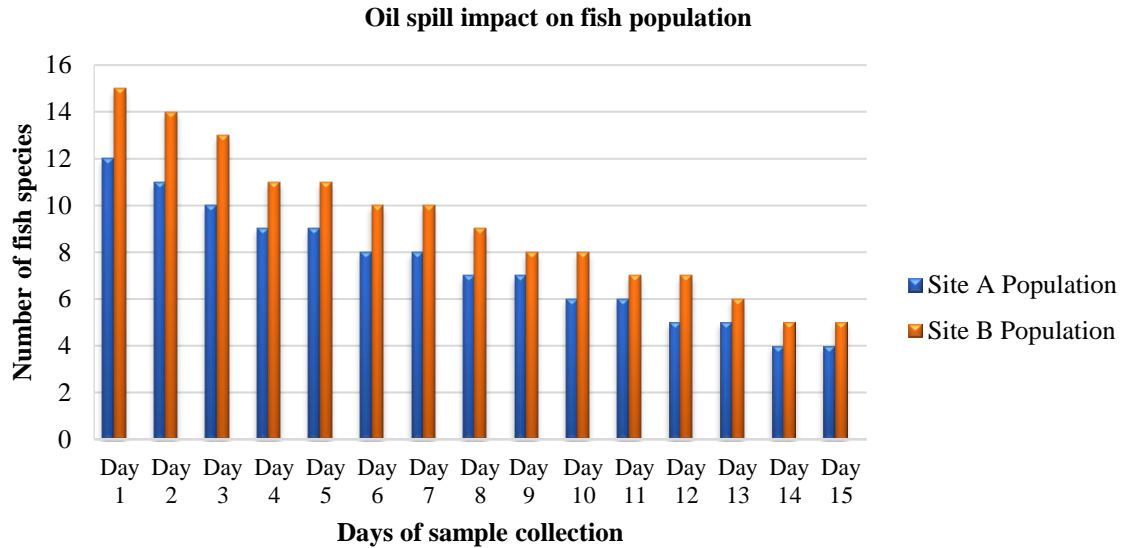


Figure 3: Impact of oil spills on population of fish species

In Figure 3, a stacked area chart was used to explain the impact on the fish population (number of species) over time at Site A and B over 15 days. The number of fish species was 12 on Day 1. A few days later, the population decreased steadily, with the number of species falling to 9 on the fourth day and remaining stable at 9 through Day 5. The reduction resumed, with eight species recorded on Days 6 and 7, persisting until finally decreasing to 4 species on Days 14 and 15.

The initial number of fish species was higher at Site B, starting at 15 on the first day. A similar declining pattern was observed, with the species count decreasing to 14 on Day 2 and 13 on Day 3. This steady decline continued throughout the study, ultimately decreasing to 5 species on Day 14 and maintaining this count until the 15th day.

In summary, both sites exhibited a clear decline in fish species over the 15 days. At the start of the study, Site A and Site B had dissimilar numbers of fish species, with fishes in Area B showing a higher characteristic abundance. However, as the study progressed, fish populations decreased at both sites. By Day 15, there were fewer fish species at both locations, with Site B having a slightly higher number of remaining species. The impact of oil spills on the fish in Site B could be less debilitating.

Table 2: Water Quality Parameters (pH and Dissolved Oxygen)

| Site | Day 1 | Day 2 | Day 3 | Day 4 | Day 5 | Day 6 | Day 7 | Day 8 | Day 9 | Day 10 | Day 11 | Day 12 | Day 13 | Day 14 | Day 15 |
|-------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|--------|--------|--------|--------|--------|--------|
| pH (Site A) | 7.8 | 7.7 | 7.6 | 7.5 | 7.4 | 7.3 | 7.2 | 7.1 | 7.0 | 6.9 | 6.8 | 6.7 | 6.6 | 6.5 | 6.4 |
| DO (SiteA) | 8.5 | 8.4 | 8.3 | 8.2 | 8.1 | 8.0 | 7.9 | 7.8 | 7.7 | 7.6 | 7.5 | 7.4 | 7.3 | 7.2 | 7.1 |
| pH (Site B) | 7.9 | 7.8 | 7.7 | 7.6 | 7.5 | 7.4 | 7.3 | 7.2 | 7.1 | 7.0 | 6.9 | 6.8 | 6.7 | 6.6 | 6.5 |
| DO (SiteB) | 8.6 | 8.5 | 8.4 | 8.3 | 8.2 | 8.1 | 8.0 | 7.9 | 7.8 | 7.7 | 7.6 | 7.5 | 7.4 | 7.3 | 7.2 |

Table 2 presents two water quality parameters, pH and dissolved oxygen (DO), measured over 15 days at Site A and Site B. These parameters are important indicators of aquatic health and capacity to support aquatic life. The pH value at Site A was 7.8 on day 1. On day 15, the trend toward pH 6.4 continued daily, while there was greater variability in

water acidity than observed. Similarly, the initial pH values at site B were slightly higher, starting from 7.9 on day 1, but gradually decreased to 6.5 on day 15. The pattern of pH decrease at Site B was similar to that at location A, indicating that a similar process was carried out in water at both locations, affecting the quality.

In addition, Site A's dissolved oxygen (DO) concentration showed a gradual decrease from the initial value of 8.5 mg/L on day 1 to 7.1 mg/L on day 15. A decrease in the DO concentration means decreased water oxygen levels, adversely affecting aquatic life. Dissolved oxygen also began to increase at Site B, 8.6 mg/L on day 1, and gradually decreased over 15 days until it reached 7.2 mg/L on day 15. Dissolved oxygen concentrations decreased and might adversely affect aquatic life. These factors could significantly impact aquatic ecosystems, affecting the health and diversity of aquatic species in these waters. The consequences of the above parameters on fish life are buttressed below in the Analysis of variance (ANOVA) table.

ANOVA table for fish population decline

Site A

| Source of Variation | SS (Sum of Squares) | df (Degrees of Freedom) | MS (Mean Square) | F Value | P Value |
|---------------------|---------------------|-------------------------|------------------|---------|---------|
| Between Days | 360.00 | 14 | 25.71 | 32.64 | < 0.01 |
| Within Days | 11.50 | 30 | 0.38 | | |
| Total | 371.50 | 44 | | | |

Site B

| Source of Variation | SS (Sum of Squares) | df (Degrees of Freedom) | MS (Mean Square) | F Value | P Value |
|---------------------|---------------------|-------------------------|------------------|---------|---------|
| Between Days | 572.00 | 14 | 40.86 | 51.08 | < 0.01 |
| Within Days | 24.00 | 30 | 0.80 | | |
| Total | 596.00 | 44 | | | |

The ANOVA tables analyzed the decline in fish populations at Sites A and B over 15 days, confirming statistically significant changes. The F value of 32.64 and a P value less than 0.01 show a significant difference in fish species count across days. Similarly, Site B recorded an F value of 51.08 and a P value less than 0.01, indicating a significant decline in fish species. Both sites show that the decline in fish populations is statistically significant and likely due to oil contamination.

Impact of oil spills on bird species population

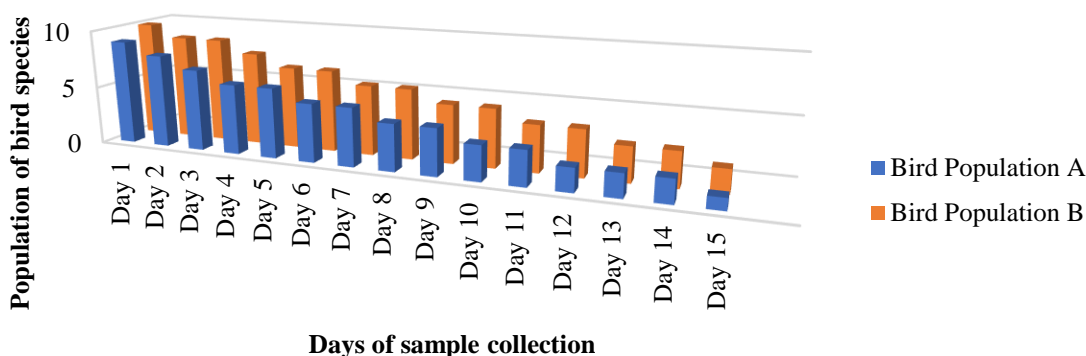


Figure 4: Impact of oil spills on bird species population

Figure 4 is a grouped bar chart illustrating the changes in bird populations (number of species) between Site A and Site B over the 15-day study period. Initially, both sites had a similar number of bird species with very slight differences.

As the study progressed, bird populations declined at both locations. By Day 15, Site A had fewer bird species than Site B, indicating potential negative impacts on bird populations in that area.

The above results showed that water quality is compromised by oil spills (Figure 1 and Table 2). Although it was noted that certain water bodies might show potential recovery in quality over time, the study believes that it remains critically hazardous for water to lose its natural state of purity. Oil spills petroleum hydrocarbons into the water, which biological or natural agents may not entirely degrade. It would consequently permeate ecological food chains, negatively impacting the well-being of both terrestrial and aquatic life forms.

DISCUSSION

Based on the findings of this study, the oil spill has a significant likelihood of negative repercussions for the water and sediments and their impact on fish and birds. This is clear from the diminished oil concentration in water samples, as illustrated in Fig 1, which was analyzed for fifteen days and corroborated statistically through regression analysis. The study by Lv *et al.* (2018) also shows natural attenuation as the main mechanism of reduction of the section of the contaminated aquifer by petroleum hydrocarbon plume, where it was reduced by over 60 per cent in four years through sulphate reduction and methanogenesis, thereby supporting this work.

Despite starting with different initial concentrations, both sites exhibited consistent daily decreases in oil concentration, indicating the effectiveness of natural remediation processes in reducing oil contamination levels in water bodies. Similarly, the TPH concentrations in sediment samples, also established and illustrated in Figure 2, indicated lower TPH concentration during the period under study, supported by the study of El-Din *et al.* (2021), which revealed lower TPH values in the pre-sedimentation analysis. This confirms that sediment matrices contain oil-related pollutants, and retention and subsequent attenuation occurred at different rates for every Site.

Furthermore, the analysis of water quality parameters, including pH and dissolved oxygen (DO) levels, underscores the adverse effects of oil spills on aquatic habitats. The consistent decline in pH levels and DO concentrations observed at Site A and Site B, as illustrated in Table 2 and supported by time-series analysis, highlights the deteriorating water quality conditions resulting from oil contamination. These changes can have profound implications for aquatic organisms, affecting their physiological functions and overall health. The significant decrease in fish and bird populations, as evidenced by Figures 3 and 4, further underscores the detrimental impacts of oil spills on biodiversity and ecosystem health. Ukhurebor *et al.* (2021) documented that petroleum spillages in the Niger Delta region of Nigeria result in irreparable environmental dilapidation and potential hazards to human health, agriculture, and the ecosystem in general. The species density and species numbers of both areas indicate that the current conditions of this area are not suitable for habitation and can have strong effects on the place where these vulnerable species dwell. Therefore, the variation and shifts in the degree and extent of Site A's and Site B's environmental degradation helped us appreciate the variation of oil spillage's impact. Thus, the changes in water and sediment quality and fish and bird populations at the two sites were as follows: This was still less in Site B than in Site A, though, again, to a small degree only and perhaps because more species were available for selection in the case of the latter. This might be due to various effects that include regional variation in conditions that govern access to water, regional characteristics of the environment the system is located in, and the intrinsic ability of the system to self-regenerate after a disturbance. All the trends used in the study indicate the need to prevent oil spills and devise remediation techniques each time these occurrences happen to minimize further nasty effects on the ecosystems.

In summary, this study underscores the multifaceted impacts of oil spills on aquatic ecosystems, emphasizing the interconnectedness of water quality, sediment contamination, and biodiversity loss. The study's implications also raise the significance of monitoring and management actions that can be taken to avert the destructive consequences of

oil pollution and facilitate the recovery of affected environments. The health and integrity of aquatic environments require preservation through conservation measures, strict policies, and the education of the general public in case of any environmental threats such as oil spills. This research shows that the effects of oil spills are nearly universal in the aquatic environment: excess nutrients, shifts in water and sediment texture, and reduced fish and bird populations. The studies have helped to ascertain the time series and geographical patterns of the environmental degradation index concerning oil contamination. This is based on a general reduction in oil concentration in water samples and Total Petroleum Hydrocarbon (TPH) levels in sediment samples, which depict that natural attenuation processes possibly work in reducing the effects of contamination for a period but at a slow rate at the different sampling sites. However, revelations in the concurrent alterations in other water quality parameters like PH and dissolved oxygen concentrations suggested that the impacts of oil spills are continuing and complex on the habitats. Moreover, the persistent decrease in fish and bird populations indicates the devastating effects of oil contamination on the environmental structure and overall functioning of various ecosystems. These findings support increased recognition and action to monitor and remediate the environmental impacts left by oil spills and prevent further detriment to marine life.

RECOMMENDATIONS

The following recommendations are made based on the study's findings to lessen the effects of oil spills on aquatic habitats. Firstly, monitoring and surveillance should control water quality and determine the presence of oil precursors. Secondly, using physical, chemical and biological methods of remediation processes is necessary for combating oil pollution in water and sediment. Thirdly, increasing the scope of communication with stakeholders and their awareness can contribute to preventing oil spills and providing measures for their elimination. It is necessary to enhance the enforcement of regulations to prevent oil leaks and punish offenders. Finally, it is important to increase funding for research and innovation to expand knowledge of the processes occurring in the context of oil spills and ways to prevent or minimize their potential harm. Combining such methodological strategies as scientific evidence gathering and stakeholder participation can promote effective oil spill prevention and minimize its negative effects on aquatic life and the environment in general.

CONFLICT OF INTERESTS

All authors declare that they have no conflicts of interest.

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