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Removal of Hydrocarbon from Produced Water by Phytoremediation Method, Using Water Hyacinth (Eichhornia Crassipes)

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ABSTRACT

The Niger Delta region faces significant environmental challenges due to the discharge of untreated or inadequately treated produced water from oil exploration activities. This study investigates the potential of water hyacinth (Eichhornia crassipes) as a phytoremediation agent to remove hydrocarbons and improve the quality of produced water. Produced water samples were collected from the Obagi Flow Station in Rivers State, Nigeria, and subjected to treatment with water hyacinth under controlled laboratory conditions. Key parameters such as Biological Oxygen Demand (BOD), Total Dissolved Solids (TDS), and Total Petroleum Hydrocarbons (TPH) were monitored over 35 days. The results demonstrated significant reductions in pollutant concentrations: BOD levels decreased by 71.3%, TDS by 76.5%, and TPH by 98.9%. These reductions were attributed to the plant's extensive root system, which facilitates pollutant absorption and microbial activity in the rhizosphere. The study highlights the scalability, cost-effectiveness, and environmental sustainability of phytoremediation, particularly in resource-constrained regions. This research underscores the potential of water hyacinth as a viable alternative to conventional produced water treatment methods, offering a sustainable approach to mitigating hydrocarbon pollution and protecting aquatic ecosystems in oil-producing areas. Recommendations include integrating phytoremediation with existing treatment systems and further exploring biomass utilization post-remediation to enhance the economic viability of this method.

Keywords: Produced Water, Phytoremediation, Water Hyacinth, Hydrocarbon Removal, Environmental Pollution, Niger Delta.

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I. INTRODUCTION

The global economy depends heavily on the oil and gas sector, which supplies vital energy resources and brings in large sums of money for the producing nations. But it also has a lot of environmental problems, particularly with regard to the management of generated water, which is the main waste stream from the extraction of oil and gas. A variety of contaminants, such as hydrocarbons, salts, heavy metals, and hazardous organic compounds like benzene, toluene, ethylbenzene, and xylenes (BTEX), as well as phenols and organic acids, are found in produced water, a consequence of the synthesis of hydrocarbons (Khatib & Verbeek, 2003). It is difficult to handle and dispose of because it frequently contains chemical additions, excessive salinity, and traces of naturally occurring radioactive materials (Veil et al., 2004). Over 98% of the waste produced by the oil and gas industry worldwide during exploration and production activities is produced water (Clark & Veil, 2009). In established oil fields, where water-to-oil production ratios frequently surpass 10:1, its volume is very high (Bader, 2007). Improper disposal of produced water has serious negative effects on the environment, including groundwater and surface water contamination, disturbance of aquatic ecosystems, and damage to local biodiversity (Guerra et al., 2011).

Inadequate treatment facilities and a lack of strict enforcement of environmental restrictions exacerbate the effects of generated water discharge in Niger Delta region of Nigeria. Nigeria is thought to produce more than one billion barrels of water a year, much of which is discharged into the environment without adequate treatment (Ajuzieogu et al., 2018). Rivers, streams, and wetlands become contaminated as a result of the released effluents' frequent overflow of the Department of Petroleum Resources' (DPR) allowable limits. Aquatic life and the livelihoods of nearby populations that depend on agriculture and fishing have suffered greatly as a result (Ukoli, 2022).

Conventional produced water treatment techniques, including thermal distillation, filtration, and chemical coagulation, have been used all over the world. Although these techniques are useful in lowering some pollutants, they are frequently costly, resource-intensive, and inappropriate for widespread use in underdeveloped areas (Mondal & Wickramarachchi, 2022). Moreover, supplementary or alternative methods may be required if these technologies are unable to fully eliminate hydrocarbons and other persistent organic pollutants (Ghasemi et al., 2014).

A viable substitute for mitigating the environmental effects of generated water is phytoremediation. This approach offers a low-cost and environmentally friendly way to eliminate, detoxify, or stabilize pollutants in soil and water by using plants (Ali et al., 2013). Water hyacinth (Eichhornia crassipes), one of the many plants employed in phytoremediation, has drawn special attention because of its quick development, wide root system, and excellent tolerance for contaminated environments (Reddy & DeBusk, 1985). This aquatic plant is a desirable option for treating complex wastewater streams, including generated water, due to its exceptional capacity to absorb heavy metals, nutrients, and organic contaminants (Odjegba & Fasidi, 2007).

The release of produced water that has not been properly treated presents serious environmental and financial problems. Widespread disregard for legal requirements in the Niger Delta has led to contaminated waterways, which have a negative impact on fisheries, aquatic ecosystems, and agricultural output (Ajuzieogu et al., 2018). Due to diminishing earnings, health hazards from contaminated water, and the loss of biodiversity that is essential to their livelihoods, local communities frequently suffer the most from these environmental effects (Ukoli, 2022). Despite the existence of regulatory structures like the DPR, enforcement is

still inadequate because of a lack of funding and technical resources. Even if they work well in affluent nations, traditional produced water treatment techniques are usually not feasible to implement in areas with limited resources. According to Guerra et al. (2011), this leads to the continued release of untreated or partially treated generated water into the environment, which exacerbates pollution levels and undermines efforts to attain sustainable oil production.

II. METHODS AND MATERIAL

A. Study location and experimental set-up

OML 58 lies in the Eastern Niger Delta, approximately 85-kilometer Northwest of Port Harcourt city. It is the only onshore OML within the NNPC/Total Energies Joint Ventures. It contains five fields: Erema, Olo, Ubeta, Obagi (the oldest field in the JV and one of the largest in Nigeria) and the Ibewa gas/condensate field. Oil production from OML started in 1966 from Obagi field while gas production started in 1999 from Ibewa. Gas export from the facility to Bonny NLNG is through the GTS1 while oil is exported to shell Bonny terminal through SPDC lines at Rumuekpe. Produced water sample needed was obtained from oil mining lease (OML) 58, Obagi Flow Station, Total Onshore Operation, in Rivers State, Nigeria, at a point before discharge. It was stored in 5L container which was sterilized using distilled water, and then transported to the laboratory. Produced water sample collected was labeled as PW. The aquatic macrophyte used for this experiment was Water Hyacinth (Eichhornia Crassipes). It was obtained (harvested) from Epie Creek in Yenagoa, Bayelsa State. After collection, they were rinsed with tap water to remove any epiphytes and insects' larvae grown on the plant.

B. Water quality analysis

Table 1: Initial Properties of Produced Water Collected from Niger Delta Oil Fields

Parameter	Values
Salinity	13.7 ppt
pH	9.11
Temperature	Ambient Temp.
Total Dissolved Solid (TDS)	8652 ppm
Electrolysis Conductivity (EC)	1730us/cm
Biological Oxygen Demand (BOD)	15.6 mg/l
Chemical Oxygen Demand (COD)	23.8mg/l
Turbidity	34.7 NTU

All the parameters were investigated and analysed according to APHA; 1998 standards as shown in Table 1. The pH of the sample was measured by an automatic digital pH meter, calibrated with standard buffer solutions and the TOC was determined with the aid of a total organic compound analyser. The parameters included the determination of chemical oxygen demand (COD), Dissolved Oxygen (DO), Total Alkalinity (TA) AND Biochemical Oxygen Demand (BOD). All the samples were investigated before and after treatment.

C. Laboratory Analysis Of Sample

pH was measured by automatic digital pH meter. The pH meter was first calibrated with standard buffer solutions. The glass electrode was washed with distilled water. Then glass electrode was dipped in the beaker containing water sample until the reading stabilized at a certain point. Then pH reading was recorded.

For Electrical Conductivity, the instrument used was digital conductivity meter. The conductivity meter was first calibrated with standard Potassium chloride solution of 0.01N. Then reading was noted by immersion of the sensors into the water sample.

Nephelometric method was used for turbidity determination. The principle of this method is based

on a comparison of the intensity of light scattered by the sample under defined conditions with the intensity of light scattered by a standard reference suspension under the same conditions. Turbidimeter, type Jenway- 6035 Turbidity meter was standardized to zero NTU using distilled water before standardizing using 100 NTU standard and 40 NTU standard. The sample was shaken thoroughly and 10ml of sample was taken and transferred into a cuvette and readings were recorded in Nephelometric units.

The value of dissolved oxygen (DO) was read on site using dissolved oxygen meter JENWAY-3405 (Manufacturer: Barloworld Scientific Ltd-England). The meter probe was immersed into the sample and readings taken directly.

Total organic compound (TOC) was determined with the aid of total organic compound tester. The value of TOC was read by injecting the about 5 ml of water sample into the sample detection holder containing the sensors and readings taken directly.

Exactly 100ml of water sample was measured after the sample was shaken. The water sample was thereafter passed through quantitative ash free filter paper. Platinum dish was weighed, and the filter paper was placed in the dish, which was later placed in the oven at 100°C. After drying, the dish was weighed again.

$$SS(mgl^{-1}) = \frac{mgSS \times 1000}{100ml.sample} \quad \text{.....Equation 3.1}$$

For the determination of Total Alkalinity (TA), Three drops of bromcresol green indicator were added to 50 mL of the sample and titrated with 0.02 N H2SO4 to pH 4.5 and total alkalinity was estimated (bromcresol green indicator was changed the color from blue to yellow at pH 4.5). Amount of acid used at this moment starting phenolphthalein was used to react with hydroxide, carbonate and bicarbonate and it was constituted of total alkalinity.

For the determination of Biochemical Oxygen Demand (BOD), The amount of oxygen, taken up by the microorganisms that decompose the organic waste matter in waste water is known as biological oxygen demand or biochemical oxygen demand. Therefore, it is used to measure the amount of certain type of organic water pollution BOD is calculated by keeping a sample of water containing a known amount of oxygen for five days at 20 °C. The oxygen content is measured again and BOD is calculated. A high BOD indicates the presence of a large number of microorganisms which indicates a high level of pollution in wastewater.

Four 300 ml BOD bottles were taken and 10ml of sample was added to two bottles and fill the remaining volume with dilution water. The two remaining BOD bottles with only dilution water for blank. The bottles were immediately closed airtight without any air bubbles. One blank and one sample were immediately determined for the dissolved oxygen. Incubate one sample and one blank bottle at ambient for 5 days. Analyze immediately remaining one blank and one sample bottle for dissolve oxygen (DO).

Analyze incubated bottles for DO after 5 days. The water sample was incubated for 5 days in the dark, using the bottle incubation method (Hammer, 1986). The reduction in dissolved oxygen concentration during the incubation period yields a measure of the biological oxygen demand. (APHA, 1998).

$$BOD = \frac{(D_0 - D_5 - BC) \times V_d}{V_s} \quad \text{..... Equation 3.2}$$

Where: D0 = the initial dissolved oxygen of diluted sample

D5 = the dissolved oxygen at the end of 5 days for diluted sample

BC = Blank Correction C0 – C5

C0 = initial dissolved oxygen for blank

C5 = dissolve oxygen at the end of 5 days for blank

Vd = volume of diluted sample

Vs = volume of sample taken

III. RESULTS AND DISCUSSION

Biological Oxygen Demand (BOD) serves as an indicator of the amount of oxygen required by microorganisms to decompose organic matter in water. High BOD levels signify organic pollution, which can lead to oxygen depletion and adverse effects on aquatic ecosystems. Similarly, Total Dissolved Solids (TDS) reflect the concentration of dissolved inorganic and organic substances, with elevated TDS levels posing risks to water usability and ecosystem health.

Table 2: Periodic Reduction of Biological Oxygen Demand (BOD) and Total Dissolved Solids (TDS) During Phytoremediation

Day	Biological Oxygen Demand (BOD, mg/L)	BOD Reduction (%)	Total Dissolved Solids (TDS, ppm)	TDS Reduction (%)
1	23.81	-	8652	-
2	17.52	26.4%	7482	13.5%
3	10.67	55.2%	4216	51.3%
4	6.84	71.3%	2034	76.5%

Table 2 presents the progressive reduction in BOD and TDS levels over the four-day treatment period with water hyacinth. The initial BOD and TDS values of 23.81 mg/L and 8652 ppm, respectively, significantly exceeded the regulatory limits set by EGASPIN (2018), which are 10 mg/L for BOD and 2000 ppm for TDS.

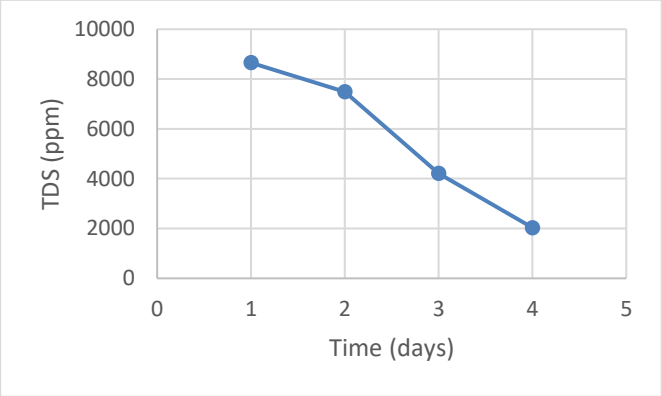


Fig 1: reduction in total dissolved solids (tds) over time

Fig. 1 depicts the decline in Total Dissolved Solids (TDS) concentration during the four-day treatment period. The initial TDS level of 8652 ppm was reduced to 2034 ppm, marking a significant decrease of approximately 76.5%. The graph demonstrates a rapid reduction in TDS during the first three days, followed by a more gradual decline on Day 4. The decrease in TDS is primarily due to the absorption of dissolved salts and nutrients by water hyacinth through its root system. The large root surface area and rapid growth of the plant facilitate the uptake of various ions, effectively reducing TDS levels in the treated water. This aligns with the findings of Reddy and DeBusk (1985), who reported the high efficiency of water hyacinth in nutrient and salt removal from polluted waters. The observed reduction in TDS levels is particularly significant for water reuse or safe discharge, as high TDS concentrations in produced water pose a threat to soil and water quality in receiving environments. The results underscore the potential of phytoremediation as a practical solution for improving the quality of produced water.

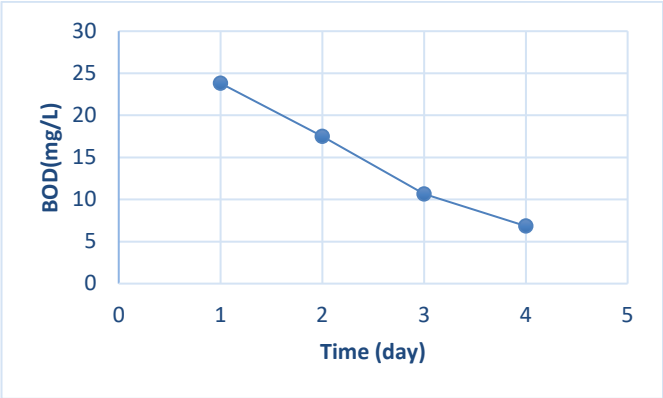


Fig 2: reduction in biological oxygen demand (bod) over time

Fig. 2 illustrates the progressive reduction in Biological Oxygen Demand (BOD) levels in produced water during the four-day phytoremediation process with water hyacinth (Eichhornia crassipes). The initial BOD concentration of 23.81 mg/L was reduced to 6.84 mg/L by Day 4, representing a total reduction of approximately 71.3%. The graph shows a steep decline in BOD levels during the first three days, followed by a slower reduction on Day 4. This trend indicates that the microbial activity and nutrient uptake associated with water hyacinth were most effective during the initial stages, likely due to the availability of organic matter. As the BOD concentration decreased, the microbial degradation rate slowed because of reduced substrate availability. This reduction in BOD signifies the plant's ability to effectively mitigate organic pollution in produced water. The results align with findings from Sharma and Tyagi (2021), who demonstrated the capacity of water hyacinth to restore dissolved oxygen levels by reducing the organic load in contaminated water systems.

The data show a consistent reduction in both parameters, with BOD decreasing by 71.3% and TDS reducing by 76.5% by Day 4. The effectiveness of water hyacinth is attributable to its extensive root system, which facilitates nutrient uptake and promotes microbial activity, breaking down organic pollutants and reducing dissolved solids. This result is consistent with a study by Okpokwasili et al. (2020), who observed a 60–70% reduction in hydrocarbons and organic pollutants in water treated with water hyacinth over two weeks. The findings affirm the suitability of water hyacinth for treating highly polluted water bodies in areas with limited resources for conventional water treatment technologies.

3.2 Total Petroleum Hydrocarbon (TPH)

Petroleum hydrocarbons are a major contaminant in produced water, posing significant risks to both aquatic ecosystems and human health. The phytoremediation process using water hyacinth demonstrated a substantial decrease in TPH levels over the 35-day treatment period. The results, summarized in Table 3, reveal a steady decline from an initial concentration of 64.88 mg/L to just 0.71 mg/L, representing an overall reduction of 98.9%.

Table 3: Reduction in Total Petroleum Hydrocarbon (TPH) Concentration and Corresponding Absorbance Changes with Percentage Variations Over 35 Days

Day	TPH Concentration (mg/L)	TPH Reduction (%)	Absorbance	Absorbance Increase (%)
1	64.88	-	0.275	-
7	28.75	55.7%	0.391	42.2%
14	14.42	77.8%	0.437	58.9%
21	3.82	94.1%	0.471	71.3%
28	1.95	97.0%	0.477	73.5%
35	0.71	98.9%	0.481	74.9%

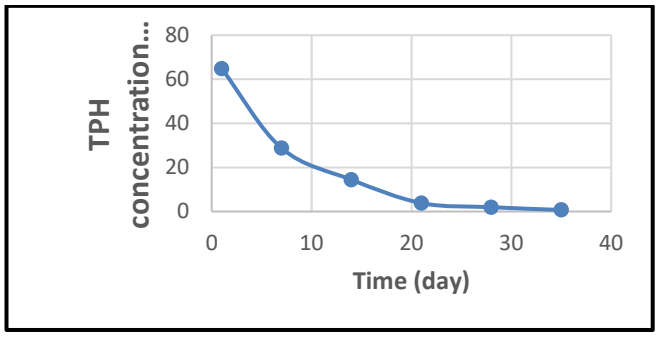


Fig 3: reduction in total petroleum hydrocarbon (tph) over time

Fig. 3 illustrates the reduction in Total Petroleum Hydrocarbon (TPH) concentration in produced water over a 35-day treatment period using water hyacinth (Eichhornia crassipes). The initial TPH concentration of 64.88 mg/L decreased significantly to 0.71 mg/L by the end of the study, representing a reduction of approximately 98.9%. The graph shows a steep decline in TPH concentration during the first two weeks, followed by a gradual decrease as the phytoremediation process progressed. This pattern can be attributed to the initial high adsorption rate of hydrocarbons onto the plant roots, coupled with active microbial degradation in the rhizosphere. Over time, the remediation efficiency slowed as the residual hydrocarbon concentration became minimal, approaching the plant's uptake limit. This trend corroborates findings by Khan et al. (2021), who highlighted the role of plant-microbe interactions in the effective breakdown of hydrocarbons during phytoremediation. These findings also are in agreement with Khan et al. (2021), who highlighted the synergy between water hyacinth roots and hydrocarbon-degrading microbes in reducing pollutant levels. The reduction achieved in this study is higher than the 75% reduction observed by Adhikari et al. (2022) in similar conditions, likely due to the optimized treatment duration. The results confirm that water hyacinth is a viable option for addressing hydrocarbon contamination in produced water.

IV. CONCLUSION

Due to the continuous production activities of crude oil exploration companies in the Niger Delta, this region is constantly facing serious and diverse kinds of environmental pollution. Some of such pollution comprises the discharge of untreated produce water into water bodies such as rivers within the Niger Delta region. Exploratory and exploitative discharges of produced water and drill cuttings from the downstream sector are an incessant source of contaminants to continental shelf ecosystems. Produced water discharged into the environment have resulted in destruction of mangrove forests, death of aquatic organisms, destruction of farm lands and contamination of fresh water bodies in the affected region.

This study has shown that some physio - chemical properties of produced water from some of the Niger Delta oil fields are higher than the stipulated regulatory limit for discharge into the environment, Total dissolved solids, total suspended solids and some other parameters are at its high value, continuous discharge of these produced water without satisfactory treatment will further damage our fragile environment. It is therefore recommended that adequate treatment, monitoring and re-use for irrigation or as industrial process water plan for produced water in the Niger Delta be put in place to ensure compliance with best global practices.

Finally, this study has also helped to discover the usefulness of Water Hyacinth (Eichhornia Crassipes) in crude oil polluted water in Niger Delta Area of Nigeria. As the number of Water Hyacinth (Eichhornia Crassipes) increases in the produced water, the greater and faster the remediating ability.

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