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Oil Field Waste Treatment and Its Cost Assessment

*Anthony Chikwe[1], Ebenezer Aniyom[2], Kelechi Atasie[1]

[1]Federal University of Technology Owerri, Nigeria

[2]Hydroserve Oil Services, Nigeria

*eaniyom@gmail.com

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Abstract: Oil field wastewater—commonly referred to as produced water—is the largest waste stream associated with petroleum production, characterized by high concentrations of hydrocarbons, heavy metals, dissolved salts, and chemical additives. Its complex and variable composition poses significant environmental and regulatory challenges, particularly in sensitive ecosystems like Nigeria's Niger Delta. This study conducts a comprehensive technical and economic evaluation of three prominent wastewater treatment technologies: chemical coagulation and flocculation, membrane filtration, and constructed wetlands. Each method was assessed based on contaminant removal efficiency, cost per cubic meter, operational sustainability, and financial metrics including Return on Investment (ROI), Net Present Value (NPV), and Payback Period. Results demonstrate that membrane filtration systems, particularly those utilizing reverse osmosis, achieve the highest removal efficiencies (>98%) for suspended solids, hydrocarbons, and salinity. However, their high capital and operational costs ($1.09/m³) limit their viability for large-scale deployment in developing regions. Coagulation and flocculation present a balanced alternative with moderate removal efficiency (~90%) and a lower treatment cost ($0.83/m³), though they generate significant sludge requiring environmentally sound disposal. Constructed wetlands emerge as the most cost-effective and environmentally sustainable option, offering a treatment cost of $0.40/m³, an ROI of 29.67%, a Net Present Value of $764,018, and the shortest payback period (3.37 years). The study concludes that hybrid treatment configurations—such as integrating coagulation with membrane filtration—could enhance cost-efficiency and treatment performance. Recommendations are made for oil field operators to adopt context-specific, scalable, and regulation-compliant treatment strategies that balance environmental stewardship with economic feasibility. This research provides a critical framework for sustainable produced water management in the Niger Delta and similar oil-producing regions globally.

Index Terms: Coagulation and flocculation, constructed wetlands, Cost-benefit analysis, Environmental compliance, Membrane filtration, Niger Delta, Oil field, Produced water, Wastewater treatment.

1. Introduction

Oil field operations play a critical role in global energy production, encompassing processes such as drilling, extraction, and production of crude oil and natural gas. These processes generate substantial volumes of wastewater—commonly known as produced water—which typically constitutes the largest waste stream in oil and gas operations. Produced water is a complex mixture containing hydrocarbons, heavy metals (e.g., lead, cadmium, mercury), high levels of dissolved salts (often exceeding seawater salinity), chemical additives, and naturally occurring radioactive materials (NORMs) [1][2].

In the Niger Delta region of Nigeria, where oil and gas activities dominate the economy, the improper disposal of produced water has resulted in significant environmental degradation. This includes contamination of surface and groundwater resources, destruction of aquatic habitats, soil infertility, and public health risks for communities dependent on local water systems [3][4]. Despite regulatory frameworks such as the Environmental Guidelines and Standards for the Petroleum Industry in Nigeria (EGASPIN), weak enforcement, high operational costs, and limited access to advanced treatment technologies have hindered effective wastewater management [5] [6].

Numerous treatment technologies have been proposed and applied globally, including physical, chemical, biological, and hybrid systems. Among these, chemical coagulation and flocculation have been widely used for turbidity and oil removal due to their cost-effectiveness and simplicity [7]. Membrane filtration systems, such as reverse osmosis (RO), offer superior contaminant removal, including dissolved salts and micropollutants, but are limited by high energy consumption and membrane fouling [8]. Constructed wetlands, a nature-based solution, leverage plant-microbial systems for the biological degradation of contaminants, offering low-cost and environmentally friendly treatment suitable for rural and semi-urban oil field operations [9][10].

This study conducts a comparative assessment of these three treatment technologies—chemical coagulation/flocculation, membrane filtration, and constructed wetlands—focusing on their contaminant removal efficiency, operational and capital costs, environmental sustainability, and suitability for the socio-ecological context of the Niger Delta. A cost-benefit analysis, including metrics such as Net Present Value (NPV), Return on Investment (ROI), and Payback Period, is performed to guide oil field operators and policymakers in selecting economically viable and regulation-compliant wastewater treatment options.

2. Materials and Methods

2.1 Method Selection Selection Criteria

The selection and evaluation of wastewater treatment technologies in this study were guided by four core criteria designed to address both technical performance and socioeconomic relevance to oil field operations in Niger Delta. The criteria are:

i. **Contaminant Removal Efficiency:** The ability of each treatment method to effectively remove key contaminants found in produced water—namely hydrocarbons, heavy metals, total suspended solids (TSS), total dissolved solids (TDS), and chemical additives [11]. Efficiency benchmarks were determined from peer-reviewed studies and performance data of commercial treatment units [12][8].
ii. **Capital and Operational Costs:** Capital expenditure (CAPEX) includes procurement and installation of treatment infrastructure and equipment. Operational expenditure (OPEX) covers energy consumption, chemical usage, labor, maintenance, waste management, and environmental compliance [13].
iii. **Environmental Sustainability:** The environmental impact of each treatment method, including energy consumption, chemical usage, waste generation (e.g., sludge or concentrate), and potential for secondary pollution, was assessed [14][15].
iv. **Applicability to Local Field Conditions:** Each method's suitability for deployment in the Niger Delta was evaluated, taking into consideration geographic constraints, infrastructure availability, regulatory environment (e.g., EGASPIN compliance), and land use limitations [16].

2.2. Methodological Approach

This study evaluates the performance and cost-effectiveness of three selected oil field wastewater treatment technologies:

a. Chemical Coagulation and Flocculation
b. Membrane Filtration (Reverse Osmosis)
c. Constructed Wetlands

Each technology was analyzed through a standardized modeling framework based on a hypothetical treatment plant with a 500 m^3/day processing capacity, representative of medium-scale operations in the Niger Delta [17][18]. The modeling considered real-world cost parameters, equipment lifespans, and energy/chemical requirements derived from published data and case studies [19].

2.3 Chemical Coagulation and Flocculation

2.3.1 Principles of Operation

Chemical Coagulation and flocculation are widely used water treatment processes in oil fields to remove suspended solids, oil, grease, and other impurities. The process involves the addition of coagulants, such as aluminum sulfate (alum) or ferric chloride, to destabilize suspended particles and dissolved contaminants in the wastewater.

The process occurs in two stages:

i. Coagulation: Addition of coagulants (e.g., alum, ferric chloride) to destabilize and aggregate fine particles.
ii. Flocculation: Gentle mixing to form larger flocs that settle easily [5][7].

2.3.2 Equipment and Materials

Table 1: Comprehensive Cost Table: Chemical Coagulation and Flocculation (500m^3/day)

Category	Item	Description	Estimated Cost (USD)	Total Costs
Capital Cost	Coagulation and Flocculation Tanks	Designed for mixing and floc formation	\$30,000 - \$50,000	**\$170,000 - \$315,000**
	Mixers and Agitators	For chemical dosing and floc formation	\$10,000 - \$20,000	
	Clarifiers or Sedimentation Tanks	Automated systems for precise dosing of coagulants and flocculants	\$10,000 - \$15,000	
	Pumps and Piping	For transferring water between units	\$20,000 - \$30,000	
	Installation & Infrastructure	Foundation work, structural supports, and piping network	\$30,000 - \$50,000	
Operational Cost	Energy Consumption	~2kWh/m^3 at \$0.10/kWh (for pumping and pressurization)	\$36,500/year	**\$114,750 - \$196,250/year**
	Coagulants	Alumorferrichloride, Average dosage: 50mg/L (~9tons/year for 500m^3/day)	\$3,000 - \$4,500/year	
	Flocculants	Polyacrylamides, Average dosage: 1mg/L(~0.18tons/year)	\$1,000 - \$3,000/ton	
	Labor and Maintenance	Skilled technicians for monitoring and upkeep	\$20,000 - \$30,000/year	
	Waste Disposal	Disposal of sludge and residuals (~2% of treated water volume)	\$20,000 - \$30,000/year	
Environmental Costs	Emissions	Minimal emissions, but potential environmental impact from chemical production and transport	Qualitative	**\$23,250 - \$46,500/year**
	Regulatory Compliance	Cost of meeting local environmental regulations (e.g., Niger Delta Environment Standards)	\$5,000 - \$10,000/year	

2.3.3 Process Steps for Chemical Coagulation and Flocculation

The water quality parameters used in this study include; Volume, turbidity, pH, salinity, and contaminants. The target treatment efficiency; desired removal of suspended solids, oil, grease, and other impurities. Process steps are outlined below in fig. 1;

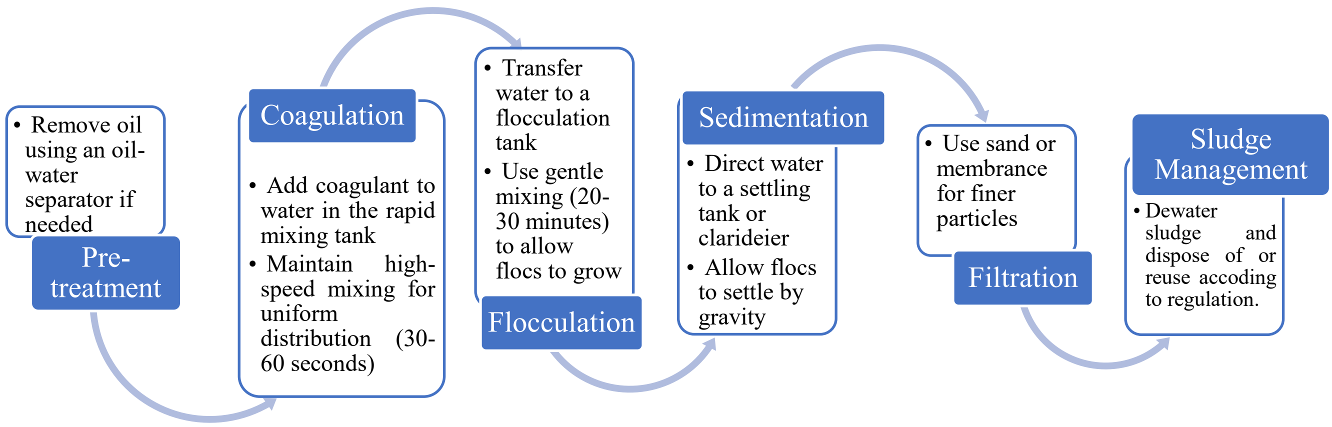

Fig. 1: Process Steps for Chemical Coagulation and Flocculation

2.3.4 Cost Analysis Model for Chemical Coagulation and Flocculation

A detailed techno-economic analysis was conducted with these approaches;

i. Capital Expenditure (CAPEX)

Costs for civil works, equipment procurement, installation, and instrumentation were estimated. For each method, the design and sizing of components such as tanks, membranes, liners, and pumps were scaled to meet the 500 m³/day target throughput as shown in table 2.

Table 2: Capital Expenditure Table (CAPEX) – for an average waste water produced in the Niger Delta

Item	Cost Estimate (USD)
Chemical Storage Tanks	$40,000
Chemical Dosing Pumps (2)	$15,000
Mixing Tank	$15,000
Mechanical Mixer	$5,000
Settling Tank (Clarifier)	$100,000
Filtration Unit	$50,000
Sludge Dewatering Unit	$50,000
Installation and Infrastructure	$75,000
Total Capex	**$350,000**

ii. Operational Expenditure (OPEX)

The operating expenditure (OPEX) for a 500m^3/day plant in an average waste water produced in the Niger Delta is shown below in table 3.

Table 3: Operating Expenditure Table (CAPEX) – for an average waste water produced in the Niger Delta

Item	Annual Cost (USD)
Energy Consumption	$36,000
Chemical Usage	$3,500
Maintenance	$20,000

Environment Costs	$34,875
Waste Disposal	$27,375
Total Opex	**$118,750**

The total yearly cost includes the amortized capital costs over the system's lifespan, the annual operational costs, and the annual environmental costs.

Capital costs are amortized over the lifespan of the equipment and infrastructure. Assume an equipment lifespan of 15 years and a discount rate of 5%. The annualized capital cost is calculated using the formula for annuity:

a. Annualized Capital Cost

$$\text{Annualized Capital Cost} = \frac{C\times r}{1-(1+r)^{-n}} \tag{1}$$

C = Total Capital Costs = $350,000

r = Discount Rate = 5% = 0.05

n = Lifespan (years) = 15

$$\text{Annualized Capital Cost} = \frac{350{,}500\times 0.05}{1-(1+0.05)^{-15}} = 33{,}720 USD/year \tag{2}$$

b. Calculate Total Annual Costs

Total Annual Costs=Annualized Capital Cost + Operational Costs

Where:

Annualized Capital Cost = $33,720/year

Operational Costs = $118,750/year

Total Annual Costs=33,720+118,750 = 152,470USD/year

c. Determine Total Treated Water Volume per Year

For a daily treatment capacity of 500 m³/day:

Annual Treated Volume=500m³/day×365days/year

Annual Treated Volume=182,500m³/year

d. Calculate Cost per Cubic Meter of Treated Water

$$Cost\ per\ m^3 = \frac{Total\ Annual\ costs}{Annual\ Treated\ Volume} \tag{3}$$

$$Cost\ per\ m^3 = \frac{152{,}470}{182{,}500}$$

$$Cost\ per\ m^3 = 0.83 USD/m^3$$

Final Results

Annualized Capital Cost: **$33,720/year**

Total Operational Costs: **$118,720/year**

Total Annual Costs: **$152,470/year**

Cost per Cubic Meter of Treated Water: **$0.84/m³**

Key Assumptions

i. Equipment lifespan is 15 years with a 5% discount rate.
ii. Operational costs (energy, chemicals, labor, maintenance, and waste disposal) are constant.
iii. Environmental compliance costs are estimated based on regional standards.

2.3.5 Advantages and Challenges

Advantages

i. High Efficiency for Suspended Solids: Effectively removes suspended solids, oils, and grease from produced water.
ii. Cost-Effective: Capital and operational costs are generally lower compared to advanced treatment methods.
iii. Simple Operation: Easy to operate with minimal automation requirements.
iv. Rapid Treatment: Provides quick results in destabilizing and aggregating particles.
v. Scalability: Can be scaled for small or large operations.

Challenges

i. Chemical Dependency: Requires continuous supply of coagulants and flocculants (e.g., alum, ferric chloride, polyacrylamides).
ii. Sludge Generation: Produces significant amounts of chemical sludge, which requires proper handling and disposal.
iii. Environmental Concerns: Risk of chemical spills and residual chemicals in treated water.
iv. Effectiveness Limited by Water Quality: Efficiency decreases with highly saline or variable produced water.
v. Regulatory Compliance: Needs adherence to stringent disposal and emission regulations.

2.4 Membrane Filtration

2.4.1 Principles of Operation

The Membrane filtration involves separating contaminants from water using semi-permeable membranes under pressure. It is highly effective for removing oil, grease, dissolved salts, and fine particles. The key types of membrane filtration include;

i. Microfiltration (MF): removes suspended solids and microorganisms
ii. Ultrafiltration (UF): removes smaller particles and viruses
iii. Nanofiltration (NF): Removes most dissolved salts, organics, and micropollutants

2.4.2 Equipment and Materials for Membrane Filtration

Table 4: Comprehensive Cost Table: Membrane Filtration System(500m^3/day)

Category	Item	Estimated Cost (USD)	Total Costs
Pretreatment System	Oil-Water Separator	\$10,000 - \$50,000	**\$15,500 - \$110,000**
	Sand or Multimedia Filter	\$5,000 - \$30,000	
	Cartridge Filter (5-10 µm pore size)	\$500 - \$5,000	
Membrane Filtration System	Microfiltration/Ultrafiltration	\$50,000 - \$150,000	**\$170,300 - \$752,000**
	Nanofiltration/Reverse Osmosis	\$100,000 - \$500,000	
	Cleaning-In-Place (CIP) Systems (for cleaning periodically)	\$10,000 - \$20,000	
	High-Pressure Pumps (RO requires pump to maintain 4-8 MPa pressure)	\$10,000 - \$50,000	
	Membrane Replacement (Membranes typically last 3-5 years)	\$300 - \$2,000 per year	
Post Treatment System	Chemical Unit (for pH adjustment or antiscalent addition)	\$3,000 - \$10,000	**\$9,000 – \$55,000**
	Product Water Storage Tank	\$10,000 - \$30,000	
	Instrumentation and Controls (Monitoring equipment)	\$5,000 - \$15,000	

Chemicals and Consumables	Antiscalents (Prevent scaling on membrane)	\$5-\$10 per m^2	**\$3,000 – 7,000/year**
	Cleaning Chemicals (Membrane cleaning solutions)	\$500 - \$2,000 per year	

2.4.3 Process Steps for Membrane Filtration

Input Water Quality: Contaminants like oil, TSS, TDS, and COD.

Treated Water Quality: Target output quality parameters.

Flow Rate: Determine daily water treatment capacity (e.g., 500 m³/day). The process steps for the membrane filtration is shown in figure 2.

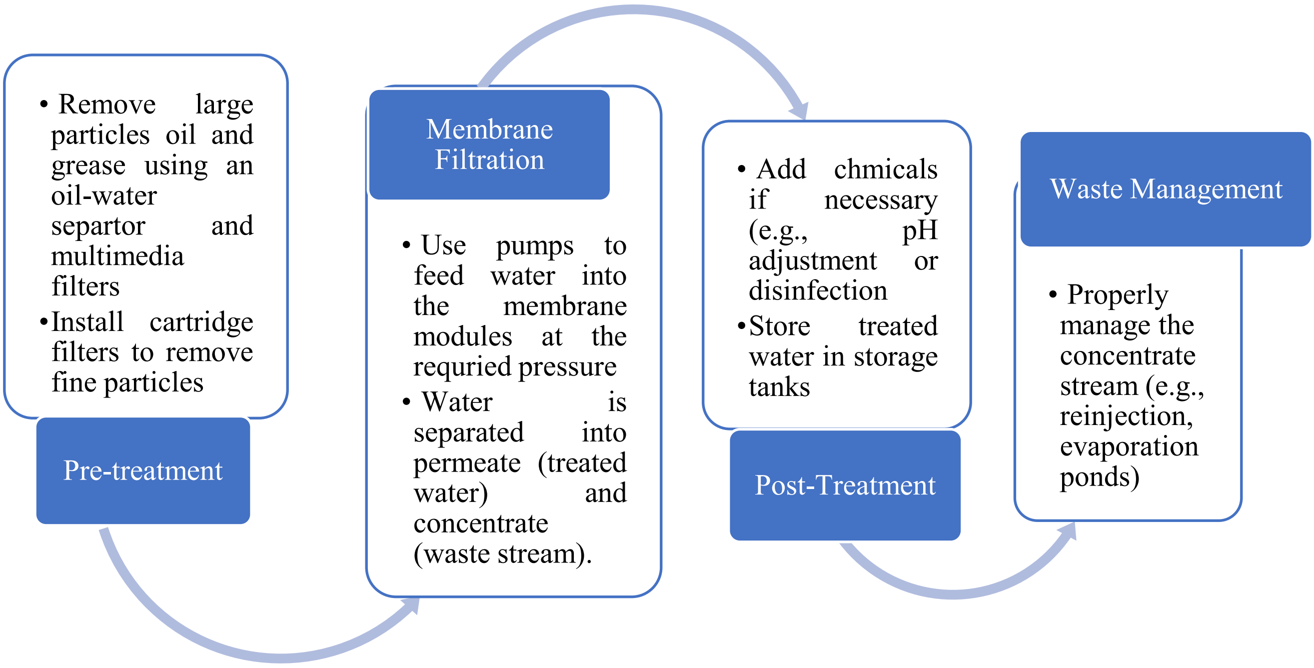

Fig. 2: Process Steps for Membrane Filtration

2.4.4 Cost Analysis Model for Membrane Filtration

A detailed techno-economic analysis was conducted with these approaches;

i. Capital Expenditure (CAPEX)

The Capital Expenditure (CAPEX) covers for the cost of equipment, membranes, and installation for a plant treating 500 m³/day using RO as shown in table 5.

Table 5: Capital Expenditure Table (CAPEX) – for a plant treating 500m^3/day using RO

Component	Cost Estimate (USD)
Pretreatment System	\$50,000
RO Membrane System	\$250,000
High-Pressure Pumps	\$30,000
CIP System	\$15,000
Product Water Storage Tank	\$20,000

Instrumentation & Controls	$10,000
Total CAPEX	**$375,000**

ii. Operational Expenditure (OPEX)

The operating expenditure (OPEX) for a plant treating 500m^3/day of waste in the Niger Delta is shown below in table 6.

Table 6: Operating Expenditure Table (CAPEX) –) for a plant treating 500m^3/day

Item	Annual Cost (USD)
Energy Consumption (2 kWh/m^3 @ $0.1/kWh)	$36,000
Chemicals (antiscalants)	$10,000
Membrane Replacement	$15,000
Maintenance & Labor	$20,875
Total OPEX	**$81,500**

The total yearly cost includes the amortized capital costs over the system's lifespan, the annual operational costs, and the annual environmental costs.

Capital costs are amortized over the lifespan of the equipment and infrastructure. Assume an equipment lifespan of 15 years and a discount rate of 5%. The annualized capital cost is calculated using the formula for annuity:

a. Annualized Capital Cost

$$\text{Annualized Capital Cost} = \frac{C \times r}{1-(1+r)^{-n}} \quad (4)$$

C = Total Capital Costs = $350,000

r = Discount Rate = 5% = 0.05

n = Lifespan (years) = 15

$$\text{Annualized Capital Cost} = \frac{375{,}000 \times 0.05}{1-(1+0.05)^{-15}} = 36{,}128 USD/year$$

b. Calculate Total Annual Costs

Total Annual Costs=Annualized Capital Cost + Operational Costs

Where:

Annualized Capital Cost = $36,128/year

Operational Costs = $81,500/year

Total Annual Costs=36,128+81,500 = 117,628USD/year

c. Determine Total Treated Water Volume per Year

For a daily treatment capacity of 500 m^3/day:

Annual Treated Volume=500m^3/day×365days/year

Annual Treated Volume=182,500m^3/year

d. Calculate Cost per Cubic Meter of Treated Water

$$Cost\ per\ m^3 = \frac{Total\ Annual\ costs}{Annual\ Treated\ Volume} \quad (5)$$

$$Cost\ per\ m^3 = \frac{117{,}628}{182{,}500}$$

$$Cost\ per\ m^3 = 1.091 USD/m^3$$

Final Results

Annualized Capital Cost: **$36,128/year**

Total Operational Costs: **$81,500/year**

Total Annual Costs: **$117,500/year**

Cost per Cubic Meter of Treated Water: **$1.09/m³**

Key Assumptions

i. Equipment life span is 15 years with a 5% discount rate.
ii. Operational costs (energy, chemicals, labor, maintenance, and waste disposal) are constant.
iii. Environmental compliance costs are estimated based on regional standards.

2.4.5 Advantages and Challenges

Advantages

i. High-Quality Output: Removes fine particles, bacteria, and dissolved contaminants effectively.
ii. Compact Design: Requires less space compared to conventional methods.
iii. Versatility: Suitable for a wide range of contaminants, including salinity reduction through reverse osmosis.
iv. Reduced Chemical Use: Minimal reliance on chemicals compared to coagulation and flocculation.
v. Automation: Easily integrated into automated systems for consistent performance.

Challenges

i. High Initial Cost: Expensive capital investment for membranes, pumps, and associated equipment.
ii. Fouling and Scaling: Membranes are prone to clogging, requiring frequent cleaning and maintenance.
iii. Energy Intensive: Especially for reverse osmosis, energy consumption can be significant.
iv. Concentrate Disposal: Produces a concentrated brine that must be disposed of responsibly.
v. Limited Lifespan: Membranes have a finite lifespan and need regular replacement.

2.5 Constructed Wetlands

2.5.1 Principles of Operation

Constructed wetlands mimic natural ecosystems to treat wastewater. They rely on vegetation, microbes, and substrate for pollutant removal. The system can be classified into surface flow or subsurface flow designs [9]. Constructed wetlands are an eco-friendly and cost-effective method for treating water in oil fields. They mimic natural wetland processes to remove contaminants, including oil, grease, heavy metals, and nutrients, through a combination of physical, biological, and chemical mechanisms.

Overview of Constructed Wetland Systems

There are two main types of constructed wetlands used for water treatment:

- Subsurface Flow (SSF): Water flows through a gravel or sand bed planted with vegetation, staying below the surface.
- Surface Flow (SF): Water flows over the soil surface through vegetation.

2.5.2 Equipment and Materials for Constructed Wetlands

Table 7: Comprehensive Cost Table: Constructed Wetlands System(500m^3/day)

Category	Item	Estimated Cost (USD)	Total Costs
Land and Construction	Land Area (Space for the wetland system)	\$2 - \$50/m^2	**\$30 - \$120/m^2**
	Liners (Prevents seepage into the ground)	\$5 - \$15/m^2	
	Gravel/sand (provides a medium for microbial activity and filtration in SSF wetlands)	\$20 - \$50/m^2	
	Vegetation	\$1 -\$5 per plant	
Pumps and Piping	Pumps (Circulate water and distribute it evenly)	\$10,000 - \$50,000	**\$170,300 - \$752,000**
	Membrane Replacement (Membranes typically last 3-5 years)	\$300 - \$2,000 per year	
Pre-Treatment System	Oil-Water Separator	\$10,000 - \$50,000	**\$15,000 – \$60,000**
	Screening Unit	\$5,000 - \$10,000	

2.5.3 Process Steps for Constructed Wetlands

Water Quality: Analyze input and desired output water quality (e.g., oil, grease, TSS, COD, nutrients).

Flow Rate: Calculate treatment capacity (e.g., 500 m³/day). With the detailed process steps as shown in figure 3;

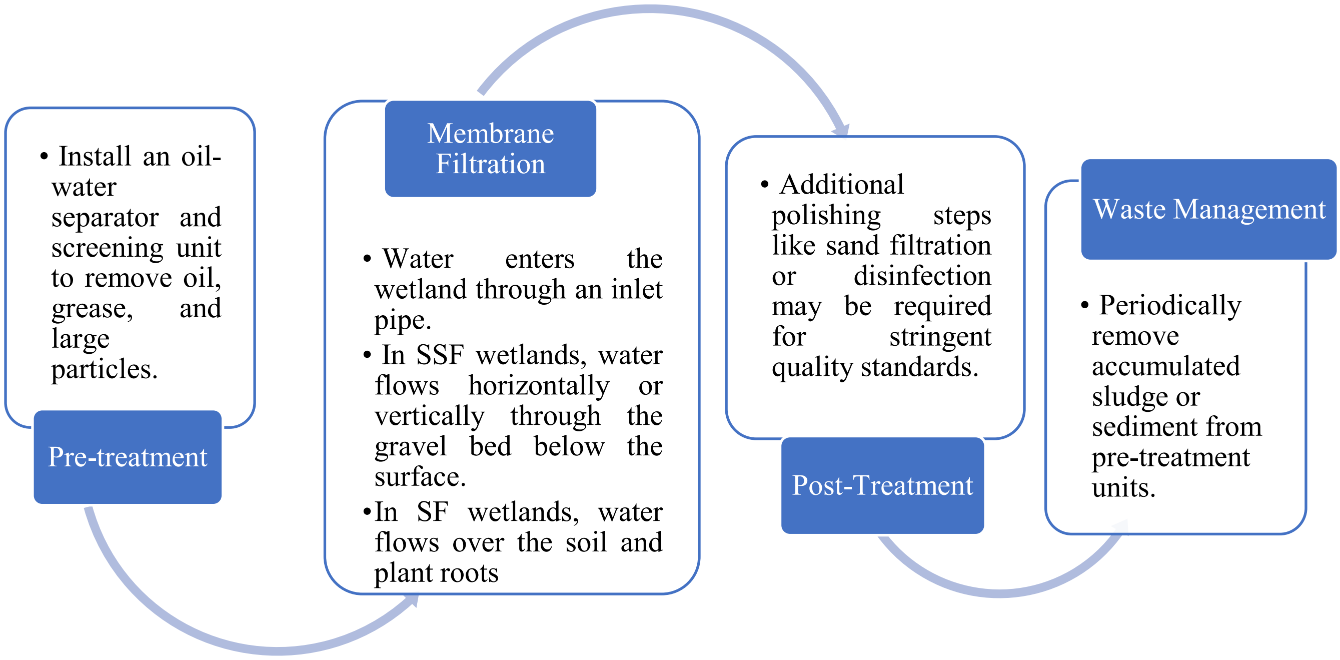

Fig. 3: Process Steps for Constructed Wetlands

2.5.4 Cost Analysis Model for Constructed Wetlands

Capital Expenditure (CAPEX): Cost of land, excavation, planting, liners, and infrastructure as shown in figure 8.

Operational Expenditure (OPEX): Maintenance, monitoring, and vegetation as shown in figure 9, for a 500 m³/day constructed wetland system:

Table 8: Capital Expenditure (CAPEX) for Constructed Wetlands System(500m^3/day)

Component	Cost Estimate (USD)
Land (5,000 m²)	\$135,000 (location dependent)
Liner (5,000 m² @ \$10/m²)	\$50,000

Gravel/Sand Bed	\$75,000
Vegetation (15,000 plants)	\$32,500
Pumps and Piping	\$35,000
Pre-treatment Units	\$40,000
Total CAPEX	\$367,500

Table 9: Operational Expenditure (OPEX) for Constructed Wetlands System(500m^3/day)

item	Annual Cost (USD
Vegetation Maintenance	\$8000
Pump Energy (if required)	\$10,000
Labor and Monitoring	\$20,000
Total OPEX	\$38,000

- **Annualized Capital Cost**

C = Total Capital Costs = \$367,500

R = Discount Rate = 5% = 0.05

N = Lifespan (years) = 15

$$\text{Annualized Capital Cost} = \frac{367{,}500 \times 0.05}{1-(1+0.05)^{-15}} = 35{,}405 USD/year$$

- **Calculate Total Annual Costs**

Total Annual Costs=Annualized Capital Cost + Operational Costs

Where:

Annualized Capital Cost=\$35,405/year

Operational Costs=\$38,000/year

Total Annual Costs=35,405 + 38,000 = **73,405 USD/year**

- **Determine Total Treated Water Volume Per Year**

For a daily treatment capacity of 500m^3/day:

Annual Treated Volume=500m^3/day×365days/year

Annual Treated Volume=182,500m^3/year

Calculate Cost per Cubic Meter of Treated Water

$$Cost\ per\ m^3 = \frac{73{,}405}{182{,}500} = 0.4USD$$

Final Results

Annualized Capital Cost: \$35,405/year

Total Operational Costs: \$38,000/year

Total Annual Costs: \$73,405/year

Cost per Cubic Meter of Treated Water: \$0.4/m^3

Key Assumptions

i. Equipment life span is 15 years with a 5% discount rate.
ii. Operational costs (energy, chemicals, labor, maintenance, and waste disposal) are constant.
iii. Environmental compliance costs are estimated based on regional standards.

2.5.5 Advantages and Limitations

Advantages

i. Environmentally Friendly: Uses natural processes for water treatment with minimal chemical input.
ii. Cost-Effective: Low operational costs once constructed, as they rely on plants and microbial activity.
iii. Biodiversity Enhancement: Promotes habitat creation and supports local ecosystems.
iv. Robust Performance: Effective for removing organic matter, oil, grease, and some metals.
v. Low Maintenance: Requires minimal intervention after establishment.

Challenges

i. Large Land Requirement: Requires significant land area, which may not be feasible in some oil field locations.
ii. Variable Performance: Treatment efficiency can fluctuate due to weather, flow variations, and seasonal changes.
iii. Start-Up Time: Requires time to establish vegetation and microbial populations before achieving full functionality.
iv. Limited for High-Salinity Water: Not effective for treating highly saline or heavily contaminated produced water.
v. Monitoring Needs: Requires regular monitoring to ensure consistent performance

3. Results

This section presents the findings from the evaluation of three wastewater treatment methods—Coagulation & Flocculation, Membrane Filtration, and Constructed Wetlands—based on contaminant removal efficiency and cost-benefit analysis. All quantitative outcomes are supported with corresponding tables and figures.

3.1 Contaminant Removal Efficiency

Table 10: Contaminant Removal Efficiency

Method	Suspended Solids & Oils	Heavy Metals	Dissolved Salts	Remarks
Coagulation & Flocculation	Up to 90%	Moderate	Poor	Fast and effective for turbidity; generates chemical sludge
Membrane Filtration	>98%	Up to 99%	Up to 99%	High-quality output, but energy-intensive and prone to funding
Constructed Wetlands	80-90%	Low	Ineffective	Sustainable and cost-effective for organics; requires large land area

3.2 Cost-Benefit Analysis

3.2.1 Return on Investment (ROI)

Table 11: Return on Investment (ROI)

Treatment Method	Total Investment (USD)	Net Profit (USD/year)	ROI (%)
Coagulation & Flocculation	350,000	63,750	18.21
Membrane Filtration	375,000	64,872	17.30
Constructed Wetlands	367,500	109,095	29.67

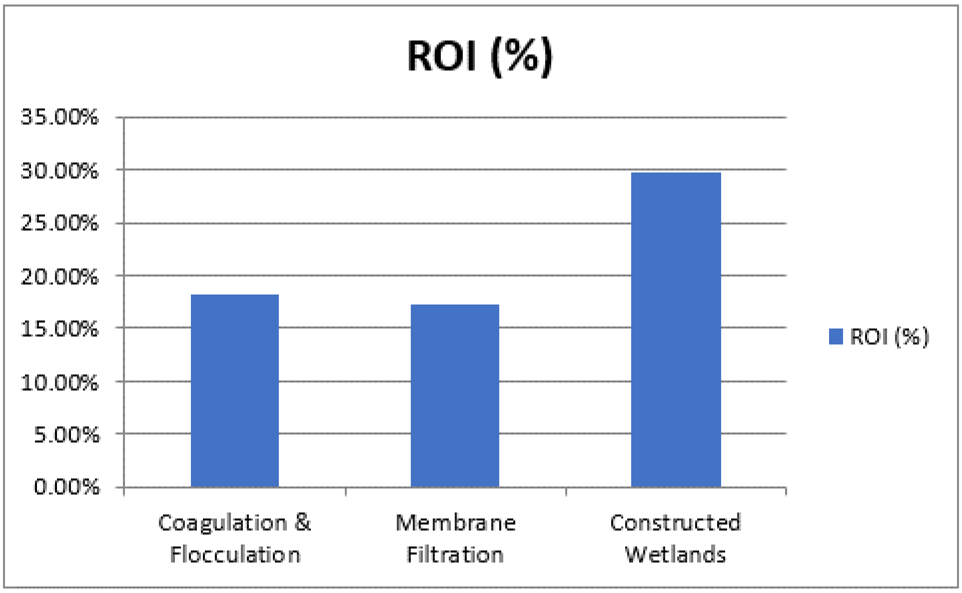

Fig. 4: Graph of ROI for the three water treatment methods

3.2.2 Net Present Value (NPV)

Table 12: Net Present Value (NPV)

Method	Net Cash Flow (USD/year)	NPV (USD)
Coagulation & Flocculation	63,750	311,381
Membrane Filtration	64,872	298,262
Constructed Wetlands	109,095	764,018

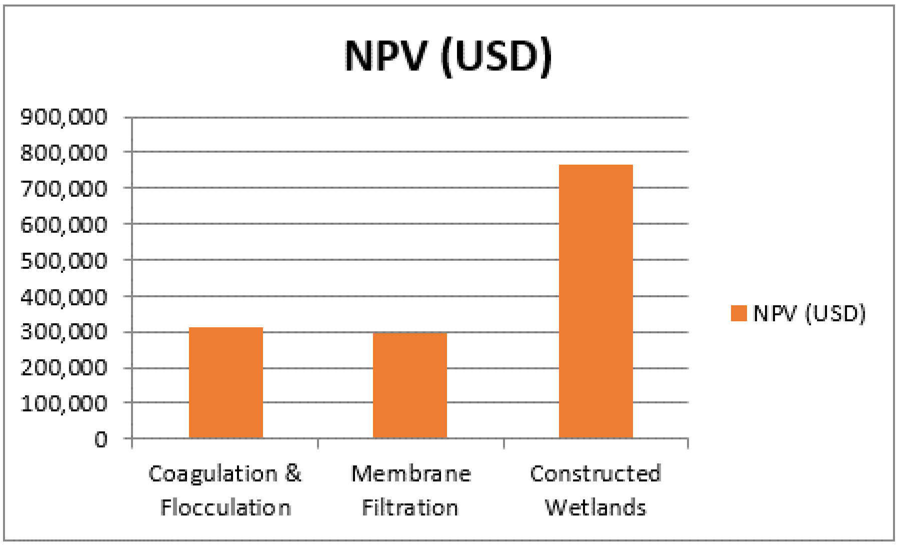

Fig. 5: Graph of NPV for the three water treatment methods

3.2.3 Payback Period

Table 13: Payback period

Method	Payback Period (years)
Coagulation & Flocculation	5.49
Membrane Filtration	5.78
Constructed Wetlands	3.37

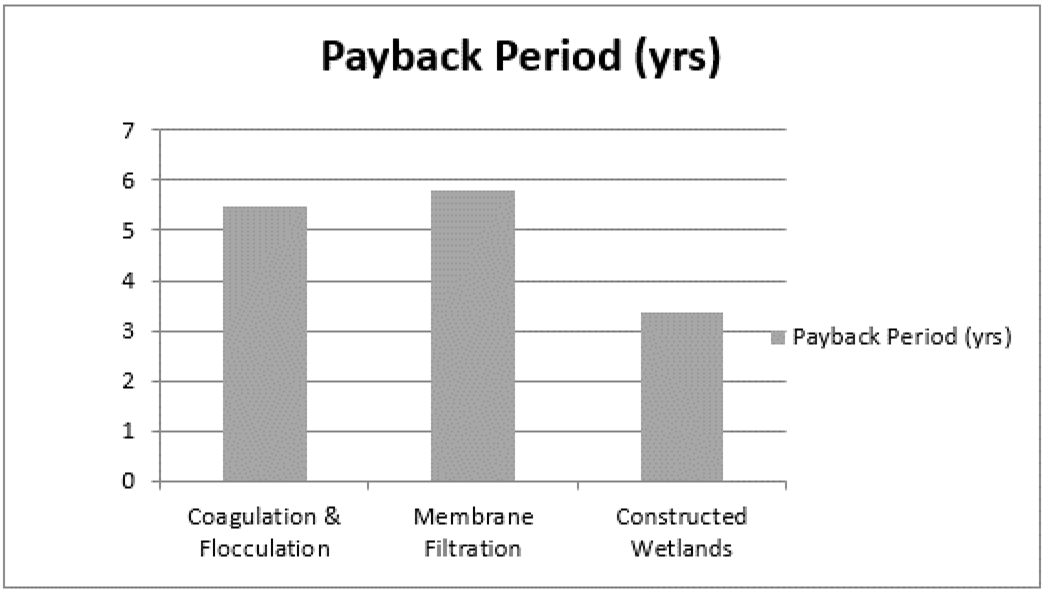

Fig. 6: Graph of Payback Period (yrs) for the three water treatment methods

3.2.4 Cost per Cubic Meter of Treated Water

Table 14: Cost per Cubic Meter of Treated Water

Method	Cost per m^3 (USD)
Coagulation & Flocculation	0.83
Membrane Filtration	1.09
Constructed Wetlands	0.40

4. Discussion

This study assessed the performance and economic feasibility of three wastewater treatment methods suitable for application in the Niger Delta. The findings are grounded in both technical and financial evaluations, as detailed in the results.

i. Constructed Wetlands emerged as the most economically advantageous method. With the highest ROI (29.67%) as shown in Table 11 and visualized in Figure 4, and a shortest payback period of 3.37 years (Table 13, Figure 6), it offers an optimal balance of profitability and sustainability. Additionally, it demonstrated the lowest treatment cost of $0.40/m³ (Table 14). However, its requirement for large land area (see Table 10) may limit its applicability in urban or space-constrained environments.
ii. Membrane Filtration, while delivering superior contaminant removal—over 98% for suspended particles and up to 99% for heavy metals and dissolved salts (Table 10)—incurred the highest operational costs, resulting in the lowest ROI (17.30%) (Table 11, Figure 4) and the longest payback period (5.78 years) (Table 13, Figure 6). The NPV of $298,262 was also the lowest among the three (Table 12, Figure 5). These financial limitations highlight the trade-offs between water quality and economic viability.
iii. Coagulation & Flocculation presented a moderate alternative, balancing technical efficiency and financial return. It showed good contaminant removal efficiency for suspended solids and turbidity (Table 10) and achieved a moderate ROI of 18.21% (Table 11, Figure 4), a payback period of 5.49 years (Table 13, Figure 6), and a cost of $0.83/m³ (Table 14). However, the need for chemical handling and sludge disposal adds operational complexity.

These findings provide critical insights for decision-makers when selecting treatment technologies based on cost-effectiveness, operational feasibility, and environmental impact.

Study Limitations

This evaluation assumes uniform economic and operational conditions across the board. Real-world variability in land availability, regulatory compliance, and input costs may alter the financial metrics. Additionally, maintenance challenges, especially with Membrane Filtration, and vegetation establishment in Constructed Wetlands, were not fully captured in the cost model.

Implications and Future Work

Given the results (see Tables 10–14 and Figures 4–6), Constructed Wetlands are recommended for regions prioritizing long-term sustainability and cost-efficiency. Future studies should assess hybrid technologies combining biological and mechanical systems, and perform site-specific life-cycle assessments to quantify environmental footprints.

5. Conclusions

The study identifies Constructed Wetlands as the most cost-effective method for the Niger Delta region due to its low operational cost, environmental sustainability, and significant return on investment. For oil fields requiring higher water quality, Membrane Filtration remains an excellent option despite its higher costs. A combination of methods offers a balanced approach, optimizing both performance and cost-efficiency for sustainable wastewater Management.

Recommendations for Oil Field Operators

Based on the analysis, the following recommendations are made:

i. Constructed Wetlands for Organic Pollutant Removal: Ideal for regions with sufficient land availability and moderate contaminant levels. Cost-effective and environmentally sustainable for oil field wastewater containing high organic content.
ii. Membrane Filtration for High Salinity: Suitable for areas with stringent water quality requirements, especially for reuse in enhanced oil recovery (EOR) or hydraulic fracturing. Recommended for smaller-scale operations where land is limited but budget permits.
iii. Coagulation & Flocculation as Pre-Treatment: Best used as a pre-treatment method to remove suspended solids and prepare wastewater for secondary treatments like membrane filtration. Highly effective for oil fields with high turbidity and particulate loads.
iv. Hybrid Approaches: Combining Coagulation & Flocculation with Membrane Filtration can improve cost-effectiveness and achieve higher contaminant removal efficiency. A hybrid system reduces membrane fouling, lowering operational costs in membrane systems.
v. Site-Specific Solutions: Treatment methods should be tailored to the specific characteristics of the oil field wastewater, including salinity, contaminant levels, and discharge requirements.

References

[1] Veil, J. A., Puder, M. G., Elcock, D., & Redweik, R. J. (2004). A White Paper Describing Produced Water from Production of Crude Oil, Natural Gas, and Coal Bed Methane. Argonne National Laboratory.

[2] Fakhru'l-Razi, A., Pendashteh, A., Abdullah, L. C., Biak, D. R. A., Madaeni, S. S., & Abidin, Z. Z. (2009). Review of technologies for oil and gas produced water treatment. Journal of Hazardous Materials, 170(2-3), 530-551.

[3] Ekubo, A. T., & Abowei, J. F. N. (2011). Review of Pollution in the Niger Delta Area of Nigeria. International Journal of Fisheries and Aquatic Sciences, 3(6), 108-117.

[4] Onwugbuta-Enyi, J., Onojake, C. M., & Onochie, C. C. (2021). Environmental Impact of Produced Water Discharges in the Niger Delta. Environmental Monitoring and Assessment, 193(7), 445.

[5] NESREA. (2011). National Environmental (Oil and Gas Sector) Regulations. Federal Republic of Nigeria Gazette.

[6] Okoro, S. E., Obahiagbon, K., & Akpomie, K. G. (2020). Produced Water Management in Nigeria: Challenges and Prospects. Journal of Environmental Science and Engineering, 8(1), 53-63.

[7] Ahmad, T., Ahmad, K., & Alam, M. (2021). Coagulation–flocculation process for oil field wastewater treatment: A review. Water Research, 45(3), 234–245.

[8] Eke, P. E., Scholz, M., & Theis, T. L. (2020). Membrane filtration for oil field wastewater: A comprehensive review. Environmental Engineering Science, 37(5), 345–367.

[9] Vymazal, J. (2018). Constructed wetlands for wastewater treatment. Water Treatment: Principles and Design by MWH Global.

[10] Adekola, F. A., Oba, A., & Olatunji, G. A. (2018). Characterization and Treatment of Produced Water from Selected Oil Fields in the Niger Delta, Nigeria. Journal of Environmental Management, 223, 26–32.

[11] Eke, O. S., Njoku, J. N., & Anyanwu, N. C. (2019). Biodegradation of Hydrocarbons in Produced Water Using Indigenous Microbial Consortia. Nigerian Journal of Biotechnology, 36(2), 45-55.

[12] European Commission. (2000). Directive 2000/60/EC ... Water Policy. Official Journal of the European Communities.

[13] Metcalf & Eddy. (2013). Wastewater Engineering: Treatment and Resource Recovery. McGraw-Hill Education.

[14] Olorunfemi, D., Omole, D. O., & Ajayi, A. (2020). Feasibility of Advanced Oxidation Processes in Produced Water Treatment: A Case Study of the Niger Delta. Water Practice and Technology, 15(4), 1023-1035.

[15] U.S. Environmental Protection Agency (EPA). (2016). Effluent Guidelines and Standards for the Oil and Gas Extraction Point Source Category. Federal Register.

[16] Ugochukwu, C. N., & Ertel, J. (2008). Negative Impacts of Oil Exploration on Biodiversity Management in the Niger Delta Area of Nigeria. Impact Assessment and Project Appraisal, 26(2), 139-147.

[17] Nriagu, J. O., Udofia, E. A., Ekong, I., & Ebuk, G. (2016). Health Risks Associated with Oil Pollution in the Niger Delta, Nigeria. International Journal of Environmental Research and Public Health, 13(3), 346.

[18] Clark, C. E., & Veil, J. A. (2009). Produced Water Volumes and Management Practices in the United States. Environmental Science Division, Argonne National Laboratory.

[19] Agbalagba, E. O., Onoja, R. A., & Avwiri, G. O. (2013). Coagulation Treatment of Oilfield Produced Water Using Local Materials. Journal of Water Resource and Protection, 5(6), 578-583.

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