Journal of Engineering Innovations and Applications
Volume 4(1), pages 1-11, April 2026
Article Number: 31CBEC611
ISSN: 2971-673X
https://doi.org/10.31248/JEIA2025.039
https://integrityresjournals.org/journal/JEIA

Full Length Research

Potentials of carbon storage and enhanced oil recovery in Niger Delta Region

Obeta, P. O.* and Ekiyor, P.

Department of Chemical and Petroleum Engineering, Igbinedion University, Okada, Nigeria.

*Corresponding author. Email: obeta.perpetual@iuokada.edu.ng; Tel: +234 803 7927 357; Orcid ID: https://orcid.org/0009-0008-2300-4625

Copyright © 2026 Obeta and Ekiyor. This article remains permanently open access under the terms of the Creative Commons Attribution License 4.0, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Received Date: 16 August 2025 | Accepted Date: 25 March 2026 | Published Date: 30 April 2026

ABSTRACT: The increasing concentration of atmospheric carbon dioxide resulting from fossil fuel exploitation and industrial activities has intensified the need for sustainable carbon management strategies. This study evaluated the potentials of carbon storage and enhanced oil recovery (CO_2-EOR) in selected reservoirs within the Niger Delta region of Nigeria. Ten depleted oil reservoirs were screened using established geological and reservoir criteria for carbon dioxide sequestration and miscible CO_2-enhanced oil recovery operations. Reservoir parameters evaluated included depth, pressure, temperature, porosity, permeability, reservoir thickness, caprock thickness, oil gravity, oil viscosity, and remaining oil saturation. Minimum miscibility pressure (MMP) values were also calculated and compared with reservoir pressures to determine the feasibility of miscible CO_2 flooding. The results showed that three reservoirs were classified as suitable for CO_2 storage, four reservoirs were fairly suitable, while three reservoirs were unsuitable mainly due to poor caprock thickness and containment concerns. Evaluation of CO_2-EOR potential revealed that eight reservoirs were good candidates for miscible CO_2 flooding, while two reservoirs showed average prospects because of low remaining oil fractions. Reservoir pressure values were greater than the calculated MMP values in all reservoirs, indicating favourable conditions for miscible CO_2 injection and enhanced oil recovery. Economic assessment further suggested that revenue generated from incremental oil production could offset operational and storage costs, thereby improving project feasibility. However, technical challenges such as reservoir heterogeneity, early CO_2 breakthrough, gravity segregation, and corrosion risks were identified as important considerations for implementation. The study demonstrates that depleted reservoirs in the Niger Delta possess significant potential for integrated carbon storage and enhanced oil recovery operations, which could contribute to greenhouse gas mitigation, improved hydrocarbon recovery, and sustainable energy development in Nigeria.

Keywords: Carbon storage, oil recovery, Minimum Miscibility Pressure, Niger Delta Region, reservoirs.

INTRODUCTION

Global climate change and environmental degradation caused by greenhouse gas emissions have become major global concerns in recent decades. Carbon dioxide (CO_2), largely generated from fossil fuel combustion, gas flaring, industrial activities, and energy production, is recognized as one of the principal contributors to global warming and atmospheric pollution. In oil-producing nations such as Nigeria, continuous hydrocarbon exploration and production activities, particularly gas flaring in the Niger Delta region, have significantly increased atmospheric CO_2 concentrations and associated environmental risks. These emissions contribute to rising global temperatures, ocean acidification, ecological imbalance, and adverse health impacts on humans and ecosystems (IPCC, 2005; Nwankwo *et al*., 2023).

Carbon Capture and Storage (CCS) has emerged as one of the most promising technologies for mitigating anthropogenic CO_2 emissions. CCS involves the capture of carbon dioxide from industrial and energy-related sources, followed by transportation and injection into suitable geological formations for long-term storage. Geological storage options include deep saline aquifers, depleted oil and gas reservoirs, coal seams, and formations utilized for enhanced hydrocarbon recovery operations (Hill *et al*., 2013; Dai *et al*., 2014). Among these options, depleted oil and gas reservoirs are c onsidered particularly attractive because of their proven trapping mechanisms, existing infrastructure, and extensive geological characterization acquired during hydrocarbon exploration and production activities (Ojo and Tse, 2016).

The Niger Delta Basin is one of the largest hydrocarbon-producing provinces in Africa and contains numerous mature and depleted reservoirs that may serve as suitable sites for geological CO_2 sequestration and enhanced oil recovery (EOR). Several studies have shown that many reservoirs within the basin possess favourable petrophysical and structural characteristics for CO_2 storage, including adequate porosity, permeability, reservoir thickness, sealing integrity, and injectivity potential (Umar *et al*., 2020; Davies *et al*., 2020; Maduewesi *et al*., 2024). Recent investigations in the Niger Delta have further demonstrated the viability of depleted reservoirs for sustainable carbon storage and CO_2-EOR applications (Eigbe *et al*., 2024; Ajidahun *et al*., 2026).

Enhanced Oil Recovery using CO_2 injection is a well-established tertiary recovery technique that improves hydrocarbon recovery while simultaneously providing an opportunity for long-term carbon storage. During CO_2-EOR operations, injected carbon dioxide reduces oil viscosity, improves oil mobility, and increases reservoir pressure, thereby enabling the production of additional hydrocarbons that would otherwise remain unrecovered (Kovscek and Cakici, 2005). A significant proportion of the injected CO_2 remains trapped within the reservoir through structural, residual, solubility, and mineral trapping mechanisms, making CO_2-EOR a dual-benefit technology for both energy production and greenhouse gas mitigation (Ampomah *et al*., 2016; Azzolina *et al*., 2015).

Globally, several successful CCS and CO_2-EOR projects have demonstrated the technical feasibility and environmental benefits of geological carbon storage. Projects such as the Weyburn Field in Canada, the Sleipner Project in Norway, and the In Salah Project in Algeria have shown that CO_2 can be safely injected and stored in subsurface formations over long periods with minimal leakage risk (Hill *et al*., 2013). These projects have also established that depleted hydrocarbon reservoirs can serve as effective storage sites while supporting enhanced hydrocarbon recovery operations.

In Nigeria, interest in CCS and CO_2-EOR has continued to increase because of the country's dependence on fossil fuels and the environmental challenges associated with gas flaring and industrial emissions. Studies by Odesa and Adewale (2011), Effiom *et al*. (2024), and Ogbeiwi and Stephen (2023) emphasized the enormous potential for integrating carbon capture technologies with enhanced oil recovery operations in the Niger Delta. The region possesses vast depleted reservoirs and mature oil fields that could be repurposed for carbon storage while extending field productivity and improving national revenue generation.

Despite these opportunities, the implementation of CCS and CO_2-EOR in Nigeria remains limited due to several technical, economic, regulatory, and infrastructural challenges. Concerns relating to reservoir integrity, caprock competence, leakage risks, monitoring systems, transportation infrastructure, and high operational costs continue to hinder large-scale deployment of CCS technologies in the country (Galadima and Garba, 2008). Furthermore, comprehensive evaluation and screening of depleted reservoirs for carbon storage suitability are still inadequate in many parts of the Niger Delta Basin.

Therefore, this study evaluates the potentials of carbon storage and enhanced oil recovery in selected reservoirs within the Niger Delta region. The study focuses on assessing reservoir characteristics and comparing them with established screening criteria for geological CO_2 storage and miscible CO_2-EOR operations. The outcome of this research is expected to provide useful insights into the viability of utilizing depleted Niger Delta reservoirs for sustainable carbon management and improved hydrocarbon recovery.

METHODOLOGY

This study adopted a comparative analytical approach to evaluate the potentials of carbon storage and enhanced oil recovery (CO_2-EOR) in selected depleted oil reservoirs within the Niger Delta region. The methodology involved the assessment of reservoir characteristics and comparison of the obtained parameters with established screening criteria for geological carbon sequestration and miscible CO_2-EOR operations.

The research procedure was carried out in three major stages: (i) acquisition and assessment of reservoir data, (ii) screening of reservoirs for CO_2 storage suitability, and (iii) evaluation of reservoirs for CO_2-enhanced oil recovery potential.

Reservoir data acquisition

Reservoir and fluid properties of selected Niger Delta oil fields were obtained from available field records and published reservoir datasets. The acquired parameters included reservoir oil in place, reservoir depth, temperature, pressure, thickness, porosity, permeability, caprock thickness, well density, oil viscosity, oil gravity, and remaining oil fraction in the reservoir. The detailed reservoir characteristics used in this study are presented in Table 1.

Screening for CO_2 storage potential

The suitability of the selected reservoirs for geological carbon storage was evaluated using internationally recognized site selection criteria proposed by Bachu *et al*. (2003). The screening process focused on determining the integrity, capacity, and safety of the reservoirs for long-term CO_2 sequestration.

Critical parameters considered during the screening

Table 1. Niger Delta oil field data.

Reservoirs	OP(STB)	Depth (ft)	Temp.	Pre. (Psi)	Thic. (ft)	Por.	Perm.	CT	WD (lb/ft^3)	OV	OG	OG (°API)	°API + 131.5	BO (RB/STB)
A1	98428539	7851	133	3325	48	0.24	668	24	9975	0.8	0.77961	50	181.5	1.25
A2	93403217	7935	134	3498	48	0.25	1241	36	10494	1	0.79718	46	177.5	1.2
A3	86639358	8126	139	3500	48	0.29	1541	143	10500	1.5	0.84985	35	166.5	1.5
A4	92128174	8510	143	3728	48	0.27	3251	336	11184	1.2	0.81556	42	173.5	1.6
A5	92059531	8692	147	3838	48	0.18	458	134	11514	1.1	0.8017	45	176.5	1.2
A6	100571609	8751	147	3914	48	0.28	630	11	11742	1.8	0.83481	38	169.5	2
A7	115630552	9103	155	4034	48	0.23	932	304	12102	2.5	0.89274	27	158.5	1.26
A8	110988765	9201	158	4055	48	0.31	2545	50	12165	2.3	0.87616	30	161.5	1.3
A9	106705223	9271	159	4062	48	0.28	2448	22	12186	1.34	0.82507	40	171.5	1.45
A10	128930329	9602	162	4181	48	0.26	1421	283	12543	2	0.86544	32	163.5	1.22

Keys: Op = Oil in Place, Temp. = Temperature, Pre. = Pressure, Thic. = Thickness, Por. = Porosity, Perm. = Permeability, CT = Caprock Thickness, WD = Well Density lb/ft^3, OV = Oil Viscosity.

Table 2. Site selection criteria for ensuring the safety and security of CO_2 storage (Bachu *et al*., 2003).

Criterion level	No	Criterion	Eliminatory or unfavourable	Preferred or favourable
Critical	1	Reservoir-seal pairs; Extensive and competent barrier to vertical flow	Poor, discontinuous, faulted and/or breached	Intermediate and excellent; many pairs (multi-layered system)
	2	Pressure regime	Overpressured: pressure gradients greater than 14 kPa/m	Pressure gradients less than 12 kPa/m
	3	Monitoring potential	Absent	Present
Desirable	8	Depth	< 750-800 m	>800 m
	11	Geothermal regime	Gradients ≥ 35 ºC/km and/or high surface temperature	Gradients < 35 ºC/km and low surface temperature
	12	Temperature	< 35 ºC	≥ 35 ºC
	13	Pressure	< 7.5 MPa	≥ 7.5 MPa
	14	Thickness	< 20 m	≥ 20 m
	15	Porosity	< 10%	≥ 10%
	16	Permeability	< 20 mD	≥ 20 mD
	17	Caprock thickness	< 10 m	≥ 10 m
	18	Well density	High	Low to moderate

and monitoring potential. Additional desirable criteria such as reservoir depth, geothermal gradient, temperature, pressure, thickness, porosity, permeability, caprock thickness, and well density were also evaluated. Reservoirs that satisfied the favourable conditions specified in the screening framework were considered suitable for carbon storage applications. The adopted screening criteria are summarized in Table 2.

Table 3. Suggested characteristics of oil reservoirs suitable for miscible CO_2-EOR (metric values are given in brackets) (IPCC 2005)

Reservoir Parameter	Miscible CO_2-EOR
Size (ROIP in MMstb; or MtCO2)	≥1 (whichever condition is met first)
Depth (ft/m)	>1500 (>450)
Temperature (ºF/ºC)	82 to 250 (28 to 121)
Pressure	> MMP and < P_f
Porosity (%)	≥3
Permeability (Md)	≥5
Oil Gravity (API)	27 to 45
Oil Viscosity (cP/mPa·s)	≤6
Remaining Oil Fraction in the Reservoir	≥0.30

Screening for CO_2-enhanced oil recovery potential

The selected reservoirs were further evaluated for their applicability to miscible CO_2-enhanced oil recovery using the screening guidelines recommended by the Intergovernmental Panel on Climate Change (IPCC, 2005). Reservoir properties including reservoir size, depth, temperature, pressure, porosity, permeability, oil gravity, oil process included reservoir-seal integrity, pressure regime, viscosity, and remaining oil saturation were compared with the recommended criteria for successful miscible CO_2 flooding. The screening standards used for this assessment are presented in Table 3.

Determination of minimum miscibility pressure (MMP)

The minimum miscibility pressure (MMP) of the reservoir oils was calculated to determine the pressure condition required for achieving miscibility between injected CO_2 and reservoir oil. The calculated MMP values were subsequently compared with reservoir pressures to identify reservoirs favourable for miscible CO_2-EOR operations.

The determination of MMP was based on empirical correlations involving reservoir temperature, oil API gravity, molecular weight of the heavier hydrocarbon fraction (C5+), and oil relative density. Equations 1 to 3 were employed in the calculation procedure.

$$\mathrm{MMP} = -329.558 + (7.727\mathrm{MW} * 1.005^{\mathrm{T}}) - (4.377 * \mathrm{MW}) \quad \text{...1}$$

$$\mathrm{MW} = \left(\frac{8864.9}{\mathrm{G}}\right) * \frac{1}{1.0386} \quad \text{...2}$$

$$\mathrm{G} = \frac{141.5}{\gamma_0} - 131.5 \quad \text{...3}$$

Where: MMP = Minimum miscibility pressure (psia), MW = Molecular weight of C5+ fraction, G = API gravity of oil, ρ = Relative density of oil, T = Reservoir temperature (°F)

Reservoirs with operating pressures greater than the calculated MMP and within fracture pressure limits were considered favourable candidates for miscible CO_2-enhanced oil recovery.

RESULTS AND DISCUSSION

Screening of Niger Delta reservoirs for CO_2 storage potential

The selected Niger Delta reservoirs were evaluated using established geological screening criteria for carbon dioxide storage proposed by Bachu (2000, 2003) and the IPCC (2005). The screening parameters included reservoir-seal integrity, reservoir depth, geothermal regime, temperature, pressure, porosity, permeability, reservoir thickness, caprock thickness, and well density. The detailed screening results are presented in Table 4, while the summary classification of the reservoirs is illustrated in Figure 1.

The screening results revealed that three reservoirs were classified as suitable ("OK") for CO_2 storage, four reservoirs were categorized as fairly suitable, while three reservoirs were classified as poor candidates for geological carbon storage. The reservoirs identified as suitable exhibited favourable reservoir characteristics including adequate depth, high porosity, good permeability, sufficient caprock thickness, and acceptable pressure conditions. These characteristics are important because they enhance injectivity, storage capacity, and long-term containment of injected carbon dioxide (Bachu, 2000; Bradshaw *et al*., 2007).

Reservoir depth is a critical factor in carbon sequestration because CO_2 must be injected at depths sufficient to maintain supercritical conditions, thereby maximizing storage efficiency and reducing buoyancy-driven leakage risks. All the reservoirs evaluated exceeded the minimum depth requirement recommended for geological storage operations. This observation agrees with the findings of Umar *et al*. (2020) and Davies *et al*. (2020), who reported that many Niger Delta reservoirs possess adequate burial depths favourable for carbon sequestration.

Porosity and permeability values recorded for the reservoirs also indicate favourable storage and injectivity

Table 4. Selected Niger Delta screened against suggested reservoir properties for CO_2 storage.

Criterion	A 1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Reservoir-seal pairs	Poor	Intermediate	Excellent	Excellent	Intermediate	Poor	Excellent	Intermediate	Intermediate	Excellent
Pressure regime	9.580	9.971	9.742	9.909	10.185	10.427	10.076	9.969	9.910	9.849
Depth (m)	2392.924	2418.563	2476.831	2593.857	2649.330	2667.313	2774.603	2804.473	2825.809	2926.699
Geothermal regimeºC/km	23.448	23.430026	24.000014	23.774247	24.11511	23.952561	24.62802	24.96012	24.96842	24.67695
Temperature (ºC)	56.111	56.667	59.444	61.667	63.888	63.889	68.333	70.000	70.556	72.222
Pressure (Mpa)	22925068	24117861	24131651	25703655	26986080	27813451	27958241	27958241	28006504	28826980
Porosity (%)	24	25	29	27	18	28	23	31	28	26
Permeability (Md)	668	1241	1541	3251	458	630	932	2545	2448	1421
Thickness (m)	14.6304	15.849	73.456	12.496	6.0960	25.603	18.288	12.496	68.275	49.072
Caprock thickness	7.3152	11.008766	43.638	102.394	40.843	3.352	92.659	15.240	6.705	86.258
Well density	9975	9686.77	2091.29	13093.5	27633.6	6709.71	9681.6	14242	9681.6	6709.71
Field screening remark based on CO2 storage capacity	poor	Fairly ok	Ok	Fairly ok	Fairly ok	Poor	Ok	poor	Fairly ok	Ok

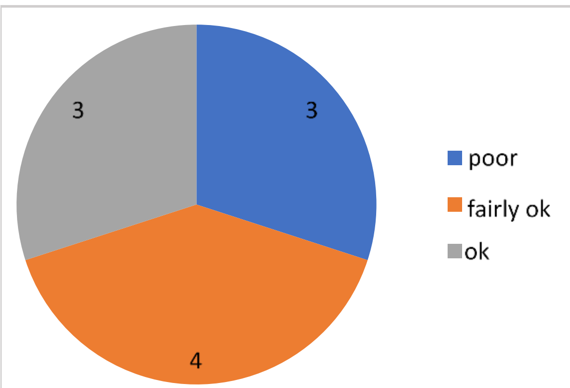

Figure 1. Oil field screening for CO_2 storage.

characteristics. High porosity enhances storage capacity, while permeability controls the ease of CO_2 injection and migration within the reservoir. Most of the evaluated reservoirs exhibited porosity and permeability values significantly above the minimum thresholds recommended for CO_2 sequestration projects. Similar observations were reported by Ojo and Tse (2016), Agunbiade *et al*. (2023), and Eigbe *et al*. (2024), who demonstrated that depleted reservoirs within the Niger Delta possess suitable petrophysical characteristics for carbon storage applications.

Caprock integrity remains one of the most important criteria for successful geological carbon storage because it determines the ability of the reservoir to prevent upward migration and leakage of injected carbon dioxide. The reservoirs classified as poor candidates generally exhibited inadequate caprock thickness, which may compromise long-term containment security. Thin or discontinuous caprocks increase the possibility of CO_2 leakage through fractures, faults, or abandoned well pathways (Lindeberg, 1997; Chadwick *et al*., 2008). Consequently, reservoirs with poor caprock characteristics were considered unsuitable for long-term storage operations. This observation is consistent with the work of Ajidahun *et al*. (2026), which emphasized the importance of structural integrity and sealing efficiency in reservoir selection for CO_2 sequestration.

The pressure and geothermal conditions of the reservoirs also indicate favourable subsurface environments for carbon storage. Reservoir pressures were sufficiently high to maintain injected CO_2 in dense phases, thereby improving storage efficiency and injectivity performance. Temperature gradients obtained from the reservoirs are within acceptable ranges for geological storage operations and compare favourably with values reported in previous Niger Delta sequestration studies (Maduewesi *et al*., 2024; Mutadza *et al*., 2025a).

Overall, the screening assessment indicates that a significant proportion of the selected Niger Delta reservoirs possess favourable geological and petrophysical conditions for carbon dioxide storage. The results support earlier studies by Momodu *et al*. (2022) and Effiom *et al*. (2024), which identified depleted hydrocarbon reservoirs in the Niger Delta as viable candidates for large-scale CCS implementation.

Minimum miscibility pressure (MMP) evaluation for CO_2-EOR

The minimum miscibility pressure (MMP) values calculated for the selected reservoirs are presented

Table 5. Parameter for calculating minimum miscibility pressure

G (Oil gravity °API)	MW	MMP (psi)
50	170.7086	1483.915
46	185.5529	1655.524
35	243.8695	2372.241
42	203.2246	1985.234
45	189.6763	1891.178
38	224.6166	2300.261
27	316.1271	3578.661
30	284.5144	3259.638
40	213.3858	2380.468
32	266.7323	3126.642

Table 6. Comparison of reservoir pressure with minimum miscibility pressure.

Reservoir	Pressure (psi)	MMP (psi)	P/MMP	Remark
A1	3325	1483.915	2.240695073	Good prospect
A2	3498	1655.524	2.112925594	Good prospect
A3	3500	2372.241	1.475398296	Good prospect
A4	3728	1985.234	1.877864306	Good prospect
A5	3838	1891.178	2.029422597	Good prospect
A6	3914	2300.261	1.701545808	Good prospect
A7	4034	3578.661	1.127237233	Good prospect
A8	4055	3259.638	1.244003279	Good prospect
A9	4062	2380.468	1.706386993	Good prospect
A10	4181	3126.642	1.33721726	Good prospect

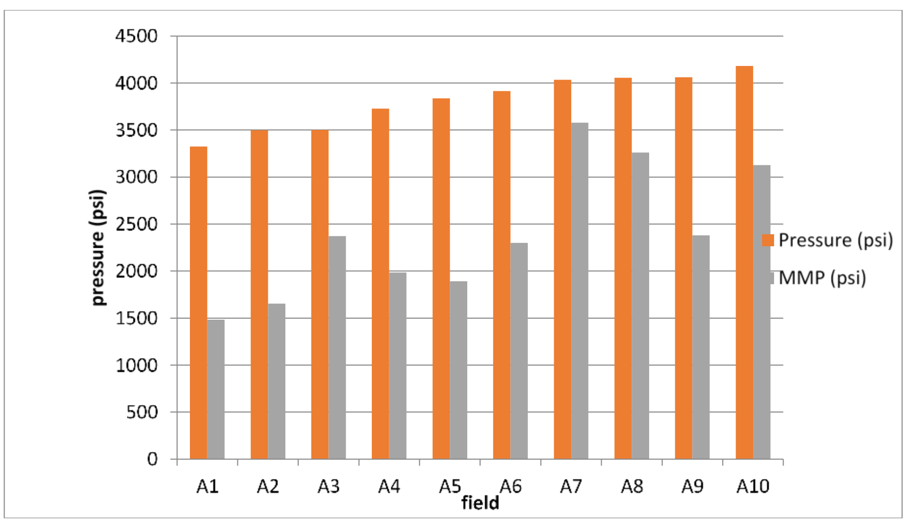

Figure 2. Comparison between reservoir pressure and MMP.

in Table 5, while the comparison between reservoir pressure and MMP is shown in Table 6 and Figures 2 and 3. MMP is one of the most important parameters in evaluating the feasibility of miscible CO_2-enhanced oil recovery because it defines the minimum pressure required for injected CO_2 to achieve miscibility with reservoir oil.

The calculated MMP values varied across the reservoirs due to differences in oil gravity, reservoir temperature, and molecular weight of heavier hydrocarbon fractions. Reservoirs with lighter oils generally recorded lower MMP values, while reservoirs containing relatively heavier oils exhibited higher MMP values. This trend agrees with the

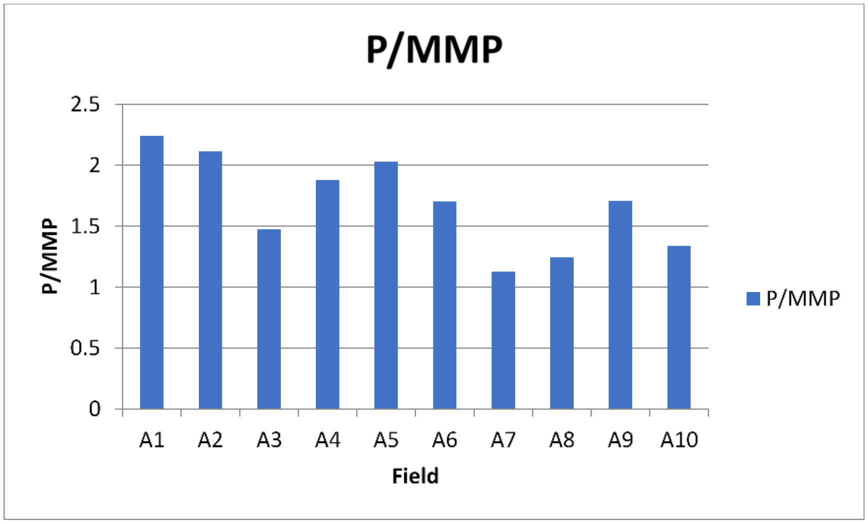

Figure 3. Ratio of P/MMP.

observations of Kovscek and Cakici (2005) and Salehpour *et al*. (2020), who reported that oil composition and reservoir temperature significantly influence miscibility behaviour during CO_2 flooding.

Comparison of reservoir pressure with MMP indicates that all evaluated reservoirs possessed pressure values greater than their corresponding MMP values. The pressure-to-MMP ratios shown in Figure 3 were all greater than unity, indicating favourable conditions for miscible CO_2 flooding. Reservoirs with pressure conditions above MMP are expected to achieve efficient oil displacement, improved sweep efficiency, and enhanced recovery performance during CO_2 injection operations (Tzimas *et al*., 2005).

The favourable miscibility conditions obtained in this study suggest that injected CO_2 would effectively interact with reservoir oil through mechanisms such as oil swelling, viscosity reduction, and interfacial tension reduction. These mechanisms improve oil mobility and increase hydrocarbon recovery efficiency. Similar results were reported by Odesa and Adewale (2011), who demonstrated that several offshore Niger Delta reservoirs possess favourable miscibility conditions for CO_2-EOR implementation.

Although all reservoirs met the miscibility requirement, reservoirs with higher pressure-to-MMP ratios are expected to exhibit better displacement efficiency and more stable miscible flooding behaviour. Reservoirs with ratios closer to unity may still experience partial miscibility under certain operating conditions, which could reduce sweep efficiency and incremental oil recovery. Nevertheless, the results generally indicate strong prospects for miscible CO_2-EOR operations within the evaluated fields.

Screening of reservoirs for CO_2-enhanced oil recovery potential

The selected reservoirs were further screened using standard CO_2-EOR screening criteria, including reservoir size, depth, temperature, pressure, porosity, permeability, oil gravity, oil viscosity, and remaining oil fraction. The screening results are presented in Table 7, while the overall assessment summary is illustrated in Figure 4.

The results show that eight reservoirs were classified as good candidates for CO_2-EOR, while two reservoirs were categorized as average candidates. The reservoirs classified as good prospects satisfied most of the recommended screening criteria for miscible CO_2 flooding, including adequate reservoir size, favourable pressure conditions, acceptable oil gravity, low oil viscosity, and sufficient remaining oil saturation.

Reservoir size is an important economic consideration for CO_2-EOR projects because larger reservoirs generally provide greater incremental oil recovery and improved economic returns. All evaluated reservoirs possessed substantial reserves of oil initially in place, indicating strong economic potential for tertiary recovery operations. This observation agrees with the findings of Godec *et al*. (2011) and Leach *et al*. (2011), who emphasized that reservoir size strongly influences the commercial viability of combined CO_2-EOR and carbon storage projects.

Oil gravity and viscosity values obtained from the reservoirs also indicate favourable conditions for CO_2 flooding. Most reservoirs contained light to medium crude oils with relatively low viscosities, which enhance miscibility and improve oil displacement efficiency during CO_2 injection. Light oils generally require lower miscibility pressures and exhibit better recovery performance than heavier oils (Adu *et al*., 2019; Yu *et al*., 2024).

The two reservoirs classified as average candidates failed to fully satisfy the remaining oil fraction criterion. Remaining oil saturation is an important parameter because CO_2-EOR becomes economically attractive only when sufficient residual oil remains within the reservoir after primary and secondary recovery operations. Reservoirs with low remaining oil fractions may not generate sufficient

Table 7. Selected Niger Delta screened against suggested reservoir properties for CO_2-EOR.

Reservoir Parameter	Miscible CO_2-EOR	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Size (ROIP in MMstb)	≥1	98428539	101186818	435001776	78692815	38358138	176000315	144538190	94802903	497957706	432453812
Depth (ft)	>1500	7851	7935	8126	8510	8692	8751	9103	9201	9271	9602
Temperature (ºF)	82 to 250	133	134	139	143	147		155	158	159	162
Pressure (psi)	> MMP and < P_f	3325	3498	3500	3728	3838	3914	4034	4055	4062	4181
Porosity (%)	≥3	24	25	29	27	18	28	23	31	28	26
Permeability (Md)	≥5	668	1241	1541	3251	458	630	932	2545	2448	1421
Oil Gravity (API)	27 to 45	50	46	35	42	45	38	27	30	40	32
Oil Viscosity (cP/mPa·s)	≤6	0.8	1	1.5	1.2	1.1	1.8	2.5	2.3	1.34	2
Remaining Oil Fraction in the Reservoir	≥0.30	0.37	0.45	0.021	0.473	0.283	0.753	0.471	0.854	0.879	0.655
Remark		Good	Good	Average	Good	Average	Good	Good	Good	Good	Good

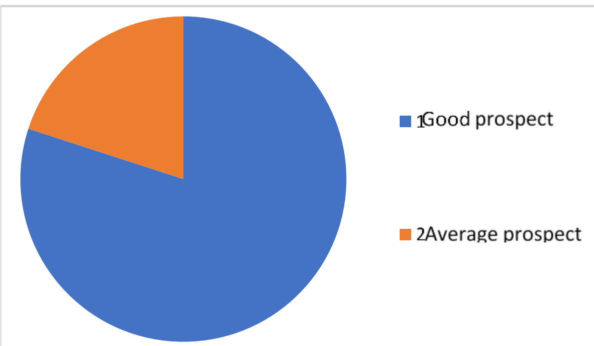

Figure 4. Summary of assessment for fields that have prospect of CO_2 –EOR.

incremental oil recovery to justify project costs. Similar conclusions were reported by Chen and Pawar (2019), who noted that residual oil saturation strongly influences CO_2-EOR performance and storage efficiency.

The porosity and permeability characteristics of the reservoirs further support their suitability for CO_2 flooding operations. High permeability values promote injectivity and fluid movement, while adequate porosity improves reservoir storage capacity for injected CO_2. These favourable reservoir properties are consistent with studies by Mutadza *et al*. (2025b) and Davies *et al*. (2020), which identified the Niger Delta Basin as a promising region for combined CO_2 sequestration and enhanced oil recovery operations.

The overall screening results demonstrate that the majority of the selected Niger Delta reservoirs possess strong technical potential for integrated CO_2-EOR and carbon storage projects. The findings support previous studies by Ogbeiwi and Stephen (2023) and Effiom *et al*. (2024), which concluded that CO_2-EOR could serve as a viable strategy for reducing greenhouse gas emissions while simultaneously improving oil recovery and economic performance in Nigeria's petroleum sector.

Economic implications of CO_2-EOR and carbon storage

The economic evaluation indicates that integrated CO_2-EOR and storage projects could be economically feasible within the selected Niger Delta reservoirs. Economic assessment considered major cost components including CO_2 capture and compression, transportation, storage, monitoring, and revenue generated from incremental oil production. Based on the estimated world oil price used in the analysis, projected revenues from additional oil recovery significantly exceeded the estimated operational costs.

This finding suggests that revenue generated from incremental hydrocarbon production could offset the cost of carbon storage operations while providing additional economic benefits. Similar conclusions were reached by Ogbeiwi and Stephen (2023) and Leach *et al*. (2011), who demonstrated that combined CO_2-EOR and sequestration projects often become economically attractive when supported by favourable oil prices and existing infrastructure.

The availability of mature oil fields, existing production facilities, and transportation networks within the Niger Delta further improves the economic attractiveness of CCS and CO_2-EOR implementation. Existing infrastructure reduces initial capital investment requirements and facilitates integration of carbon management technologies into ongoing petroleum operations.

Technical challenges associated with CO_2-EOR and carbon storage

Despite the favourable screening results, several technical challenges may affect the successful implementation of CO_2-EOR and carbon storage operations within the Niger Delta reservoirs. One major challenge is poor sweep efficiency resulting from reservoir heterogeneity, gas override, mobility contrast, and early CO_2 breakthrough. Highly heterogeneous reservoirs may cause uneven CO_2 distribution and reduced displacement efficiency during flooding operations.

Reservoirs containing extensive vertical fractures may also experience out-of-zone CO_2 migration and early gas breakthrough, thereby reducing oil recovery performance and storage efficiency. Similarly, reservoirs with extremely high permeability and thickness may experience gravity segregation effects, causing inefficient sweep and reduced contact between injected CO_2 and reservoir oil.

Corrosion associated with CO_2 injection represents another major operational concern. Carbon dioxide can react with water to form carbonic acid, leading to severe corrosion of pipelines, well tubing, production facilities, and injection equipment. Offshore operations may experience additional challenges relating to platform modifications, equipment integrity, and increased operational complexity (Galadima and Garba, 2008).

Well spacing and reservoir management also influence the effectiveness of CO_2-EOR projects. Large well spacing may reduce sweep efficiency and delay incremental oil production, while drilling additional wells increases project costs. Consequently, careful reservoir characterization, monitoring, and optimized injection strategies are necessary to improve project performance and ensure long-term storage security.

Overall, the study demonstrates that many depleted reservoirs within the Niger Delta possess significant potential for integrated carbon storage and enhanced oil recovery operations. However, successful implementation will require detailed reservoir characterization, effective monitoring systems, economic optimization, and appropriate regulatory frameworks to address the technical and environmental challenges associated with CO_2 injection and long-term geological storage.

Conclusion

This study evaluated the potentials of carbon storage and enhanced oil recovery in selected depleted reservoirs within the Niger Delta region using established geological and CO_2-EOR screening criteria. The results demonstrated that many of the evaluated reservoirs possess favourable geological and petrophysical characteristics suitable for carbon dioxide sequestration and miscible CO_2-enhanced oil recovery operations.

The screening assessment showed that three reservoirs were highly suitable for carbon storage, while four reservoirs were fairly suitable based on parameters such as reservoir depth, porosity, permeability, pressure conditions, and caprock integrity. Reservoirs classified as poor candidates were mainly limited by inadequate caprock thickness, which could compromise long-term containment of injected CO_2.

Minimum miscibility pressure analysis indicated that reservoir pressures in all evaluated fields exceeded the calculated MMP values, confirming favourable conditions for miscible CO_2 flooding. Furthermore, eight reservoirs were identified as good candidates for CO_2-enhanced oil recovery due to favourable oil gravity, low oil viscosity, adequate permeability, and sufficient remaining oil saturation. The economic evaluation also revealed that incremental oil production from CO_2-EOR operations could potentially offset carbon storage costs and improve project profitability.

Despite the favourable prospects, the study identified several technical challenges including reservoir heterogeneity, poor sweep efficiency, gravity segregation, early CO_2 breakthrough, and corrosion-related operational concerns. Nevertheless, the findings confirm that the Niger Delta Basin possesses substantial potential for integrated carbon capture, storage, and enhanced oil recovery projects capable of supporting both environmental sustainability and improved hydrocarbon recovery.

Recommendations

1. Detailed reservoir characterization and simulation studies should be conducted on the identified suitable reservoirs to improve understanding of CO_2 injection behaviour, storage capacity, and long-term containment performance.
2. Pilot-scale CO_2-EOR and carbon storage projects should be implemented in selected Niger Delta reservoirs to evaluate operational feasibility and optimize injection strategies under field conditions.
3. Government and regulatory agencies should develop comprehensive policies, monitoring frameworks, and fiscal incentives to encourage investment in carbon capture, storage, and enhanced oil recovery technologies in Nigeria.

CONFLICTS OF INTEREST

The authors declare that they have no conflict of interest.

REFERNCES

Adu, E., Zhang, Y., & Liu, D. (2019). Current situation of carbon dioxide capture, storage, and enhanced oil recovery in the oil and gas industry. *The Canadian Journal of Chemical Engineering*, *97*(5), 1048-1076.

Agunbiade, T. O., Oluwadare, O. A., & Amusan, R. O. (2023, July). Reservoir Characterization for Co 2 Sequestration and Co 2-Enhanced Oil Recovery Techniques in Maje Field, Offshore Niger-Delta, Nigeria. In *SPE Nigeria Annual International Conference and Exhibition* (p. D021S007R004). SPE.

Ajidahun, J., Oluwajana, O. A., Ifanegan, A. S., & Odusanwo, Y. O. (2026). Structural and petrophysical assessment of CO2 storage in depleted Z-field reservoirs, Offshore Niger Delta Basin. *Marine Georesources & Geotechnology*, *44*(2), 330-347.

Ampomah, W., Balch, R., Cather, M., Rose-Coss, D., Dai, Z., Heath, J., ... & Mozley, P. (2016). Evaluation of CO2 storage mechanisms in CO2 enhanced oil recovery sites: application to morrow sandstone reservoir. *Energy & Fuels*, *30*(10), 8545-8555.

Azzolina, N. A., Nakles, D. V., Gorecki, C. D., Peck, W. D., Ayash, S. C., Melzer, L. S., & Chatterjee, S. (2015). CO2 storage associated with CO2 enhanced oil recovery: A statistical analysis of historical operations. *International Journal of Greenhouse Gas Control*, *37*, 384-397.

Bachu, S., (2000). “Sequestration of carbon dioxide in geological media: criteria and approach for site selection”. Energy Convers. Manage. 41(9), 953-970.

Bachu, S., (2003). Screening and ranking of sedimentary basins for sequestration of CO2 in geological media. Env. Geol., 44(3), 277-289.

Bradshaw, J., Bachu, S., Bonijoly, D., Burruss, R., Holloway, S., Christensen, N.P., Mathiassen, O.M. (2007). CO2 storage capacity estimation: Issues and development of standards. International Journal of Greenhouse Gas Control, 1(1), 62-68.

Chadwick, A., Arts, R., Bernstone, C., May, F., Thibeau, S., Zweigel, P., (2008). Best Practice for the CO2 Storage in Saline Aquifers – Observations and Guidelines from the SACS and CO2STORE Projects. British Geological Survey, Nottingham, UK.

Chen, B., & Pawar, R. J. (2019). Characterization of CO2 storage and enhanced oil recovery in residual oil zones. *Energy*, *183*, 291-304.

Dai, Z., Middleton, R., Viswanathan, H., Fessenden-Rahn, J., Bauman, J., Pawar, R., ... & McPherson, B. (2014). An integrated framework for optimizing CO2 sequestration and enhanced oil recovery. *Environmental Science & Technology Letters*, *1*(1), 49-54.

Davies, O. A., Israel-Cookey, C., Uko, E. D., & Alabraba, M. A. (2020). Reservoir Capacity and Injectivity Characterization for Carbon Dioxide (CO2) Geo-Sequestration in the Niger Delta. *International Journal of Research and Innovation in Applied Science*, *V*(X), 19-26

Effiom, P. C., Effiom, S. O., Evareh, J. E., Uket, I. O., & Osim-Asu, D. (2024). Prospects of carbon capture technologies for enhanced oil recovery in Nigeria’s oil and gas sector. *International Journal of Engineering & Technology*, *13*(2), 286-293.

Eigbe, P. A., Ajayi, O. O., Olakoyejo, O. T., & Adelaja, A. O. (2024). Characterization of depleted hydrocarbon reservoir AA-01 of KOKA field in the Niger Delta basin for sustainable Sub-Sea carbon dioxide storage. *Journal of Marine Science and Application*, *23*(3), 544-564.

Galadima, A. &Garba, Z. N. (2008). Carbon Capture and Storage (CCS) in Nigeria: Fundamental Science and Potential Implementation Risks. Science World Journal, 3 (2):95-99.

Godec, M., Kuuskraa, V., Van Leeuwen, T., Melzer, L. S., & Wildgust, N. (2011). CO2 storage in depleted oil fields: The worldwide potential for carbon dioxide enhanced oil recovery. *Energy Procedia*, *4*, 2162-2169.

Hill, B., Hovorka, S., & Melzer, S. (2013). Geologic carbon storage through enhanced oil recovery. *Energy Procedia*, *37*, 6808-6830.

IPCC (Intergovernmental Panel on Climate Change), (2005). Chapter 5: Underground geological storage. In: Special Report on Carbon Dioxide Capture and Storage. Cambridge University Press, Cambridge, U.K., and New York, NY, U.S.A.

Kovscek, A. R., & Cakici, M. D. (2005). Geologic storage of carbon dioxide and enhanced oil recovery. II. Cooptimization of storage and recovery. *Energy conversion and Management*, *46*(11-12), 1941-1956.

Leach, A., Mason, C. F., & van‘t Veld, K. (2011). Co-optimization of enhanced oil recovery and carbon sequestration. *Resource and energy Economics*, *33*(4), 893-912.

Lindeberg, E., (1997). Escape of CO2 from aquifers. Energy Convers. Manage., 38S, S235-S240.

Maduewesi, C. O., Dosunmu, A., & Osokogwu, U. (2024). Technical Assessment for Carbon Dioxide Storage of a Field in Niger Delta. *Petroleum & Coal*, *66*(2), 477-486.

Momodu, E., Kelechi, F. M., Soro, A., Shittu, S., Osime, K. V., & Olawunmi, E. O. (2022, August). Prospective Application of Carbon Capture and Storage: A Case Study of Field X in OML Y in the Niger Delta Basin. In *SPE Nigeria Annual International Conference and Exhibition* (p. D021S012R004). SPE.

Mutadza, I., Ikiensikimama, S. S., & Joel, O. F. (2025). Preliminary Assessment of the Reservoir Rock in the Niger Delta for Carbon Capture and Storage in Depleted Reservoirs. *Journal of GeoEnergy*, *2025*(1), 4230897.

Mutadza, I., Ikiensikimama, S. S., & Joel, O. F. (2025b). Petrophysical and petrographic characterisation of the reservoirs in Niger Delta for carbon capture and storage. *Scientific African*, *29*, e02774.

Nwankwo, C., Tse, A. C., Nwankwoala, H. O., Giadom, F. D., & Acra, E. J. (2023). Below ground carbon stock and carbon sequestration potentials of mangrove sediments in Eastern Niger Delta, Nigeria: Implication for climate change. *Scientific African*, *22*, e01898.

Odesa, D., & Adewale, D. (2011, July). Carbon Capture for Enhanced Oil Recovery in Niger Delta: A Case Study of Okota/Okpoputa Field in Offshore Niger Delta. In *SPE Asia Pacific Enhanced Oil Recovery Conference* (pp. SPE-145049). SPE.

Ogbeiwi, P., & Stephen, K. D. (2023). Techno-economic evaluation of the potential of CO2 storage and Enhanced Oil Recovery in the Niger-Delta Hydrocarbon Basin using reservoir simulation: Case Study. Retrieved from https://eartharxiv.org/repository/view/5673/

Ojo, A. C., & Tse, A. C. (2016). Geological characterisation of depleted oil and gas reservoirs for carbon sequestration potentials in a field in the Niger Delta, Nigeria. *Journal of Applied Science & Environmental Management*, *20*(1), 45.

Salehpour, M., Riazi, M., Malayeri, M. R., & Seyyedi, M. (2020). CO2-saturated brine injection into heavy oil carbonate reservoirs: Investigation of enhanced oil recovery and carbon storage. *Journal of Petroleum Science and Engineering*, *195*, 107663.

Tzimas, E.; Georgakaki, A.; Garcia Cortes; C.& Peteves, S. D. (2005). Enhanced Oil Recovery using Carbon Dioxide in the European Energy System. DG JRC, Institute for Energy, Petten, The Netherlands.Stevens, S.H.; Kuuskraa V.A.; Gale, J. &Beecy, D. (2001). CO2 Injection and Sequestration in Depleted Oil and Gas Fields and Deep Coal Seams: Worldwide Potential and Costs. Environmental Geosciences, 8(3):200-209.

Umar, B. A., Gholami, R., Nayak, P., Shah, A. A., & Adamu, H. (2020). Regional and field assessments of potentials for geological storage of CO2: A case study of the Niger Delta Basin, Nigeria. *Journal of Natural Gas Science and Engineering*, *77*, 103195.

Yu, H., Tang, H., Han, X., Song, P., Ma, R., Zhang, L., ... & Wang, Y. (2024). Enhanced oil recovery and CO2 storage by enhanced carbonated water injection: a mini-review. *Energy & Fuels*, *38*(14), 12409-12432.