Strategy for Managing to Reduce Environmental Risks of Produced Water Discharges from Oil Production. Case Study: "Kizombaa Platform" in Block 15, Coastal Zaire Province, Angola (2019-2021).

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ABSTRACT

The objective of the study is to develop a management strategy to reduce the environmental risks generated by produced water discharges during oil production on the Kizomba A Platform, Block 15, along the coast of Zaire Province (2019–2021). Methods: qualitative and quantitative approaches; interview techniques, laboratory research, and questionnaires; population of 50 elements, sample of 30. Results: the proposed management strategy contributes to mitigating the environmental impacts of produced water discharges, highlighting that oil activities cause significant impacts on local and global biodiversity. Although petroleum toxicity degrades over time, it continues to represent pollution and risk for ecosystems; management measures can reduce direct risks during and after exploration..

Keywords: Management; Spills; Risks; Oil; Sustainability

INTRODUCTION

Global energy demand continues to drive oil and gas development in offshore basins, including Angola. One of the country's key offshore assets is the Kizomba A platform, located in Block 15. As offshore production intensifies, the environmental burden of routine operations becomes more visible, particularly through the generation of produced water.

Produced water—the formation water that emerges with hydrocarbons—typically contains dissolved salts, dispersed hydrocarbons, heavy metals, naturally occurring radioactive materials, and additives used during production and treatment. If not managed effectively, produced water discharges can contribute to marine contamination, loss of ecosystem health, and non-compliance with environmental and operational regulations. Therefore, there is a practical need for management strategies that reduce environmental risk while supporting continued production.

Dissertation objective

This study aims to analyze and propose a management strategy to reduce environmental risks associated with produced water generated by oil production on the Kizomba A platform (Block 15, Zaire Province), operated by ExxonMobil in partnership with Sonangol and other stakeholders.

The study focuses on:

1. Identifying major environmental risks linked to produced water handling and discharge.

2. Reviewing technologies currently used to treat produced water and the basis for selecting them.
3. Assessing monitoring approaches and compliance mechanisms required to support responsible discharge.

Relevance of the study

The proposed work is relevant because it supports:

- Protection of Angolan marine resources, particularly in the Zaire Province offshore area.
- Alignment with sustainable development principles and corporate environmental responsibility.
- Technological and operational improvement in produced water management for offshore operators.

Problem statement, research question, and hypotheses

Problem statement

Angola is a major oil producer with sustained large-scale offshore output. In produced water handling, the volume of produced water generated during processing can be substantial—often exceeding the amount of extracted oil in early separation stages. Even after treatment, discharged water may still contain residual contaminants. These residuals can create environmental impacts when monitoring, operational controls, or treatment performance are insufficient or inconsistent over time.

Guiding research question

How can produced water management on the Kizomba A platform (Block 15, Zaire Province) be improved to reduce the environmental risks associated with produced water discharges?

Hypotheses

- H1: Implementing an improved management strategy reduces the environmental risks associated with produced water discharges on Kizomba A.
- H2: Variability in the timing and interpretation of monitoring/benchmark reference values (i.e., measurement intervals and control criteria) can contribute to undesired discharges and environmental consequences.

Specific objectives

To address the research question and test the hypotheses, the dissertation will:

1. Conduct a critical analysis, grounded in theoretical and epistemological foundations, of environmental risk factors related to produced water management in Block 15 and on the Kizomba A platform.
2. Identify and classify the environmental risks associated with produced-water discharges from oil production on Kizomba A.
3. Develop a management strategy—including practical control and monitoring recommendations—to reduce identified risks on Kizomba A, Block 15.

The oil industry is crucial for Angola's budget but also generates relevant environmental impacts on local and global biodiversity.
Support that direct impacts of extraction are not limited to the project period, since oil, as it degrades, continues to pollute ecosystems for long periods.

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The research aims to contribute to reducing environmental risks associated with water discharged into the sea after extraction, providing a basis for changes in corporate action and public policy, as well as raising awareness among authorities about the socio-environmental impacts of offshore production.

Scope of the research

- Territorial delimitation: Kizomba A Platform, Block 15, coast of Zaire Province, Angola.
- Temporal delimitation: study focused on 2019–2021.
- Content limitation: focus on produced-water discharges from oil production, including risk assessment, treatment technologies, disposal, and monitoring.

Technical context and practical implications

- Angolan production involves a mix of companies, with the operator Exploration Angola Block 15 Limited holding about 40%, BP Exploration 26.67%, Agip Angola Exploration 20%, and Statoil 13.33%, with Sonangol acting as concessionaire.
- The first discovery in Block 15 occurred in 1998, with exploration authorized since 1994. The economic importance of the oil industry for Angola is high, requiring cutting-edge technology for research, production, treatment, transport, and storage.
- Produced-water treatment is mandatory in the production chain to separate water from oil and reduce environmental impacts. Even with treatment, discharged water can cause significant damage to marine ecosystems.
- Environmental regulation in the country involves decrees and laws that, according to the text, present gaps and needs for improvement in the management of spills and disposal of industrial wastewater, pointing to the need for stricter compliance and more robust management strategies.

Expected contribution

By proposing a management strategy for environmental risks of produced waters, the dissertation aims to provide a framework that can be applied not only to Kizomba A but also potentially adaptable to other offshore platforms in Angola. The research seeks to promote a culture of prevention, ecological efficiency, and technological innovation in the offshore oil industry, with direct impacts on environmental protection, corporate responsibility, and sustainable development of the sector.

Notes on the study's relevance

The study recognizes that although petroleum degradation reduces its toxicity over time, oil remains a source of pollution with long-term effects on marine organisms.
By structuring a management strategy, the dissertation aims to strengthen the capacity to reduce coastal risks and improve produced-water management, contributing to safer, more efficient, and environmentally responsible offshore exploration in Angola.

Development

The revised literature defines the central terms for this study: risk, produced water (oil production effluent) and the treatment technologies used for the final disposition of these waters. The central theme is the management of environmental risks associated with produced waters in the offshore oil industry, with a focus on Platform Kizomba A, Block 15, in Angola, where exploration involves large volumes of produced water that must be treated before disposal.

Definition of risk

Risk is understood as the combination of the probability of an undesirable event and its negative consequences, resulting from the interaction between hazards and vulnerabilities (UNISDR, 2004; Wisner, 2011).

Socioeconomic inequalities amplify the impacts of risks, especially in contexts of climate change and unplanned human interventions (Beck, 2010).

Risks have no fixed borders; pollution, technological and climatic risks affect different communities, requiring contextual historical and geographical assessment.

Concepts of produced water and flotation

Produced water: effluent that accompanies oil during extraction, containing hydrocarbons, heavy metals and other contaminants. Even after treatment, its discharge can impact marine ecosystems.

Flotation (liquid–liquid separation theory): process where particles adsorbed on gas bubbles rise to the surface for removal. Key factors include particle hydrophobicity, bubble diameter (typical 10–200 μm) and turbulence level. The proper bubble–particle ratio maximizes removal efficiency (Beck, 2010; Ebrahimi, 2008).

Types of risk and environmental effects

Physical risks (green color): cold/heat, pressure, humidity, noises, radiations, vibrations; exposure limits defined by regulatory standards.

Chemical risks (red color): dusts, fumes, gases, vapors, mists; exposure via respiratory route, skin or ingestion.

Biological risks (group 3): bacteria, viruses, fungi, protozoa; protection varies with pathogenicity.

Environmental effects of discharges: acute toxicity tends to dilute rapidly in open waters, but chronic effects persist, especially when there is low dilution, reduced turbulence or a more stable coastal area. Contaminants of concern include polycyclic aromatic hydrocarbons, alkylphenols and some metals; nitrates and phosphates can favor microbial and phytoplankton growth, altering receiving ecosystems. Some treatment compounds can be toxic if discharged at high concentrations (Pinto; Reuters; Shaw; Neff).

Monitoring and gaps

The literature points to the need to monitor chronic effects in aquatic ecosystems to assess long-term impacts, going beyond acute toxicity observed in rapid tests.

In Angola, there are few in-depth studies on marine toxicity based on local data; environmental management shows gaps, relying largely on experiences of large global companies.

The ocean disposal option is the main one, but there is an alternative of subsurface injection, whose viability varies according to technical and regulatory conditions.

Regulatory implications and justification

Angola presents a regulatory framework with relevant decrees and laws, but with gaps for monitoring and comprehensive management of spills and produced waters.

The need for integrated risk management strategies is highlighted to align offshore exploration with sustainable development principles, corporate responsibility and environmental protection.

Theoretical application to the Kizomba A case

The review grounds the hypothesis that well-designed risk management strategies can reduce the impacts of produced waters on Platform Kizomba A, Block 15, taking into account: the connectivity between physical, chemical and biological risks; the cadence of environmental monitoring; advances in treatment and disposal technologies; and compliance with Angolan regulatory frameworks.

The study emphasizes the importance of a multidisciplinary approach that combines science, technology, public policy and corporate responsibility for the sustainability of offshore production.

Practical notes for implementation and implications

Development of a risk management framework that includes: hazard classification, vulnerability assessment, safe disposal flows, and continuous environmental monitoring.
Integration of produced water treatment technologies with disposal mechanisms that minimize impacts on fauna, flora and surface and marine water resources.
Strengthening local capacity through training, transparent regulatory data and stakeholder participation to improve environmental governance.

Notes on the presentation format in the text

Thus, it is important to recognize the long-term consequences of offshore oil and gas installations, which can have a life cycle of 15 to 20 years. Additionally, cumulative effects related to the future expansion of production operations should be considered. It is clear that additional information is needed to improve the accuracy of existing risk assessment models for produced water discharges.

Multidisciplinary scientific studies are needed within an ecosystem-based management approach to provide information on environmental destinations (dispersion, precipitation, biological and abiotic transformation) and effects of chronic, low-level exposures to different chemicals in produced water and the plume of produced water. Numerical models need to be improved to better predict the fate and effects of chemical components in produced-water plumes that disperse rapidly. It is necessary to develop improved sampling recovery techniques and analytical techniques to support model validation requirements.

Currently, many of the potentially concerning contaminants in produced water cannot be detected in open ocean environments with standard analytical protocols. The future development of high-efficiency, cost-effective produced water treatment technologies depends on identifying and monitoring the main environmenta l concern target components (for example, PAHs, phenols, nitrates, trace metals) in produced water and the produced-water plume.

Interpreting ecological risk from biological effect studies based on biomarker techniques remains challenging. According to Pilar (2006), biomarkers can be used to indicate that: a) an organism was exposed to a particular chemical or group of chemicals; b) a organism is affected by a contaminant and is responding to it; and c) the organism was harmed.

For a comprehensive protection plan, it is necessary to support the development of enhanced monitoring protocols to provide early warning of potential problems related to sediment and water quality (such as primary productivity), fish quality, and fish health. Given that the development of real-time monitoring systems (specific contaminant sensors and data transfer technologies) will increase our capacity to manage the ocean and its living resources. Taking into account the natural disturbances currently affecting the ocean (climate change, for example) and the potentially associated impacts from other ocean users (maritime transport, fisheries), an ecosystem-based integrated management must adopt an approach to fully assess the risks of produced water discharge offshore.

Produced Water Chemicals. Produced Water During oil and gas production is commonly produced together with water, called produced water, production water, or processing water. This fluid is basically composed of the water that forms the reservoir itself and seawater injected into the field, both to maintain reservoir pressure and to increase secondary oil recovery.

In fields where seawater injection exists, chemicals are also injected, such as anticorrosives, biocides, anti-foaming agents, anti-pulsatives, oxygen scavengers, ethanol, triethylene glycol, demulsifiers, among others. Some of these products are associated with the oil and, consequently, are not discarded; however, other chemicals are associated with the water and may be discharged into the sea together with produced water. (Véu, 2004, p. 18).

According to Neff (2002, p. 108), "produced water (PW) is the main effluent of oil and gas production facilities, and gas platforms tend to produce smaller quantities but with higher concentrations of organic contaminants, and oil platforms tend to produce large volumes of this effluent, and the PW volume tends to increase over time." In mature fields, the volume of produced water can be ten times greater than the volume of oil produced.

For Collins (2005, p. 110), "produced water is often generated during oil and gas production from onshore and offshore wells." Formation water is seawater or freshwater trapped for millions of years with oil and natural gas in a geological reservoir composed of a porous sedimentary rock formation between impermeable rock layers within the Earth's crust.

When a hydrocarbon reservoir is penetrated by a well, the produced fluids may contain this formation water, in addition to oil, natural gas and/or gas condensates. Freshwater, brines, and production chemicals are sometimes injected into a reservoir to increase recovery rates and operational safety; these surface waters and chemicals sometimes penetrate the production zone and are recovered with oil and gas during production. (Véu, 2004, 18).

In this context, there is considerable concern about the disposal of offshore produced water from oil production operations, since discharges are continuous during production, discharge volumes are increasing in the more mature offshore production areas, and the concentrations of many potentially toxic organic compounds and metals are higher in treated produced water than in receiving waters, raising concerns about chronic ecological damage.

Produced water contains the same salts as seawater, with sodium and chloride being the most abundant ions.

Technical context. Produced water is a by-product of oil and gas production, containing salts, hydrocarbons, heavy metals, and various production additives. In offshore waters, concentrations of inorganic ions and hydrocarbons vary with the geological age of the reservoir, geography, and injection process (formation water, injected seawater, additives). Assessing environmental risks associated with produced water requires an integrated understanding of water chemistry, toxicology, and ocean dynamics.

Inorganic constituents of produced water. The most abundant inorganic ions, in order of abundance in high-salinity produced water, are: sodium (Na^+), chloride (Cl^-), calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+), sulfate (SO_4^{2-}), bromide (Br^-), bicarbonate (HCO_3^-), and iodide (I^-). Compared with seawater, the relative concentrations differ, which can influence the aquatic toxicity associated with produced water.

Table 1. Concentrations (mg/kg or parts per million) of various elements and inorganic ions in produced waters of different geological ages, compared with average concentrations in seawater.

Produced water			
Element/ion	Seawater (ou Sea water)	Highest concentration (geological age)	Range of average concentrations
Salinity	35,000	----------------------	<5,000—>300,000,000
Sodium	10.700	120.000 J	23,000—57,300
Chloride	19,353	270.000 (P)	46,100—141,000
Calcium	416	205.000 (P)	2,530—25,800
Magnesium	1,294	26.000 (D)	530—4,300
Potassium	387	11.600 (D)	130—3,100
Sulfate	2,712	8.400 (T)	210—1,170
Bromide	87	6.000 (J)	46—1,200
Strontium	0.008	4.500 (P)	7—1,000
Ammonium	—	3.300 (P)	23—300
Bicarbonate	142	3.600 (T)	77—560
Iodide	167	1.410 (P)	3—210
Boron	4.45	450 (T)	8—40
Carbonate	—	450 (M)	30—450
Lithium	0.17	400 (J)	3—50

Source: Pilar (2006).

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Typical seawater salinity is ~35 g/kg.
Sodium in seawater: ≈ 120,000 mg/L; in produced water it varies with geology, potentially exceeding 300,000 mg/L in very saline cases.

Chloride in seawater: ≈ 270,000 mg/L; in produced water it can reach higher ranges (e.g., 46,100–141,000 mg/L in certain samples).

Calcium, magnesium and potassium show relevant variations between produced water and seawater, reflecting influences from formation water and dissolved salts.

Sulfate and bromide tend to occur in meaningful quantities; bicarbonate and iodide appear at concentrations that also differ between produced water and seawater.

These concentration patterns affect not only water chemistry but also scale formation, corrosion, and potential toxicity to aquatic organisms.

Chemical transformations and scale formation

• Interaction between seawater injected to maintain pressure/uptake and formation water can lead to precipitation of salts such as barium and calcium, forming scale in pipelines. The presence of sulfates can favor the formation of species such as sulfides under certain conditions, which raises discussions about toxicity and bioaccumulation.
• Natural radionuclides can co-precipitate with barium scale, raising concerns about local radiotoxicity in some systems.

Aromatic hydrocarbons and BTEX

• BTEX (benzene, toluene, ethylbenzene, xylene) are priority volatile hydrocarbons, with potentially high concentrations in produced water (up to 600 mg/L in untreated waters). Due to volatility, BTEX tends to decrease rapidly during degassing treatment and in the initial plume mixing with the ocean.
• Polycyclic aromatic hydrocarbons (PAH) are of great environmental concern due to toxicity and persistence. In produced water, total PAH typically range from 0.04 to 3 mg/L, with 2–3 ring congeners predominating in the dissolved fraction; PAH with 4–6 rings are less detectable in treated water.

Phenols and other organic contaminants

• Total phenols are usually below 20 mg/L in produced water; concentrations off the Gulf of Mexico coast and in the North Sea vary from 2.1–4.5 mg/L and 0.36–16.8 mg/L, respectively. Longer-chain alkylphenols (7–9 carbon atoms) are particularly toxic, with significant endocrine-disrupting disturbances. Alkylation-heavy phenols tend to decrease as the number of carbons in the chain increases.

• In addition to BTEX and PAH, other fractions include oil formed by a mixture of aromatic compounds (BTEX, naftalenes, phenos), dispersed oil in droplets, and oil soluble in less insoluble fractions. The presence of oil in produced water favors dispersed phases that complicate separation by conventional processes.

Management and monitoring solutions

• Ecological risk assessment based on biomarkers remains challenging but can indicate exposures to different contaminants, responding with biological signals. Improved monitoring protocols, with real-time contaminant sensors and data transfer, can enable early alerts on sediment quality, water, and biota health.
• Monitoring should distinguish between acute and chronic exposure, especially in areas with high dilution/turbulence versus coastal zones with lower plume mixing. In regulatory terms, it is essential to align models, sensitive analytical techniques, and target components (PAH, phenols, metals, BTEX).
• Analytical techniques need to evolve to detect contaminants not captured by standard protocols, especially in

open-ocean environments. Integrated ecosystem-based management is recommended to assess risks considering natural disturbances (climate change) and multi-user activities at sea (shipping, fishing).

Practical implications for offshore platforms

• Produced water quality control requires attention to geological and regional variation of inorganic ions, as well as the complexity of organic mixtures that include BTEX, PAH, phenols, and heavy metals.
• Prevention of scale formation and mitigation of toxicity depend on efficient treatment strategies that account for dilution, dispersion, and biological/abiotic transformation of these components.
• Communication between engineering, environmental chemistry, regulators, and local communities is crucial for implementing consistent disposal, reinjection, or advanced treatment standards.

IN SUMMARY

• Inorganic ions in produced water vary widely with geologic age and provenance, with sodium, chloride, calcium, and magnesium dominating. Produced water may show concentrations different from seawater, influencing corrosion, scaling, and environmental toxicity.
• Organic compounds, especially BTEX, PAH, and phenols, stand out for toxicity and persistence. BTEX tends to decrease with treatment, while PAH and phenols require careful monitoring due to bioactivity.
• Effective management requires sensitive monitoring, robust sampling protocols, advanced analytical techniques, and an ecosystem approach to assess chronic risks, integrating treatment technology, regulatory oversight, and stakeholder participation.

Synthetic summary

This excerpt discusses the chemical compositions of produced water, focusing on inorganic ions, production solids, dissolved gases, and treatment techniques. Understanding these components guides environmental and operational management strategies on offshore platforms.

Inorganic ions and environmental relevance

• Ions present in produced water vary with geological age and waterflood regime, influencing corrosion, scaling, and toxicity. Sodium, chloride, calcium, magnesium, potassium, sulfate, bromide, bicarbonate, and iodide are the most abundant; concentrations differ between seawater and produced water, which can increase or reduce environmental risks.
• Geological conditions affect concentration patterns, with implications for barite and calcium scale formation when formation water mixes with injected seawater.

Production solids

• The extraction of loosely consolidated formations generates solids that act as abrasives in well components and on surfaces; their fouling and subsequent wear raise operating costs and can cause production failures or well collapse.

Dissolved gases

• Main gases in produced water: natural gas (methane, ethane, propane, butane), CO_2 and H_2S. H_2S, either natural or from sulfate-reducing bacteria, can cause iron sulfide encrustation and is toxic if inhaled. O_2 is not intrinsic; when it rises, it can render the water corrosive and promote precipitates (e.g., $CaCO_3$ with CO_2). Removal of CO_2 and H_2S increases pH, promoting precipitation.

Produced water treatment

• Global environmental regulations impose limits on total oil in produced water discharged. The goal is to produce stabilized produced water for transmission, ocean discharge, or reinjection.
• Treatment aims to remove dispersed oil, solids, volatile hydrocarbons, and corrosive gases (CO_2, H_2S). Efficiency varies; removal of dispersed oil droplets significantly improves reduction of volatile and dissolved hydrocarbons.
• In reinjection cases, salt and metal removal is dissolved according to the final destination. Oil–water phase separation can be achieved with equipment such as weirs, skimmers, coalescers, hydrocyclones, and filters; advanced techniques (high-speed centrifugation, membranes) can improve removal of fine particles (0.01–2 µm).
• Relationship between produced water quality and regulatory effectiveness: the global average concentration of total hydrocarbons in discharged produced water was about 21 mg/L (regional variation 14–39 mg/L), indicating that treatment performance is critical to meet discharge standards.

Separation techniques and organic components

• BTEX (benzene, toluene, ethylbenzene, xylene) are volatile; they decrease during treatment via degassing and initial dispersion in the ocean plume.
• PAH (polycyclic aromatic hydrocarbons) are highly toxic and persistent. Typical variations in produced water range from 0.04 to 3 mg/L, with 2–3-ring structures being more common in the dissolved fraction; PAHs with 4–6 rings are less frequent in treated water.
• Phenols, especially long-chain alkylphenols, can have endocrine effects; their concentrations vary by region and production conditions.

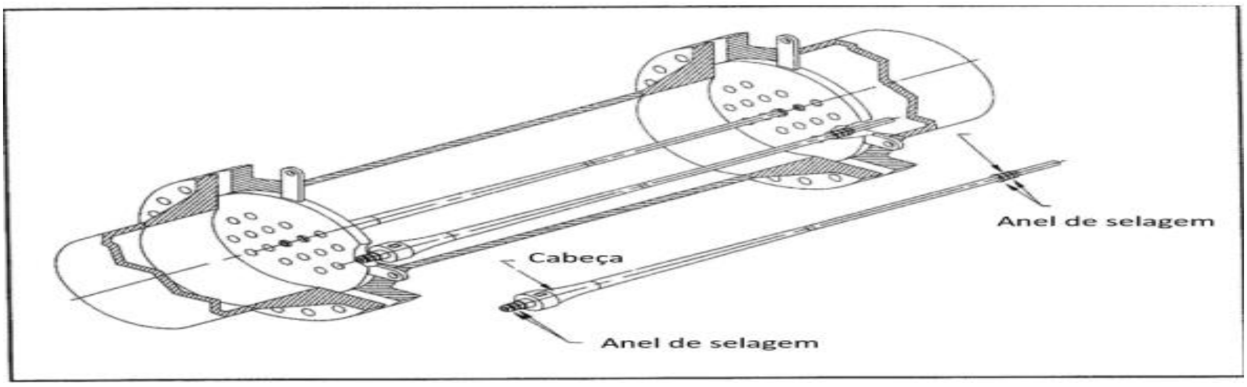
Practical implications

• Effective management requires sensitive monitoring, robust sampling protocols, and advanced analytical techniques to detect contaminants not captured by standard methods.
• Integration of engineering, environmental chemistry, and regulatory governance is essential to reduce environmental impacts while maintaining production.
• The presence of dissolved salts and metals requires specific approaches to desalination, demineralization, and scale control to avoid damage to pipelines and equipment.
• Clear legends with units (mg/L, mg/kg) and notes on geography/processing route should accompany each visual element.

Conventional physical separation

• Gravity separators: suitable for removing free oil fraction with droplets larger than ~150 µm, via horizontal flow in large settling tanks, separating free oil and solids; aqueous phase is then drawn off.

Figure 1: Diagram of the gravity separator.

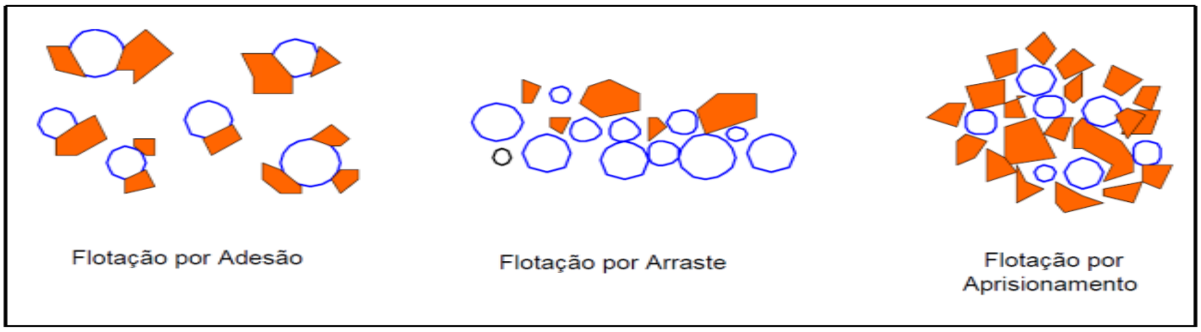


Source: Shaw (1999)

• Flotation: generates gas bubbles in the aqueous phase; bubbles attach to dispersed oil droplets, reducing density and promoting upward rise of oil to form foam; space for Figure 2: schematic of bubble flotation.

• Hydrocyclones: use a helicoidal flow to create a centrifugal field; separation based on density difference between oil and water.

Figure 3: Flow cut inside a hydrocyclone.



Source: Tominaga (2009)

Combined treatment: chemical, biological, and membranes

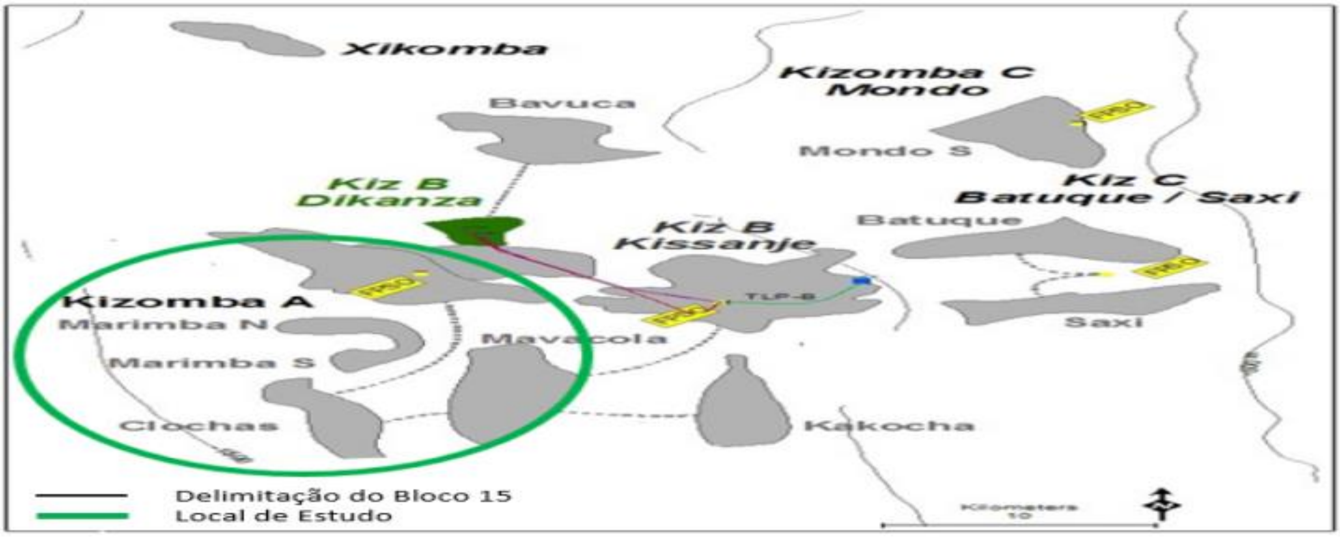
• In addition to mechanical methods, there are chemical and biological approaches, though with high costs, chemical use, and space requirements. In contrast, membranes offer a more advanced alternative but with substantial investment.

• Space for Table 1: comparison of costs, efficiency, and space required among separators, flotation, hydrocyclones, and membranes.

Hydrocyclone Vortoil: description and operation

The Hydrocyclone Vortoil consists of parallel hydrocyclone lines inside a housing, with tangential feed. Separation occurs by centripetal force: water (denser) is pushed to the wall and exits via the water outlet; oil (less dense) remains in the central body and is separated by the rejection flux.

Figure 4: Flow diagram of the hydrocyclone line.



Source: Adapted by the Author

• Flow and pressure cont ol: performance is adjusted via level/interface control and differential pressure between inlet and outlet; the rejection section can be modulated to maintain water quality.

Parameters influencing performance (Hydrocyclone Vortoil)
• Droplet size: larger droplets yield higher efficiency; upstream conditions that reduce constraints improve performance.

Temperature: higher temperature increases separation rate by reducing viscosity.
Density: greater difference between phases increases separation.
Chemical injection: can enlarge droplet size and break emulsions, improving performance.
• Solids: fine solids can stabilize emulsions; the presence of sand can affect throughput.
• Gas: free gas concentrations up to ~10% can be tolerated with good design.
• Space for Figure 6: graph of temperature vs separation efficiency.

System control and operation
• Common controls: level control, interface control, differential pressure control; fine-tuning rejection to achieve the desired flow rate.
•Practical operation: typical values indicate minimum flow rates per liner to maintain efficiency; adjustments across multiple liners allow adaptation to flow changes. Space for Table 2: typical operating ranges per liner.

Flotation process:
• Conditioning: render particles hydrophobic/hydrophilic or pre-concentrate them.
• Temperature: raise to accelerate conditioning reactions and reduce viscosity.
• Aeration: addition of microbubbles to promote particle ascent.
• Macroflocculation: aggregation of microflakes with bubbles to form macroflocs that flow more rapidly.

Flotation treatment of produced water
Flotation is an effective physical method to separate heterogeneous mixtures, removing dispersed oil and suspended solids; the resulting foam can be removed along with solids adherent to the bubbles. Space for Figure 8: flotation vs sedimentation comparison.

Practical application and limitations
The combination of mechanical techniques (separators, flotation, hydrocyclones) with chemical/biological steps offers efficiency but requires cost and space evaluation. Flotation is effective for colloidal particles, while membrane may offer better efficiency for fine solids and dissolved contaminants, though with higher investment.

RESULTS

The case study results are presented using closed-ended questionnaires. Question 1: role in the management of the final results (Table 5).

Table 5 – Role in the management of the final results.

Variables	Absolute Frequency	Relative Frequency
Ensure that the sample I take is as representative as possible so that the final result is accurate.	15	50%
Seek to maintain balance while managing multiple conflicts.	7	23,3%
Make possible the compatibility between human actions and the Environment, ensuring the protection of human and marine resources, always in a sustainable way.	8	26,6%
Total	30	100%

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Source: By Author

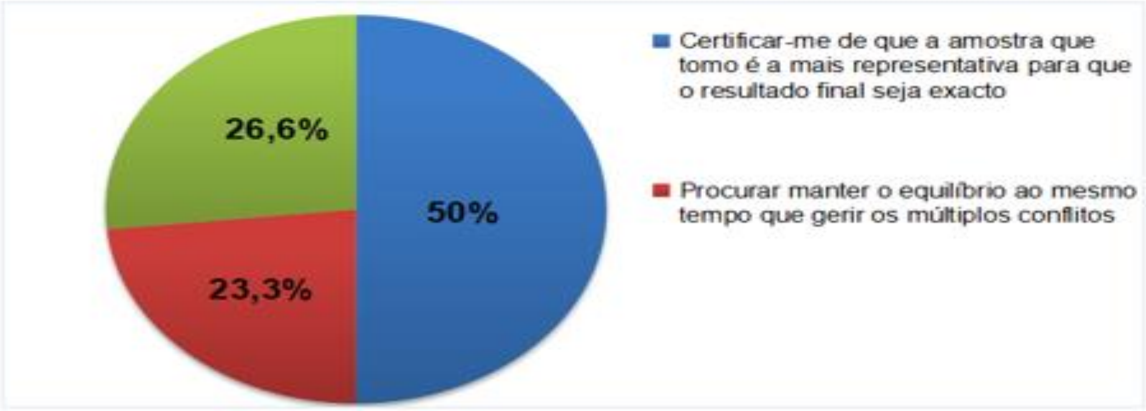
The case study results are presented using closed-ended questionnaires. Question 1: role in the management of the final results (Table 5).

The study reports the importance of ensuring a representative sample for result accuracy, balancing conflict management and human–environment actions, with a focus on sustainability in practice.

Question 1 – Role in the management of final results
Results indicate: 50% of technicians understand the role as Ensuring the sample I take is as representative as possible for the final result; 26.6% consider promoting compatibility between Human and Environment actions, with protection of human and marine resources; 23.3% point to maintaining balance and managing conflicts.

Graphic 5 - Role in the management of final results

Gráfico 5 - Papel na gestão dos resultados finais



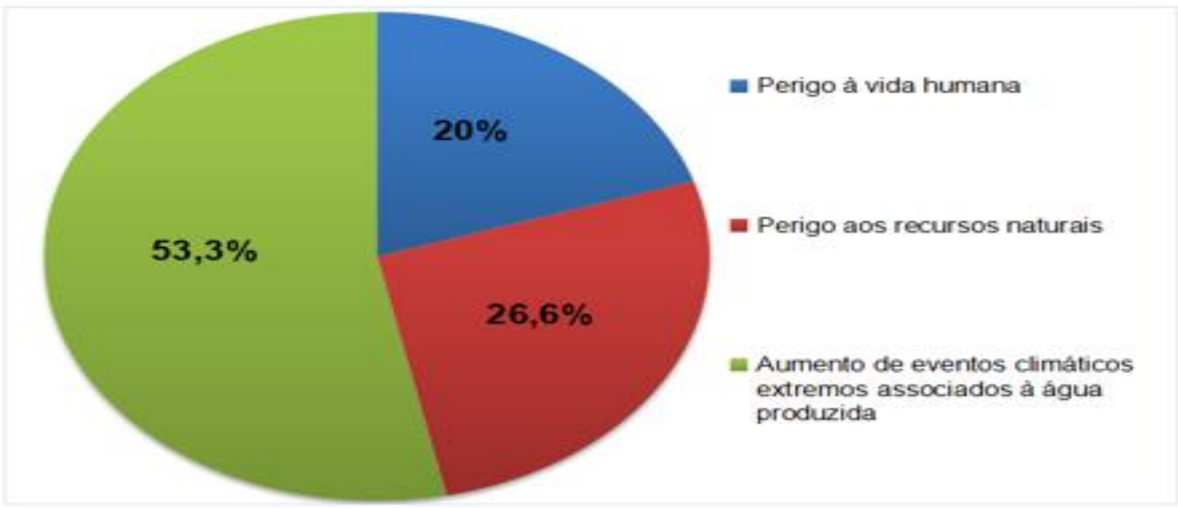
Fonte: Adaptado de acordo com tabela, 2020.

Question 2 – Dangers associated with produced water affecting the ocean
Table 6 shows: 20% perceive danger to human life; 26.6% risk to natural resources; 53.3% increase in

extreme climate events linked to produced water.

Graphic 6- Dangers associated with produced water affecting the ocean.

Gráfico 6 - tipo de perigos associados à água produzida pode afectar o oceano



Fonte: Adaptado de acordo com tabela, 2020.

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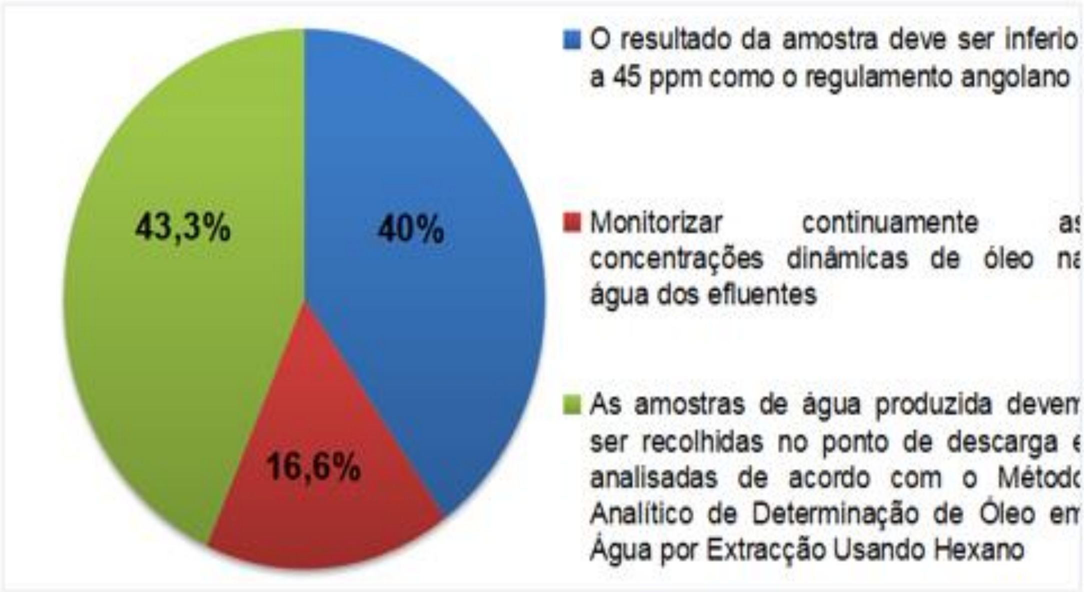
Question 3 – Precautions when preparing for the sea

Table 7 reveals: 40% sample below 45 ppm (Angolan regulation); 43.3% samples collected at the discharge point and analyzed according to the oil-in-water determination method; 16.6% monitor dynamic oil concentrations.

Graphic 7 - Precautions when preparing for the sea

Gráfico 7 - precauções são tomadas em consideração quando se prepara para o mar

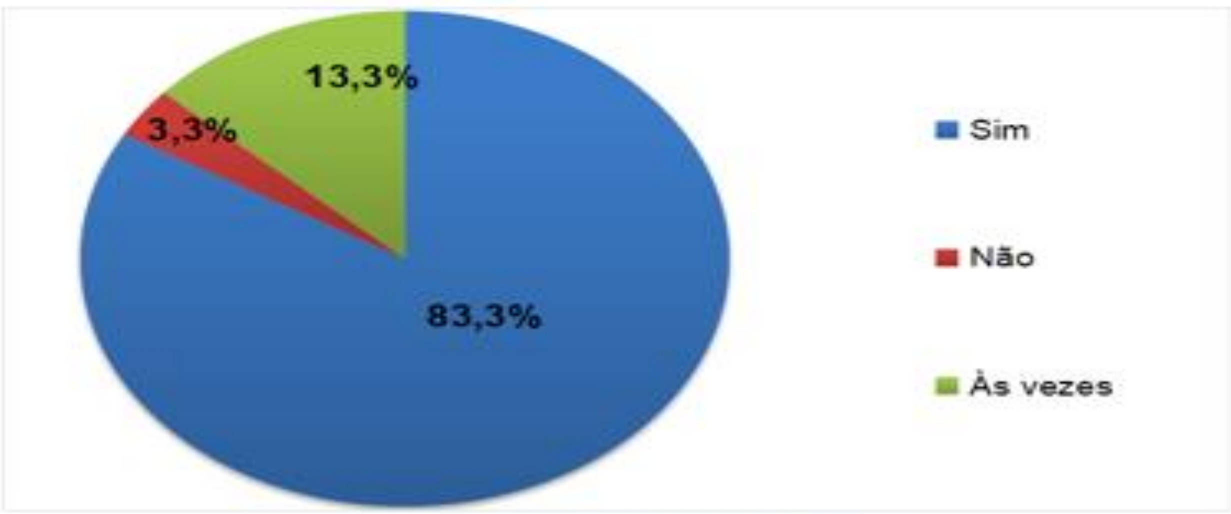


Fonte: Adaptado de acordo com tabela, 2020.

Question 4 Angolan regulatory obligation on volumes to the sea Table 8: 83.3% understand the obligation; 13.3% respond “sometimes”; 3.3% respond “no”.

Graphic 7- Angolan regulatory obligation on volumes to the sea

Gráfico 8 - Entendes a obrigação regulamentar angolana em termos de volumes ao mar (Partes por milhão de óleos na água)?



Fonte: Adaptado de acordo com tabela, 2020.

Note: The 45 ppm oil limit in water is mentioned.

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Question 5 – Water treatment process before discharge to the sea Table 9 shows: 26.6% indicate hydrocyclones separate oil from water; 23.3% point out that water comes from the HP separator to the hydrocyclone; 13.3% mention pumps; 36.6% refer to hydrocyclones as the main stage.

Question 6 – Suggestions to improve water treatment
Table 10: 96.6% suggest continuing the cleaning of hydrocyclones as part of PM and sand jetting in the GFU; 3.3% have no suggestion.

Risk Map
Describes the construction of a risk map to graphically represent existing risks at work locations, using circles of different sizes and colors to inform and raise awareness among workers and reduce accidents.

Table 4 – Probability of occurrences

Table 3: Risk map

Quadro 3 - Mapa de riscos

LEGENDA – MAPA DE RISCO					
Tipos de Agentes	Cor	Riscos (Proporção)			Exemplos
		Elevado (4)	Médio (2)	Pequeno (1)	
Químicos	Vermelho				Poeiras, fumos, gazes, vapores, névoas, neblinas, etc.
Físicos	Verde				Ruido, calor, frio, pressões, umidade, radiações ionizantes e não inoizantes, etc.
Biológicos	Marrom				Fungos, virus, parasitas, bacterias, protozoarios, insetos, etc.

Fonte: Elaborado pelo autor, dados da pesquisa.

Source: Prepared by the author, data from the survey.

DISCUSSION

Observations on sample results

From the total number of samples collected, eleven (11) samples above 40 ppm were observed, representing a daily peak surplus where the daily average percentage would be within the 20–40 ppm range, converging on the 20-30% margin, placing the installation at a moderate risk level.

In the environmental risk management plan for operational discharges, values of environmental risk are those where the discharge reading parameters of produced water exceed reference levels for oil and fats in water (45 ppm). The table below illustrates the daily sample percentages and the ppm results.

Although daily peak numbers were observed in these shifts, the risk of the installation remains reasonable at the medium level (values between 20–40 ppm), but requires prior attention given the wide time interval for sample collection, since higher peaks may occur during this period and could be uncontrollable.

CONCLUSION

The research on Platform Kizomba A, in Block 15, along the coast of Zaire Province, aims to develop a management strategy to reduce the environmental risks generated by produced water spills in the oil and gas industry. The conclusion confirms the hypothesis that an integrated management approach can indeed reduce these risks. Produced water is the main effluent of operations; gas platforms generate smaller volumes, but with more concentrated contaminants, while oil platforms tend to produce larger volumes over time. In mature fields, produced water can reach up to 10 times the volume of oil, increasing over time. Formation water results from seawater or freshwater trapped for millions of years in geological reservoirs. Thus, petroleum activity remains one of the main sources of environmental and biodiversity impacts, with effects that persist even after oil degradation, affecting ecosystems for long periods.

RECOMMENDATIONS

The proposed strategy sits within an environmentally sensitive area and requires an integrated approach, in accordance with the Environment Baseline Law (Law no. 5/98) and Angolan standards. The main legal instruments considered are: Environmental Impact Assessment (EIA), Environmental License, Environmental Audit System, Environmental Performance Report, and Environmental Management Plans (PGA). The legal basis also includes relevant sectoral decrees and laws (EIA, environmental licensing, hazardous waste management, petroleum laws, and DNPAIA).

Components of the Strategy

Environmental Impact Assessment (EIA): continuous updating of the EIA specific to Kizomba A, focusing on produced waters; identification of sensitive zones; definition of disposal or reinjection criteria; establishment of quality standards based on international benchmarks adapted to the Angolan context.

Environmental Management Plan (PGA): implementation of guidelines for treatment, reuse, and safe disposal of waters; standardization of operating procedures (SOPs) for oil–water separation, physicochemical treatment, continuous monitoring, and reinjection into reservoirs.

Environmental Monitoring System: automatic monitoring stations on the platform and at subsea points; regular laboratory analyses; use of remote sensors, drones, and AI for real-time spill or operational fault detection.

Regular Environmental Audits: independent audits in line with the legal framework; Environmental Performance Reports with KPIs such as produced water volume, reinjection rate, hydrocarbon concentrations, and resolved non-conformities.

Licensing and Compliance: periodic renewal of the Environmental License; review of EIA for expansions or infrastructural changes.

Training and Operational Management: continuous training programs for operators and managers; designation of an Offshore Environmental Management Officer with authority for urgent corrective actions.

Environmental Emergency Plan: spill response plans to be developed, regularly tested, and involve authorities, logistics operators, and coastal communities.

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