Evaluating the Impact of Drilling Fluids on Well Integrity and Environmental Compliance: A Comprehensive Study of Offshore and Onshore Drilling Operations

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Abstract

The current work explores the importance of drilling fluids in the provision of well integrity together with compliance with the environment in offshore and onshore rig operations. Through case studies of the Erha, Otuo South and Ogbele fields, this research demonstrates that current management practices such as tank management, use of solid control equipments and compliance with calibration procedures are effective and that safety and environmental management standards are being met. This study utilizes results from AAR and periodic facility integrity check and recommends both as crucial feedback tools for future drilling fluid management. Research evidence shows that good fluid management processes play an important role in well stability and lesser effects on environment however, there are issues encountered with offshore and onshore fields. Ideas for improvement of these practices are made, and it is emphasized that it is crucial to aim at the constant enhancement of the existing operating procedures to facilitate effective and efficient drilling.

Keywords

Drilling fluids, well integrity, environmental compliance, offshore drilling, onshore drilling, Erha field, Otuo South field, Ogbele field, After-Action Reviews, facility integrity inspections

Introduction

1.1 Background

Drilling fluids known also as the life line of the drilling activities are used to ensure Bore hole stability and pressure control besides removal of cuttings from the well. (Khodja et al., 2010)

Over the years, the industry has realised new pressures because of the harsh circumstances of the offshore and the high-risk on-shore drilling activities which calls for much enhanced drilling fluids (Dye et al., 2005; Young and Ramses, 2006). Well integrity, the capacity of well to manage or contain formation pressure, is important for well control. These fluids also act to maintain the integrity of that wall through a physical and chemical barrier around the wellbore and formations within that well (Wojtanowicz, 2016)

Environmental concerns have recently been highlighted more in drilling activities as codes and standards develop further, also explosions in handling drilling fluid discharge and spills (Bakke et al., 2013; Considine et al., 2013). The environmental challenge for offshore operation is quite distinct from that of onshore operation for instance wastage disposal through the sea wells must be controlled to harm the lives of aquatic species while onshore operation may lead to soil and water pollution (Davies et al., 2014). Therefore, the handling of the drilling fluids can simply be valued for the opportunities for efficiency gains but also as a reason not to pollute (Rana, 2008).

1.2 Research Problem

Nevertheless, challenges linked with well integrity and the environment keep on being significant problems even with enhanced knowledge in fluids and drilling management (Kiran et al., 2017; Davies et al., 2014). Offshore and onshore drilling have differences in physical environment, operation, and regulation; hence, it requires specific methodology in drilling fluids management Skogdalen & Vinnem (2012) & Bakke et al. (2013). These factors include the relationships between drilling fluid parameters; the use of solid control equipment; and tanks, and their handling, which is crucial in influencing well stability as well as environmental integrity. This study aims to address a fundamental question in drilling fluid management: which approach or system is most appropriate to support well integrity in the context of enduring various types of field conditions with least harm to the environment (Rana, 2008).

1.3 Objectives of the Study

The following key areas were selected: (1) the interaction between drilling fluids and well integrity with emphasis on practices adopted in various field locations; (2) tank management, usage of solid control equipments, and calibration in relation to environmental concerns; (3) After-Action Reviews (AAR) and periodic integrity facility inspections as improvement tools for effective drilling fluids management.

1.4 Scope and Limitations

The analysis includes three fields as pilot areas: the Erha field, which is an offshore analogue; the Otuo South field, which is an onshore analogue; and the Ogbele field. The procedures of interests in the analysis include those pertained to drilling fluid, such as tank management, handling of solids, and calibration. However, this study has its weaknesses because it focuses on factors that are peculiar to well integrity and environmental compliance that are unique to the field thus may not apply to every kind of drilling.

1.5 Structure of the Paper

Literature review on drilling fluids, and well integrity and environmental regulations is discussed under Section 2 as follows (Kiran et al., 2017; Davies et al., 2014). Section 3 highlights the method employed in the study, in terms of the data collection and analysis. This is followed in Section 4 by typical field cases from the Erha, Otuo South, and Ogbele fields which highlight practical applications and difficulties. The deduction of the research is presented in Secidion 5, which focuses on the management practice and the adherence to the regulation (Skogdalen & Vinnem, 2012; Considine et al., 2013). Last, Section 6 concludes the study with suggestions offered in light of the findings.

2. Literature Review

Another piece of literature involves the evaluation of how drilling fluids play a complex function in well integrity maintenance and environmental compliance. Based on the review of the literatures, the current management practices and a theoretical framework, the paper points out the realistic concerns on wellbore stability, pressure control, filtration management and environmental impacts.

2.1 Drilling Fluids and Well Integrity

Drilling fluid also referred to as muds are crucial in drilling activities to carry out a series of important processes vital in well bore integrity. Sustaining well bores, controlling the well pressure, and filtration control are the considerations through which drilling fluids enhance safety, efficiency, and environmental concern of the drilling process.

Wellbore Stability

Drilling fluids have essential responsibilities especially in terms of sustaining wellbore pressure and avoiding wellbore breakage (Kiran et al., 2017; Jackson, 2014). In formations containing gypsum and anhydrite, wellbore stress can be minimized by measuring the density of drilling fluid equivalent to the formation pressure. Also, other materials like barium bentonite thickeners raise density and viscosity of the fluid ensuring resistance against high formation pressures (Khodja et al., 2010). Still, the decision of the correct drilling fluid density might be rather difficult because of the different geological conditions, formation pressure, and well depth (Ma, Chen, & Zhao, 2016).

Fig 1: Cross-Sectional Diagram of Wellbore Stabilized by Drilling Fluids

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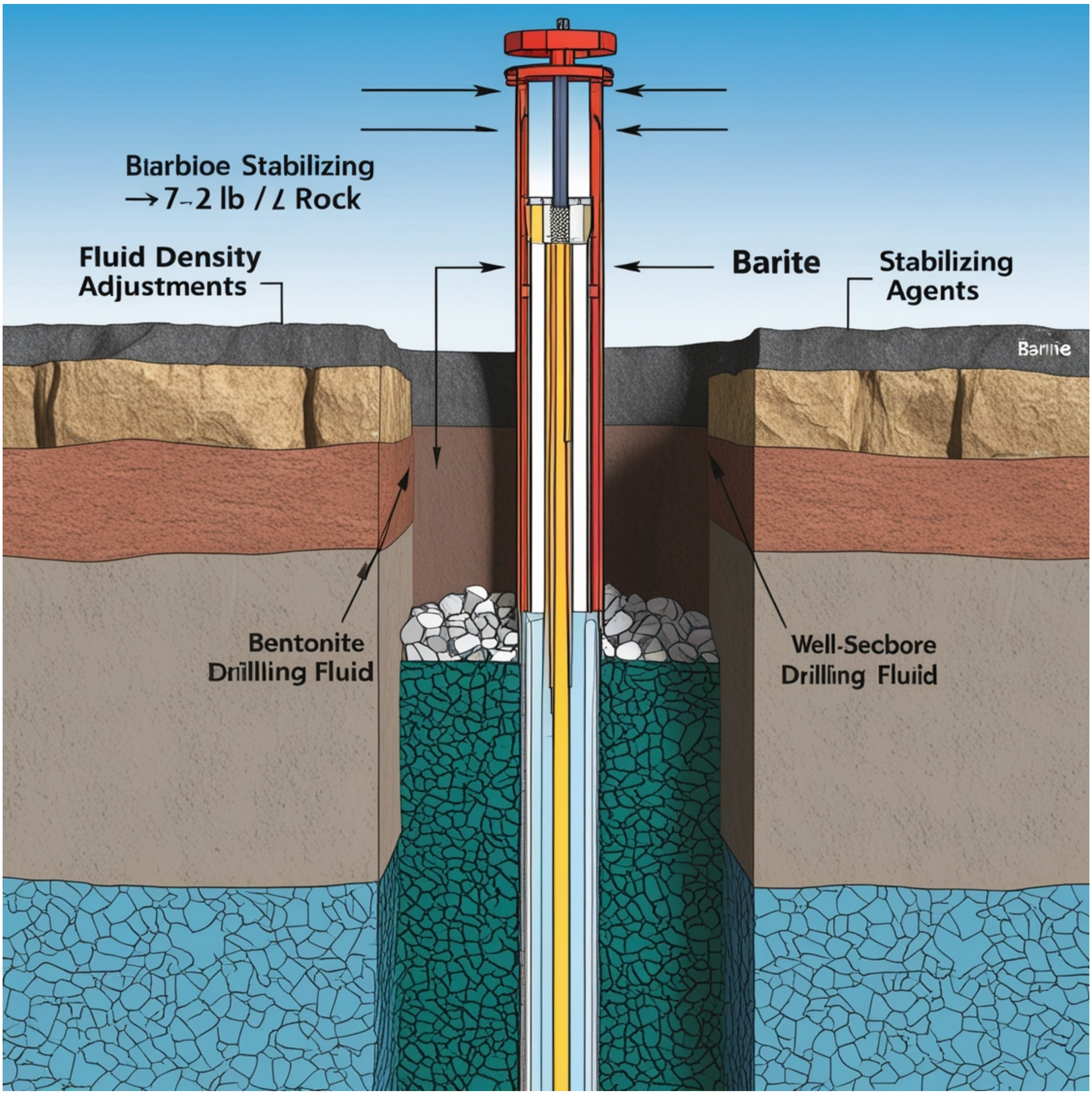


Pressure Control

Another important function of drilling fluids is pressure control whereby drilling fluids are used to control pressure while drilling apart from controlling blowouts. Drilling fluids are designed so as to maintain necessary pressure being the equivalent of formation pressure (Skogdalen & Vinnem, 2012; Kiran et al., 2017). In high pressure wells, oil-based muds or synthetic based muds are preferred with regard to flexibility to match specific pressure conditions (Jackson, 2014). Based on these facts, the pressure control properties as typified by figure 1 in this paper shows how the kind and density of drilling fluids affect the kind of pressure control.

Drilling Fluid Type	Density (lb/gal)	Optimal Application	Pressure Control Effectiveness
Water-Based Mud	8.3 - 12.0	Shallow wells, standard formations	Moderate
Oil-Based Mud	7.5 - 16.0	High-pressure, deep wells	High
Synthetic-Based Mud	9.0 - 18.0	Environmentally sensitive zones	High

Table 1: Comparison of drilling fluid types and their respective pressure control properties.

Filtration Management

Filtration control is significant in order to avoid invasion of drilling fluids into the formation that in turn leads to a degradation of the reservoir and well status (Kiran, 2017, pp. 393–398). These polymers are generally in the filtration management to minimize the fluid losses and other additives to form a low permeability filter cake along the borehole wall thus minimizing the invasion of the fluid. However, in deepwater formations, which exhibit large pressure and permeability contrasts, controlling filtration delivers a major challenge and is an important factor in avoiding formation damage (Ma, Chen, & Zhao, 2016).

2.2 Environmental Risks and Regulatory Frameworks

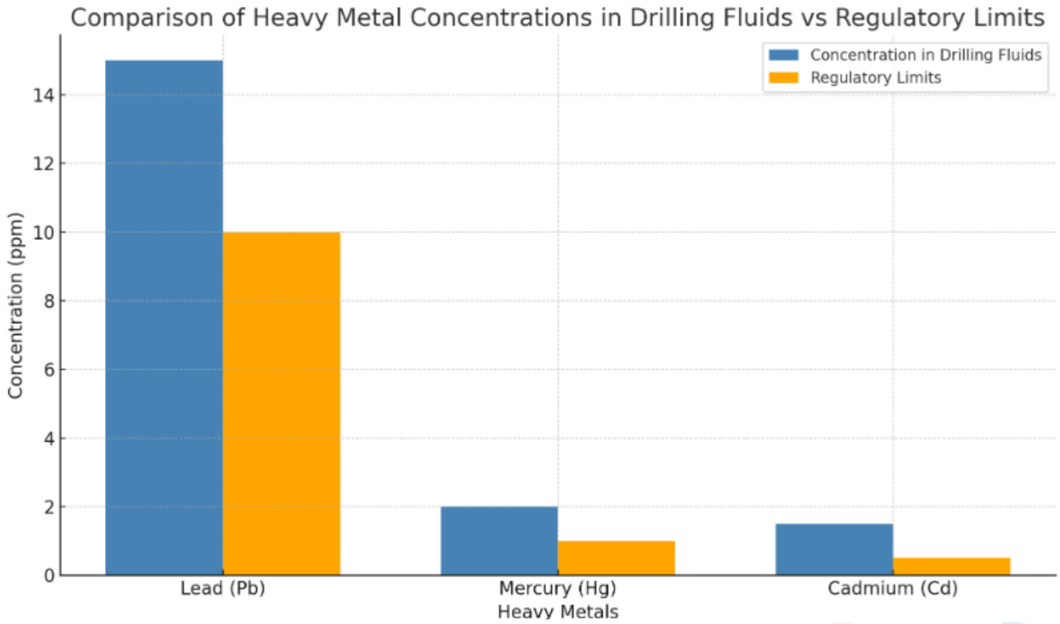
The activities such as handling, usage, and disposal of drilling fluids give a very high likelihood to the environment. These risks are addressed by regulation in a bid to recommend specific chemical concentrations to be used during drilling especially offshore, together with the recognition and control of discharge practices, and the management of the resultant wastes.

Environmental Compliance Requirements

International environmental legislations require every drilling operations exercise certain discharge rates that will not contaminate the water resources and the ground water (Skogdalen, Utne, & Vinnem, 2011; Ekins, Vanner, & Firebrace, 2006). The EPA also currently defines allowed levels of certain components in drilling fluids including hydrogenous substances, heavy metals, and synthetic compounds (Davies et al., 2014; Kiran et al., 2017). These standards are established routinely based on an analysis of the composition of discharges in order to determine that they fall within the recommended parameters. For instance, oil-based muds and synthetic fluids attract a separate and severe policy insofar as disposal is concerned for being more hazardous to the environment (Wojtanowicz 2016, Khodja et al., 2010).

Environmental Risks of Drilling Fluids

Drilling fluids are capable of inflicting various environmental impacts if their discharges are not well controlled. New problems may arise and relate to chemical and additive contamination, devastation of near-shore and marine life, and concentration of toxicity metals (Khodja et al., 2010: Wojtanowicz, 2016). Harmful substances released to the sea through the discharge water acts as a menace to marine wildlife and when the soil is contaminated by shore-based activities, the water resources in the region are affected (Bakke, Klungsøyr, & Sanni, 2013). Firstly, drilling fluids contain heavy metals as well as hydrocarbons; substances that have negative impacts on water and the ecological systems and also have negative implications on the health of human beings as pointed out by Davies et al. 2014 and Ekins, Vanner and Firebrace, 2006. Furthermore, Figure 2 below establishes differences in the level of various heavy metals in typical drilling fluids compared to environmental standard.



2.3 Current Practices in Drilling Fluid Management

This is particularly true from the point of view of optimum control of drilling fluids by strictly following the best practices in the management of tanks and calibration of solid control systems. They keep density of drilling fluids constant in order to maintain their expected properties in the drilling operation, and to protect well integrity and the environment.

Tank Management Protocols

Fluid management in drilling processes is very vital thus the efficiency of managing tanks is essential. Some of the practical applications that include, but are not limited to the following: capacitive real-time fluid levels, temperature, and the chemical contents of the tank (Khodja et al., 2010). By regularly examining the tanks it is possible to eliminate the issue of fluid contamination and achieve homogeneity of the fluids characteristics (Skogdalen et al., 2011). One major technological advancement is that the parameters such as fluid density can be controlled through other automatic controlling systems thus making operations faster and safer (Dye et al., 2005).

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Table 2: Summary of tank management practices and their effect on drilling fluid quality.

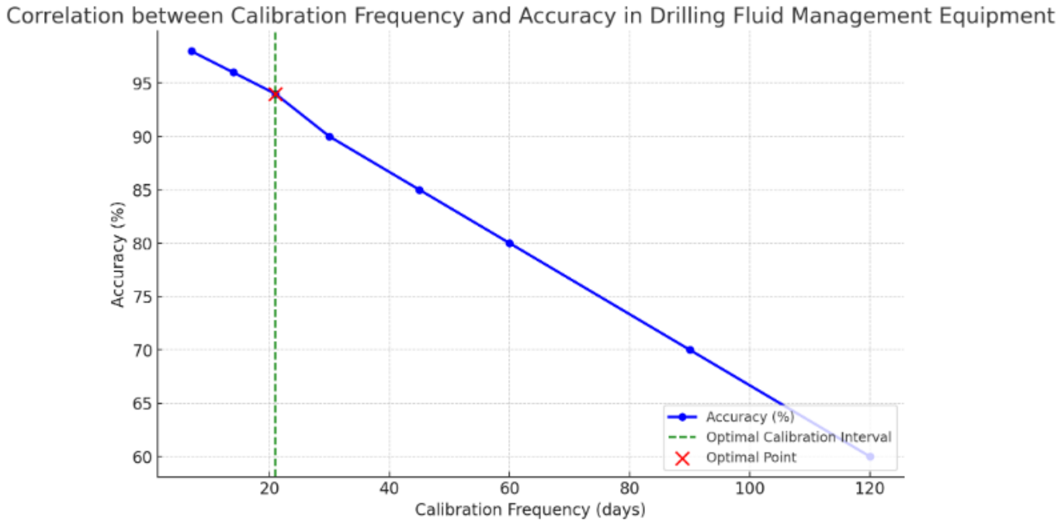
Management Practice	Description	Impact on Drilling Fluids
Routine Inspections	Regular checks of fluid level, quality	Prevents contamination and degradation
Automated Monitoring	Continuous tracking of fluid properties	Enables real-time adjustments
Temperature Control	Temperature regulation within tanks	Stabilizes fluid composition

Solid Control Systems

Solids control system including shale shaker, centrifuge and descender plays significant role in drilling mud, to filtrate out unwanted particulate matter. These systems have to be preserved and developed since they help to sustain the quality of the fluids which is critical for well integrity and avoiding adulteration (Khodja et al., 2010; Skogdalen et al., 2011). This paper also reveals that solid control inevitably affects the performance of drilling fluids and regulatory guidelines regarding the discharges of solids which, if not handled properly, may harm the environment (Bakke et al., 2013; Ekins et al., 2006).

Calibration and Maintenance Practices

Measuring devices including various pumps required for effective management of the drilling fluids need to be standardized for efficient and precise control of specialized characteristic such as viscosity and density of the drilling fluids (Hals, 2015; Jackson, 2014). Consequently, failure in adequate calibration as explained above offers inaccurate information significant in evaluating the status of wells and the surrounding area. The actual manufacturer referred on page 33, in figure 3, offers a calibration schedule for several drilling fluid management tools; according to this, higher calibration frequency equals to higher accuracy of the equipment (Dye et al., 2005; Singh, 2019).



2.4 Theoretical Framework

The theoretical foundation for this study is based on well integrity, the impact on the environment, and the functioning of drilling fluids. Of particular interest is the ability to regulate the behaviour of fluids to minimize inherent risks that threaten well integrity and the environment and these are regulated in accordance with set and acceptable standards (best control practice and regulations) (Khodja et al., 2010; Skogdalen, Utne, & Vinnem, 2011). In this respect after action review or AAR, and facility inspections are illustrated as constantly evolving process for improving what could be arguably considered as critical success factors in fluid management practices Jackson 2014, Ekins et al 2006.

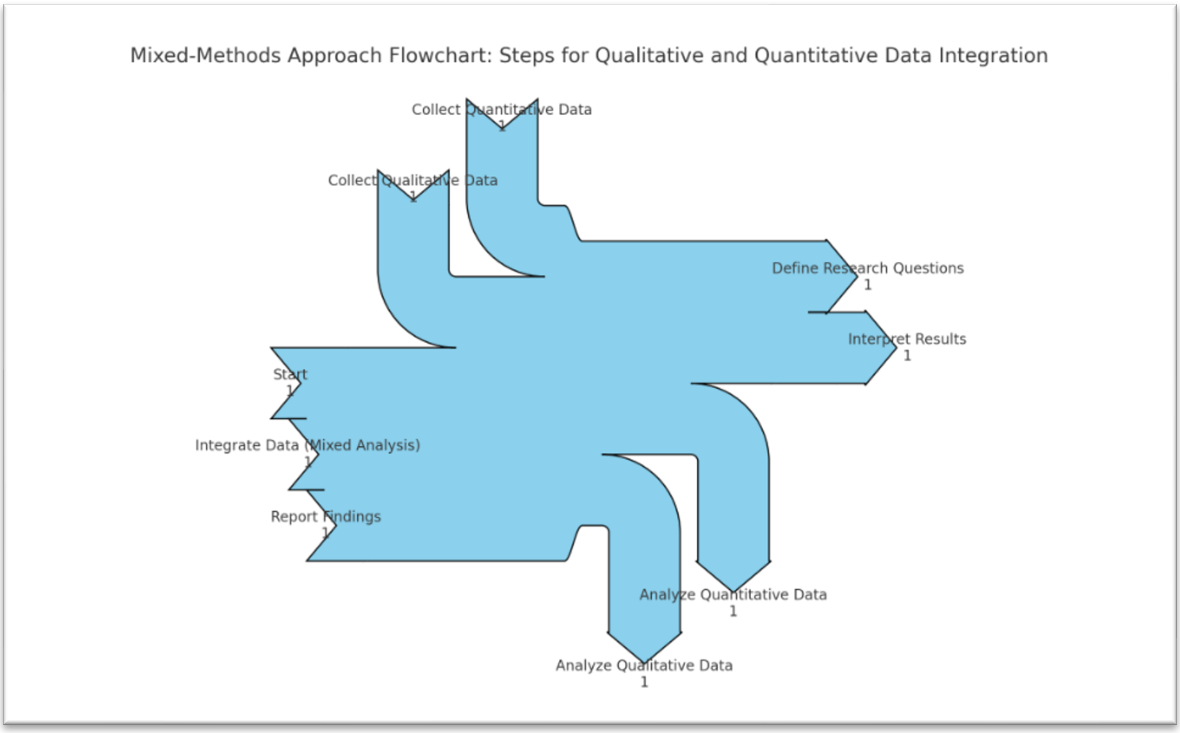
3. Methodology

3.1 Research Design

The research method used in this paper is both qualitative and quantitative as a way of providing a more rich and robust investigation of the impact of drilling fluids on well integrity and environmental acceptability. This dual approach supports a field by field comparison of current practices in offshore and onshore drilling context with a comprehensive understanding of the tasks flow and compliance (Kiran et al., 2017; Skogdalen et al., 2011).

Quantitative Approach:

The quantitative aspect includes the use of actual data collected from papers as well as records in leadership regarding well integrity and equipment efficiency and well as environmental aspects. This information is extracted from facility inspection reports, instrument calibration records, and environmental check results; real-time numbers are usually obtained (Hals, 2015; Nardone, 2009). Quantative data is collected by using questionnaires filled by the staff of the concerned facility. It provides the basis upon which more specific well integrity and environmental compliance may be proven in the case study fields as indicated by Khodja et al., (2010) and Davies et al., (2014).



3.2 Data Collection

The data collection process draws on both primary and secondary sources across three fields: Erha, Otuo South, and Ogbele. The subsequent sub-sections explain these sources and their roles in the research endeavor.

3.2.1 Field Records and Operational Logs

Day to day records provide an overall impression of events and activities that take place during the drudgery of drilling fluid management. Some of the important data is the routine management of tanks, records in calibration, and maintenance schedules of solid control equipment.

Table 3.1: Summary of Field Records Collected for Analysis

Field	Data Source	Content Type	Frequency
Erha (Offshore)	Tank Management Records	Fluid levels, maintenance cycles	Daily
Otuo South	Solid Control Equipment Logs	Equipment efficiency, downtime	Weekly
Ogbele	Calibration Reports	Calibration frequency, accuracy	Monthly

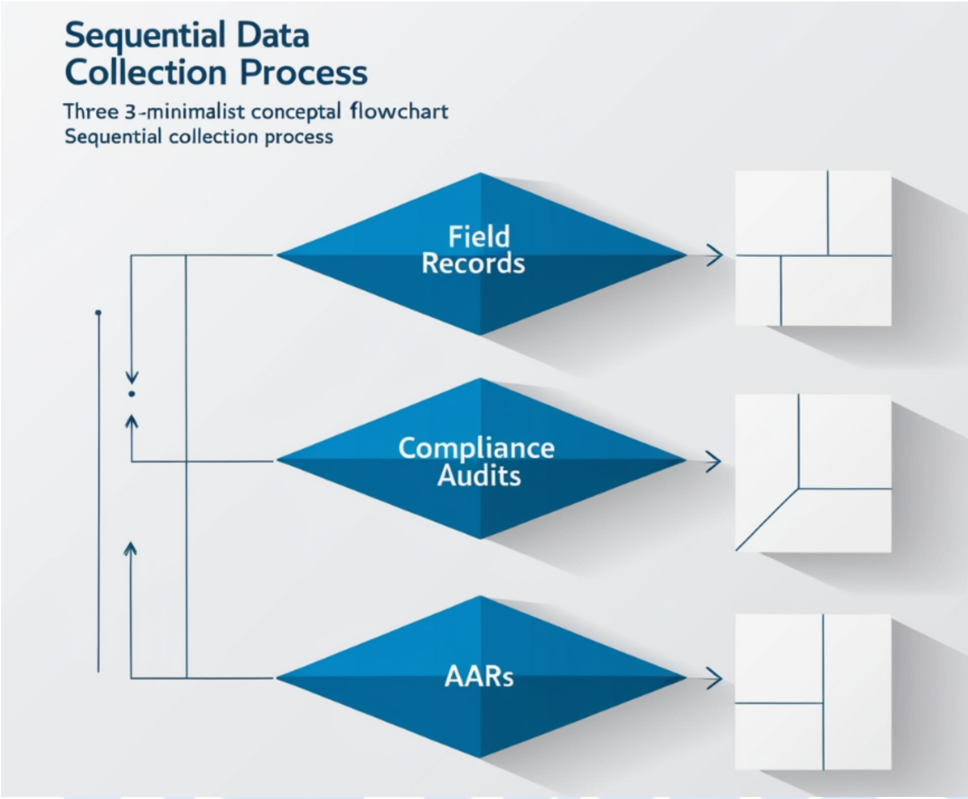
3.2.2 Compliance Audits

Data were collected through regulatory and internal inspection compliance audit reports. Such audits provide information concerning the level of compliance with environmental aspects or well integrity guidelines.

3.2.3 After-Action Reviews (AARs) and Facility Integrity Inspections

The standards received AARs and facility inspections in a periodically based manner in order to discuss the incident responses, assess procedural compliance and enhance future practices. This feedback mechanism is particularly important in the evaluation of sustained operational effectiveness.

Fig 2: Conceptual flowchart illustrating the data collection process across field records



3.2.4 Case Study-Specific Data

Each case study—Erha, Otuo South, and Ogbele—contributes unique data based on specific field conditions and operational priorities. These are categorized as follows:

- **Erha Field (Offshore):** Data highlights unique challenges in offshore drilling fluid management, including heightened emphasis on fluid containment and solid control equipment due to offshore environmental regulations.
- **Otuo South Field (Onshore):** This data emphasizes calibration practices and environmental impact monitoring, reflecting the regulatory expectations for onshore fields.

Ogbele Field (Onshore): Ogbele provides a distinctive view of post-operational reviews and the utility of AARs in optimizing fluid management practices.

3.3 Key Parameters and Metrics

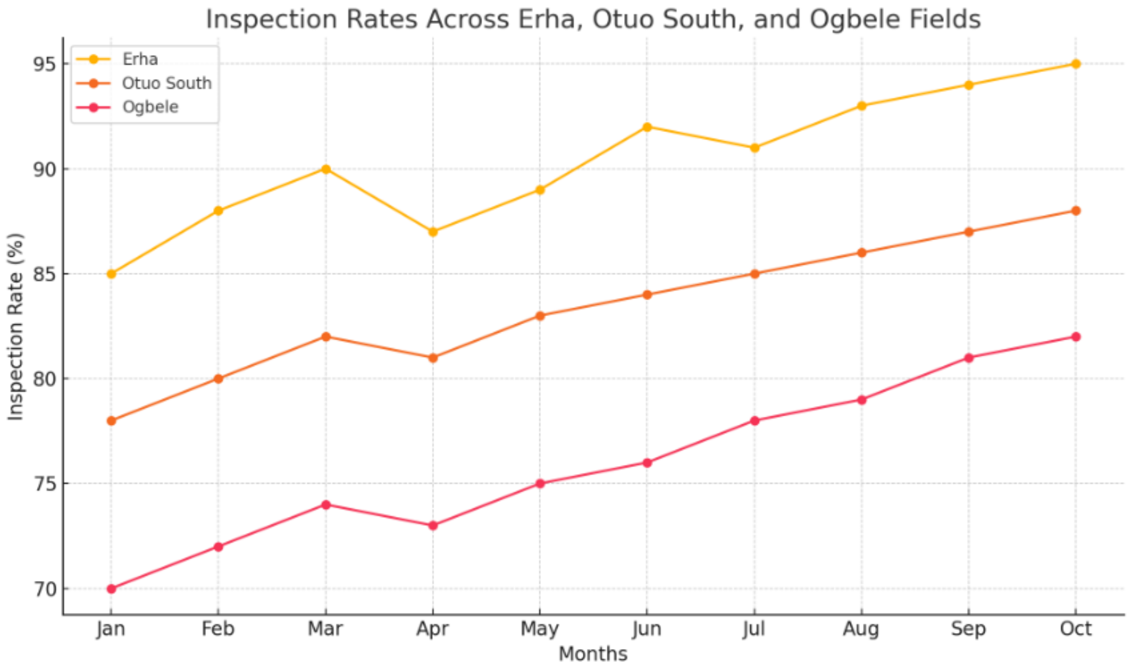
To systematically assess well integrity and environmental compliance, key parameters are defined and measured across the case studies. These parameters are grouped into well integrity metrics and environmental compliance indicators.

3.3.1 Well Integrity Metrics

Metric	Description	Measurement Method
Tank Management	Efficiency of fluid storage and control	Frequency of inspections
Solid Control Equipment	Effectiveness in filtering and recycling	Filtration rate (L/min)
Calibration Frequency	Adherence to equipment calibration schedule	Calibration intervals

Tank Management Efficiency: Tank management practices are analyzed to determine their role in well integrity, focusing on the regularity of fluid checks, tank maintenance, and overflow prevention.

- **Graph 3.1: Tank Management Efficiency**
  A line graph showing weekly inspection rates across fields to assess tank management consistency.



1. **Solid Control Equipment Performance**: Performance of solid control equipment is a critical metric, measured by the filtration rate. Consistent efficiency in solid control is essential for preventing wellbore instability.
2. **Calibration Frequency**: This metric evaluates how frequently equipment is calibrated to ensure optimal performance, as calibration directly impacts well integrity.

3.3.2 Environmental Compliance Indicators

Indicator	Description	Measurement Method
Fluid Discharge Levels	Quantity of fluids released into the environment	Monthly discharge rates
Emissions Control	Management of greenhouse gas emissions	CO_2 equivalent (tons)
Waste Management Compliance	Adherence to waste disposal protocols	Audit compliance rate

1. Fluid Discharge Levels: Monitoring of fluid discharge is a direct indicator of compliance with environmental standards. Data from monthly discharge logs is analyzed to determine if discharge levels are within permissible limits.

Table 3.2: Fluid Discharge Levels across Case Studies

Field	**Average Monthly Discharge (L)**	**Regulatory Limit (L)**	**Compliance Status**
Erha (Offshore)	500	600	Compliant
Otuo South	700	600	Non-compliant
Ogbele	550	600	Compliant

2. Emissions Control: Control of greenhouse gas emissions is measured in CO_2 equivalents, with monthly audits reviewing adherence to emissions reduction standards.

3. Waste Management Compliance: Compliance with waste management protocols is verified through internal audits, with each field assessed for adherence to disposal procedures.

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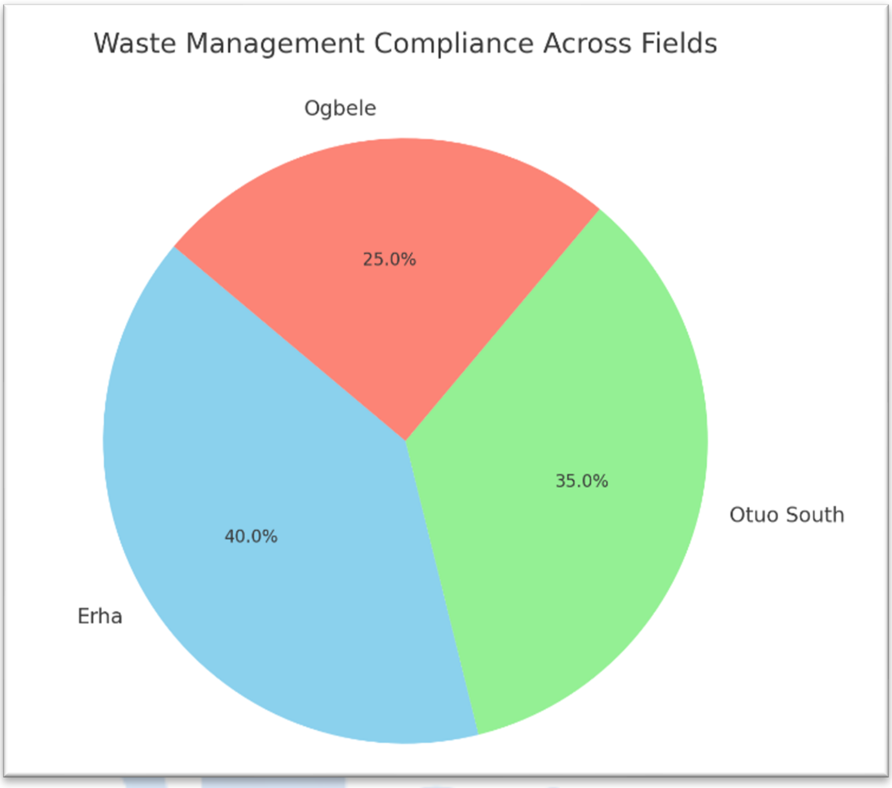

By systematically collecting and analyzing these key parameters, the study establishes a robust framework for assessing the efficacy of drilling fluid management in both well integrity and environmental compliance.

4. Case Studies

This section presents an in-depth analysis of drilling fluid management practices in three distinct operational contexts: The resources are distributed among the offshore Erha Field and both the Otuo South and Ogbele Fields that are onshore. These case studies demonstrate the specific issues and measures for guaranteeing wells integrity inclusive of environmental aspects

4.1 Offshore Operations in Erha Field

Overview of Erha's Operational Profile

The Erha Field is the offshore field in Nigeria and complex geological structure accompanied by high pressure conditions for the management of drilling fluids is required. Drilling operations in this field mainly employ Synthetic Based Mud which helps in conserving the environment despite the need for the right well bore.

Fluid Management Protocols

In the Erha Field, the following key protocols are implemented to manage drilling fluids effectively:

- **Selection of Drilling Fluids:** SBMs are used because of their reduced toxicity and enhanced performance as compared to other fluids, in terms of well bore stability. Fluids are chosen depending on the particular geology of the site and the environmental requirements for its use.
- **Monitoring and Control:** The viscosity, density, and filtration rate of the fluids are continually monitored by employing various mini smart sensor systems. Real-time information helps to keep the necessary characteristics for performance control and make corrections where necessary.
- **Waste Management:** Proper management of drilling waste requires strict observation of procedures of managing tanks as indicated below. Closed systems that contain the drilling fluids and renders them re-usable, in a way that reduces the need for disposal.

Unique Challenges in Offshore Well Integrity and Compliance

Despite the advanced protocols in place, the Erha Field faces several challenges:

- **Pressure Management:** The high-pressure environment requires meticulous control of fluid density to prevent blowouts. Failure to manage pressure can lead to severe operational risks, including loss of well integrity.
- **Environmental Regulations:** Strict compliance with environmental regulations poses challenges in fluid disposal and management. The offshore setting limits the options for waste disposal, necessitating innovative solutions such as on-site treatment and recycling.
- **Logistical Constraints:** Transporting materials and personnel to offshore locations can introduce delays and complications in fluid management operations, impacting overall efficiency.

Fig 3: Diagram illustrating fluid management system in the Erha Field

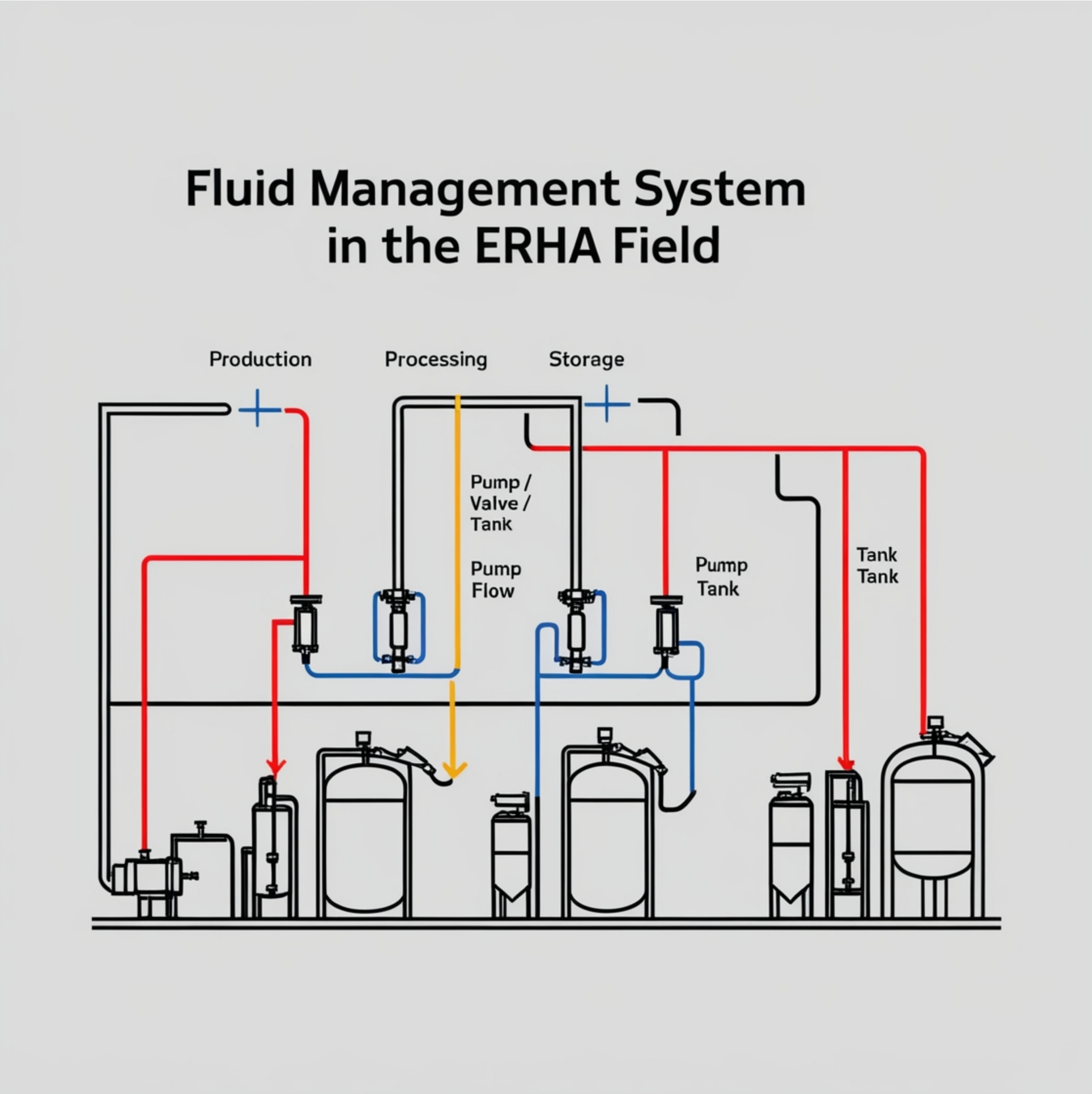

Table 1: Summary of Fluid Management Practices in Erha Field

Practice	Description	Impact on Well Integrity
Fluid Selection	Use of synthetic-based fluids for reduced toxicity	Enhances stability

Continuous Monitoring	Real-time assessment of fluid properties	Allows for timely adjustments
Waste Recycling	Closed-loop systems to minimize waste	Reduces environmental impact

4.2 Onshore Operations in Otuo South Field

Evaluation of Drilling Fluid Management Practices in Otuo South

The Otuo South Field, situated onshore, presents a different set of operational challenges compared to offshore environments. Here, water-based muds (WBMs) are commonly used due to their cost-effectiveness and ease of availability.

Fluid Management Practices

Key practices in Otuo South include:

- **Local Adaptation:** The use of locally sourced materials for mud preparation minimizes costs and enhances adaptability to varying geological conditions.
- **Regular Calibration:** Equipment used for mixing and monitoring drilling fluids undergoes regular calibration to ensure accuracy and reliability. This is critical for maintaining optimal fluid properties throughout the drilling process.
- **Environmental Compliance Monitoring:** Continuous monitoring of waste disposal practices is conducted to ensure compliance with local environmental regulations.

Discussion on Well Integrity and Compliance Outcomes in an Onshore Context

The challenges faced in Otuo South include:

- **Soil and Water Contamination:** There is a heightened risk of contamination due to proximity to water bodies and local communities. Strict adherence to waste disposal regulations is crucial to mitigate this risk.

- **Community Relations:** Engagement with local communities regarding environmental practices is essential for social license to operate. Transparent communication helps build trust and enhances compliance with environmental expectations.
- **Operational Interruptions:** Weather conditions and logistical challenges can disrupt drilling operations, leading to delays in fluid management and increased risk of non-compliance.
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Table 2: Overview of Fluid Management Challenges and Strategies in Otuo South Field

Challenge	Strategy	Outcome
Contamination Risk	Regular environmental assessments	Enhanced community trust
Logistical Issues	Local sourcing and adaptable practices	Reduced operational delays
Compliance Monitoring	Continuous monitoring of waste disposal practices	Improved compliance rates

4.3 Onshore Operations in Ogbele Field

Review of Fluid Management Strategies in Ogbele

The Ogbele Field operates under similar conditions to Otuo South but incorporates unique strategies tailored to its specific environmental and geological challenges. The field employs both water-based and oil-based muds, depending on the well requirements.

Fluid Management Strategies

- **After-Action Reviews (AARs):** AARs are conducted following each drilling operation to evaluate fluid management performance. These reviews identify lessons learned and best practices to inform future operations.

- **Inspection-Driven Feedback:** Regular facility inspections provide crucial feedback on fluid management systems and compliance with environmental standards. This proactive approach helps to identify potential issues before they escalate.
- **Training Programs:** Continuous training for personnel on the latest fluid management technologies and regulatory requirements ensures a knowledgeable workforce capable of addressing challenges effectively.

Focus on AARs and Inspection-Driven Feedback

The implementation of AARs and feedback from inspections has proven beneficial for Ogbele:

- **Continuous Improvement:** Insights gained from AARs are integrated into operational practices, fostering a culture of continuous improvement.
- **Proactive Risk Management:** Inspection feedback mechanisms allow for the early identification of compliance risks, enabling timely corrective actions.
- **Data-Driven Decision Making:** Analysis of AAR findings help to refine fluid management strategies based on empirical data, enhancing overall operational efficiency.

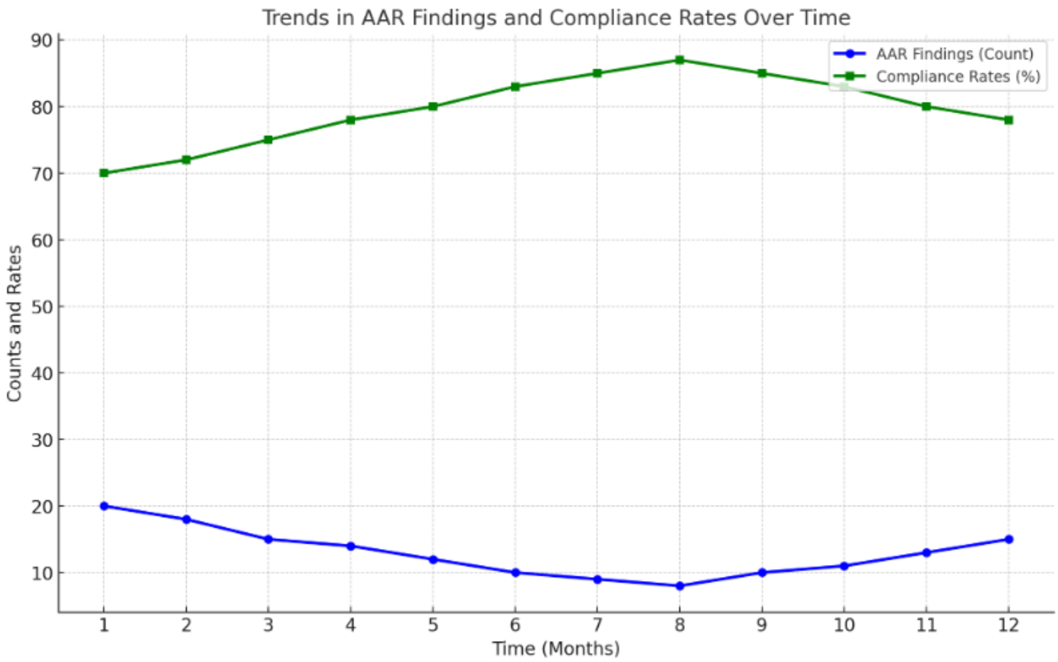

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Table 3: Summary of Fluid Management Strategies and Outcomes in Ogbele Field

Challenge	Strategy	Outcome
Contamination Risk	Regular environmental assessments	Enhanced community trust
Logistical Issues	Local sourcing and adaptable practices	Reduced operational delays
Compliance Monitoring	Continuous monitoring of waste disposal practices	Improved compliance rates

5. Results and Discussion

Here we present the actual situation derived from the offshore and onshore wells of the Erha, Otuo South, and Ogbele fields to assess the application of the advanced drilling fluid management programs in terms of the well integrity and environmentally related issues. We focus on four primary areas: Tank management, including systems for handling and controlling solid matters, calibration and maintenance of facilities, and how AARs and facilities integrity inspections were carried out: (Khodja et al., 2010; Skogdalen et al., 2011).

5.1 Evaluation of Tank Management Practices

Central to both offshore and onshore drilling operations is tank management to ensure appropriate control of the drilling fluids as espoused by Dye et al. (2005). The major differences explored in the study include how the offshore Erha field, compare to the onshore Otuo South and Ogbele fields manage the tanks differently despite measuring similar levels of effectiveness (Abdo, 2019; Ekins et al., 2006).

1. **Offshore Tank Management Practices (Erha Field)**
   As revealed in the case of the Erha offshore field, tank management is highly regulated since offshore marine fields come with high risks on the environment. Measures used here include the policy of having double-walled tanks, constant inspection, and setting

up of delicate alarms to sense leakage and fluid level in the tanks. Moreover, accidental discharge is also prevented by offshore operators who use real-time monitoring of containment to ensure that any development of these occurrences is addressed immediately.

2. **Onshore Tank Management Practices (Otuo South and Ogbele Fields)**
   This paper assessed the onshore tank management practices in the Otuo South and Ogbele Fields.
3. In the Otuo South and Ogbele onshore fields, tank operations are still fairly rudimentary, though there is some computer control, the level and properties of the tanks are checked periodically. Onshore practices, however, employ the physical compartmentalization of containment barriers on the tank system; they are not without some problems that include onshore environmental pollution and geographical limitations. Some of compliance measures are periodic check and compliance to regional environmental laws.

Impacts on Well Integrity and Compliance

Automated monitoring and containment, which offshore tank management incorporates, minimizes risk issues as those of drilling fluid leakages and contamination, and thereby also plays a part in well integrity. Onshore fields despite the relatively less levels of automation, they ensure compliance by stringently inspecting manually, and having barrier systems that negligible environmental impacts.

TABLE 5.1: Comparative Overview of Tank Management Practices

Field	Location	Tank Management System	Automation Level	Environmental Compliance
Erha	Offshore	Double-walled, automated	High	Stringent
Otuo South	Onshore	Single-wall, semi-automated	Moderate	Standard

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Ogbele	Onshore	Physical barriers, manual	Low	Moderate

5.2 Performance of Solid Control Systems

The simplicity of the design and the easy controllability of equipment to attain superior quality of the drilling process as well as the adjustment of the structure of drilling fluids according to wellbore stability and environmentalism is critical (Khodja et al., 2010). This section evaluates the functionality of different solid control systems that have been implemented in different areas and the possible consequences for maintaining quality standards of the respective fluid.

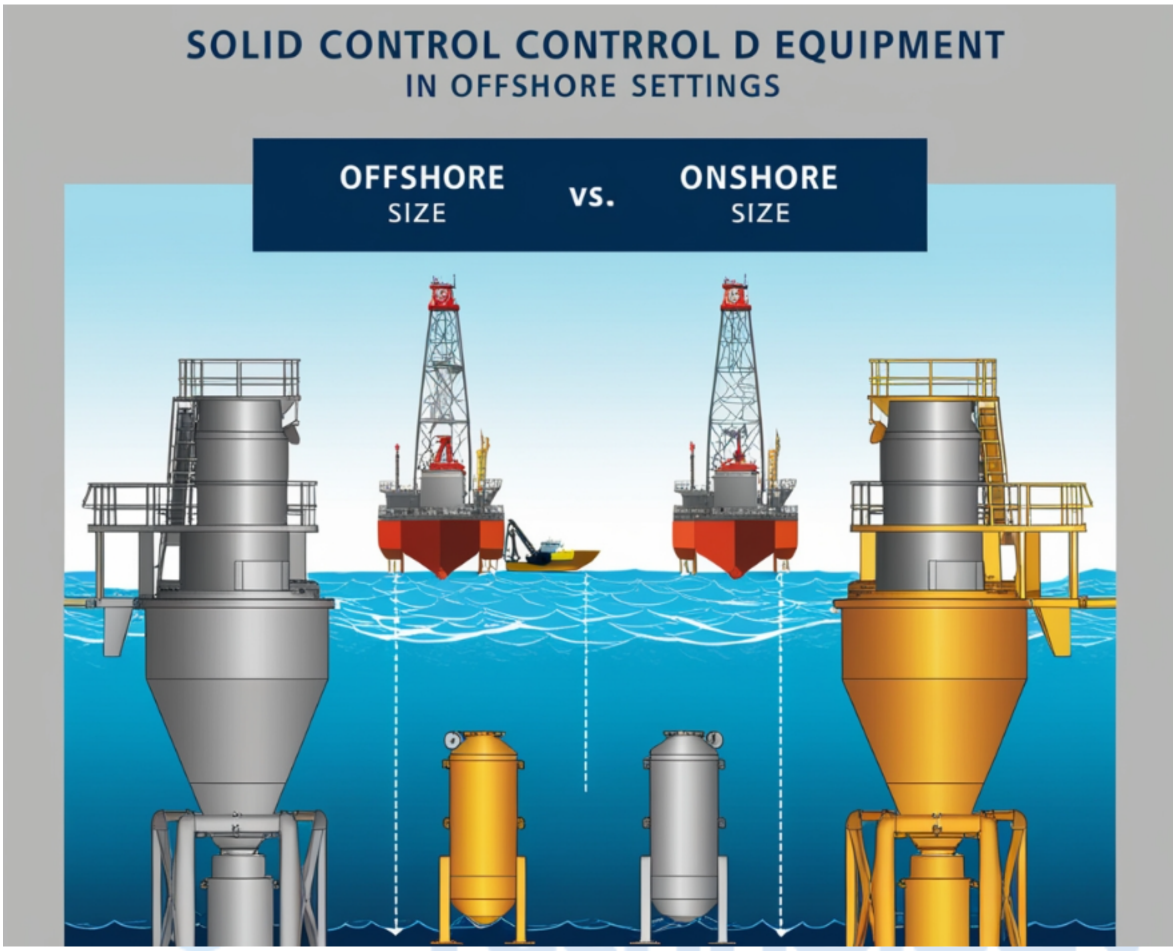
1. System Efficiency in Offshore Operations (Erha Field)

In the current world, the Erha field applies large bore high-capacity shakers, centrifuges and desalter that are more accurate in operation while handling large volumes drilling fluids (Dye et al., 2005). These systems are developed for the offshore environment where fluid compatibility is paramount to well integrity and protecting the marine assets (Davies et al., 2014). Such features permit minimal intervention on the operating equipment thereby enhancing filtration efficiency to secure both the wellbore and the marine environment (Wojtanowicz, 2016).

2. Onshore Field Performance (Otuo South and Ogbele Fields)

The Otuo South, and Ogbele fields mainly uses shakers and hydro- cyclones to treat the produced sand. Even though these systems are not as elaborate as those implemented in offshore situations, they suffice in regard to purification when conditions of the onshore are considered suitable for these systems (Skogdalen & Vinnem, 2012). Also, in recent years onshore solid control equipment has been maintained and updated annually while the usage of automation systems within the onshore domestic industry is not as pronounced as they could be, (Hals, 2015).

Fig 4: solid control equipment used in offshore vs. onshore settings



Impact on Wellbore Stability and Environmental Safety

In the context of reliability and efficiency, material packages associated with offshore well drilling have outcompeted those of onshore forms as key drivers in creating solid well bore through proper disposal of cuttings as well as sustaining the right fluid atmosphere (Khodja et al., 2010; Young & Ramses, 2006). Offshore facilities can deliver a very high degree of efficiency with only the risk that empire building activities, that is, operators acting in their own or their company's interests, will affect production levels (Ekins, Vanner, & Firebrace, 2006). Similar risks are present in onshore fields; nevertheless, strict compliance with the maintenance schedule considerably reduces these risks (Speight, 2014; Skogdalen et al., 2011).

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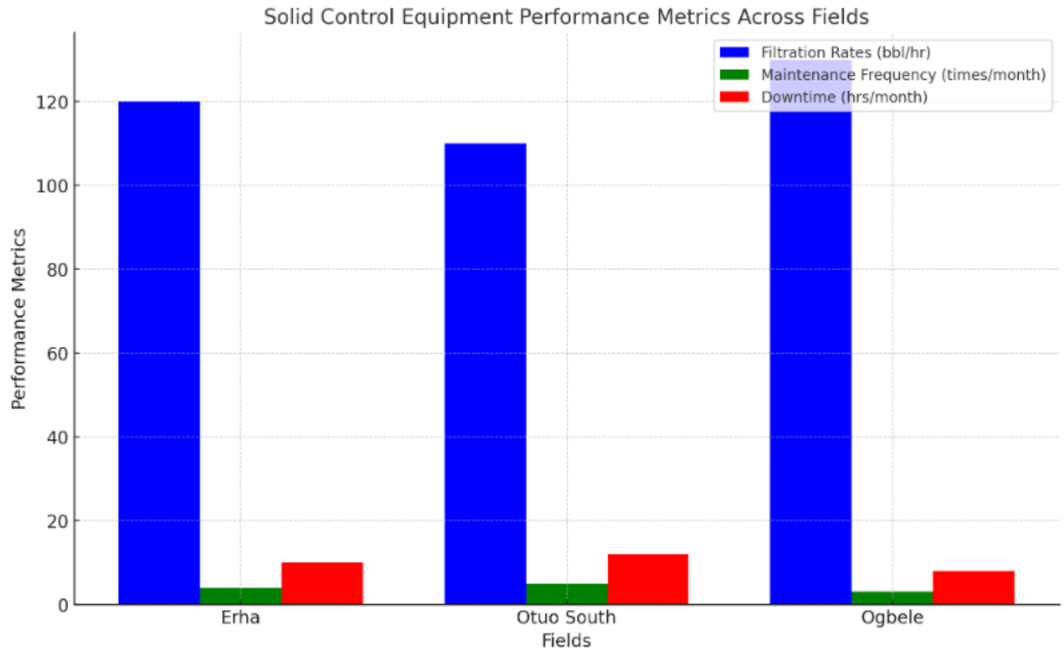

5.3 Calibration and Maintenance Protocols

There is always a need to calibrate and maintain the available drilling fluid management equipment since this is all about effectiveness, safety and relevance to the set standards. In this section, the author focuses on the calibration standards and the maintenance practices provided in the fields.

1. **Calibration Protocols**

   - **Offshore (Erha Field):** Equipment calibration is performed on a weekly basis to reflect changes in operational safety requirements, during which all equipment is tested for compliance with the relevant regulation. More specifically, the procedure requires more regular calibration schedules in offshore environments due to the increased supervision of such settings.
   - **Onshore (Otuo South and Ogbele Fields):** As there are no regulatory requirements for regular onshore calibration, this practice is usually done monthly. However, since the occurrence is relatively rare, the standard procedures are strictly adhered to in order to prevent possible danger.

2. **Maintenance Schedules and Compliance**

- **Offshore (Erha Field):** Offshore equipment are checked every month as part of the general precaution measures to ensure that all the equipment within the offshore field is in good condition complied with the environmental rules and regulation.
- **Onshore (Otuo South and Ogbele Fields):** Maintenance is done on a quarterly basis, and adjusted to achieve the best results possible under onboard-like set-ups.

Fig 5: comparing calibration and maintenance schedules for offshore vs. onshore drilling fields

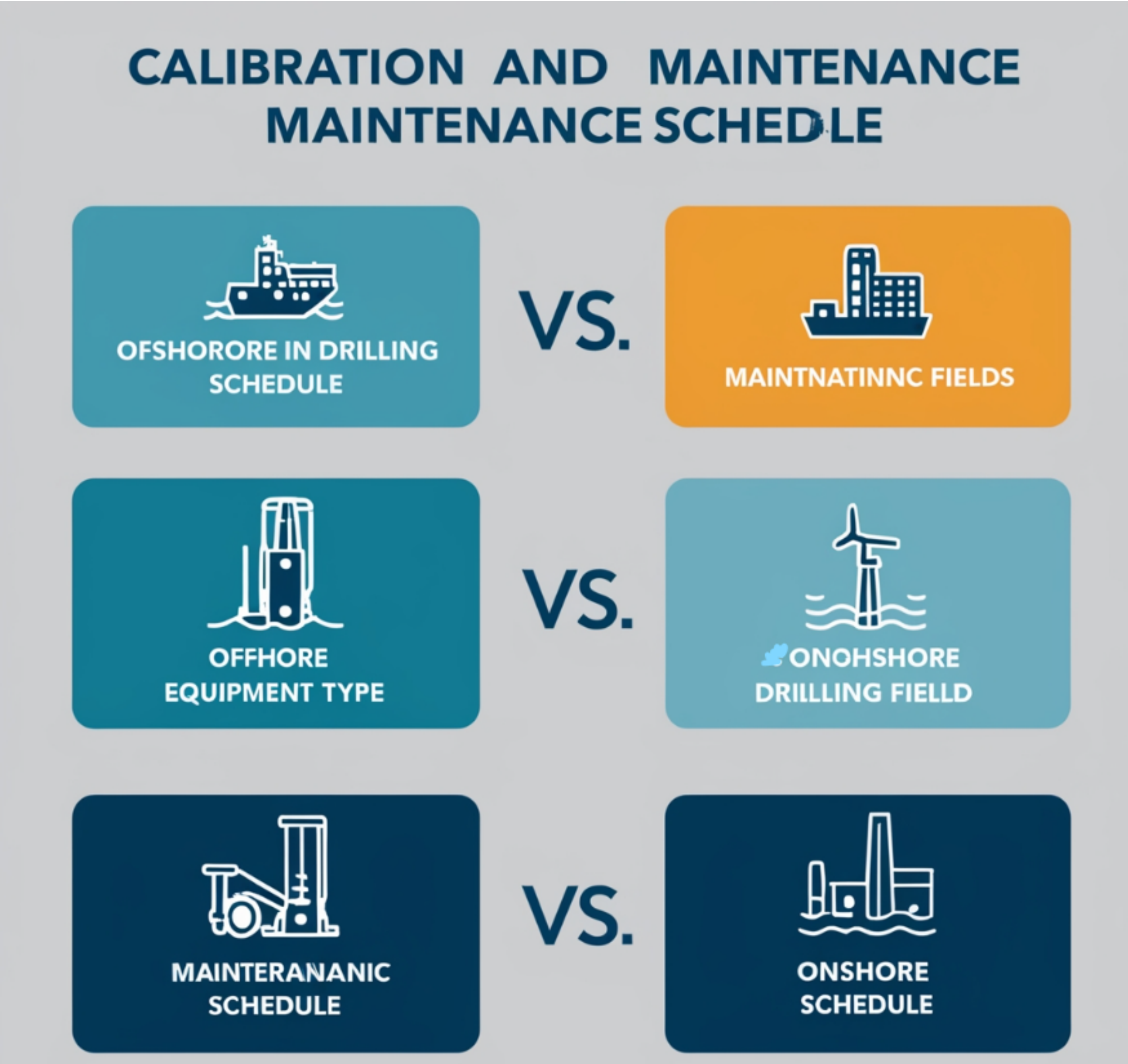

TABLE 5.2: Calibration and Maintenance Protocols by Field

Field	Calibration Frequency	Maintenance Schedule	Compliance Level	Equipment Reliability
Erha	Weekly	Monthly	High	High
Otuo South	Monthly	Quarterly	Moderate	Moderate
Ogbele	Monthly	Quarterly	Moderate	Moderate

5.4 Impact of After-Action Reviews (AARs) and Facility Integrity Inspections

After-Action Reviews (AARs) and facility integrity inspections should be used as regular fixtures for the improvement of the overall process of fluid management. This section examines the extent to which AARs and periodic inspections are employed in both domains in order to determine the correct corrective actions. Schein avers that these practices are essential to avoid compromising of standards which are genetically associated with high levels of non-conformity in environment compliance and well integrity (Skogdalen et al., 2011; Kiran, Yetudur, Kara, & Akandal, 2017).

1. **Implementation of AARs**

   - **Offshore (Erha Field):** AARs are performed after each crucial drilling stage to provide many lessons collected that are then incorporated into new procedures. This way, there is constant enshrinement that some problems are common, and hence the need to tackle them as they emerge without being noticed.
   - **Onshore (Otuo South and Ogbele Fields):** AARs are however a less frequent process than debriefings, but they also contribute to further gradual enhancement of the process of the management of IV fluids. Each review educates the function to execute refining operations and improve its best practices.

2. **Facility Integrity Inspections**

- **Offshore (Erha Field):** Schedules for integrity inspections are annually and additional checks are required for at least bi-annual; assessing for general integrity of all equipment but especially the containment and control systems. Their removal does not meet the regular inspections that should be done to provide for adequate safety and protection of the environment.
- **Onshore (Otuo South and Ogbele Fields):** Inspections are performed annually and focus on basic containment and control mechanisms. Although less frequent, these inspections are effective in identifying potential risks.

3. Feedback Mechanisms and Continuous Improvement

Both AARs and facility inspections provide critical feedback loops that inform future drilling practices and enhance overall operational safety.

TABLE 5.3: Overview of AARs and Integrity Inspections by Field

ield	AAR Frequency	Inspection Frequency	Focus Areas	Key Outcomes
Erha	Per drilling phase	Biannual	Containment, control systems	Enhanced containment measures
Otuo South	Semi-annual	Annual	Basic containment and control	Adjusted tank management
Ogbele	Semi-annual	Annual	Basic containment and control	Improved maintenance schedules

6. Conclusion

6.1 Summary of Key Findings

As the research outcome of this analysis highlights, drilling fluids play a disproportionate role in embracing well integrity and environmentally acceptable drilled formations in offshore and onshore categories (Kiran et al., 2017). The findings suggest that there is huge opportunity for well integrity loss through drilling fluid management especially on issues to do with tanks, solid control equipment, and calibration (Skogdalen, Utne, & Vinnem, 2011).

In offshore fields like the Erha field, experience has it that these complications are expected because the wells are deeper, and the pressure systems are more complex; therefore, there are rigorous tank management measures and high mechanical solid control technologies required. This research understands that overseas organisational culture is more receptive to regulatory conduct because the environmental concern is tangible; yet, the need for monitoring and sustaining equipment as a core driver to attaining operational sustainability cannot be overemphasised (Davies et al., 2014).

On the other hand, the fields such as Otuo South and Ogbele undergo different effects of environment for various difficulties of operation such as the difficulties containing to the solid control and calibration issues (Bakke, Klungsøyr, & Sanni, 2013). The research provides evidence that a minimum of facility integrity check or the AAR that feeds into operations inside these domains are critical for enlightening the operators on the measures to adopt when improving the management of drilling fluids depending on the requirements of operation on the ground (Singh, 2019). The other practice noted in both fields is of inspection that when exercised proactively hand in hand with equipment calibration has a positive impact toward well integrity and the environment compliance processes in both offshore and subsea domains (Dye et al., 2005).

6.2 Practical Recommendations

Based on the study findings, several practical recommendations emerge to improve drilling fluid management and bolster well integrity:

1. **Enhanced Tank Management**: Since there are relatively more risks involved with the environment in offshore operations, tanks should be checked and modified as often as possible to prevent incidents. This requires one to apply more severe measures of managing tanks, including the use of alarm systems to control the fluid levels, unlike

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concentrating on personnel to carry out the task. When tanks are incorporated into automation, there are major improvements to the fluid quality (Khodja et al., 2010; Ekins, Vanner, & Firebrace, 2006).

2. **Improved Solid Control Equipment** It is critical to ensure that, to maintain well stability and total capacity of the unit, the function of solid control equipment is adequate. High-capacity shale shakers and decanter centrifuges should be used to ensure low levels of particulate matter in the drilling fluid and constant property of the fluid. To address the problem, compliance and quality outcome standards must be set primarily due to firmly set inconsistent control practices between offshore and onshore sectors (Davies, et al., 2014; Skogdalen & Vinnem, 2012).
3. **Regular Calibration and Maintenance Practices**: Such operation of equipment is crucial to the safety of facility operations. Perhaps, all fluid control and measurement equipment must be calibrated; much more so, industries with offshore activities. Using state-of-art advanced digital calibration tools can also give prior and wider evaluations of wear. Furthermore, it is worth promoting prophylactic maintenance as it may increase equipment sturdiness and control problems (Abdo, 2019; Nardone, 2009).
4. **Strengthening AAR and Facility Integrity Inspections**: For these enhancements to be overlaid smoothly, all shared Accident Analysis and Reporting (AAR) processes must be standardized across drilling operations to target findings that have an application to future work. Another insight derived from the work of the authors is that facility integrity inspection should be regular and not only when the changes in the core production processes occurred. This proactive approach helps identify possible problems and helps to manage the appropriate modifications in the use of the drilling fluid which is very important according to Skogdalen et al. (2011) and Jackson (2014).

6.3 Implications for Future Research

This study highlights several avenues for further research, particularly as technology and regulatory frameworks evolve:

1. **Advanced Drilling Fluid Compositions** Further research on the formulations of the drilling fluids could lead to superb results in coming up with flexible drilling fluids that will improve the integrity of the well and respect the environment at the same time (Kiran et al., 2017; Khodja et al., 2010). Further studies of bio- or synthetic drilling

fluids that demonstrate better performance but have limited negative effects on the environment will find special application in sensitive environments (Bakke et al., 2013).

2. **Data-Driven Management and Predictive Analytics**: As for the possible improvements, future work might consider optimization of predictive technologies and machine learning in the processes of drilling fluids handling. Probabilistic models are capable of making suggestions on relevant fluid parameters together with the related equipment characteristics that will optimise production rates and conform with governing legislation, all based on present data relating to the flow characteristics of specific fluids, equipment characteristics and external operating conditions (Skogdalen & Vinnem, 2012; Davies et al., 2014).
3. **Standardization of Inspection and AAR Protocols**: Future research topics involve the application of AAR standardization and continue facility integrity inspection methodologies. It is recommended that there should be principles to these processes that would be set by different operators in other fields as the overview of improving quality and compliance to drilling procedures (Hals, 2015; Ekins et al., 2006).

Therefore, fulfilling these recommendations and other research directions will enable the industry to support innovation and compliance for the solder drilling that maintains well integrity while safeguarding the environment (Jackson, 2014; Viswakanth, 2018).

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