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Evaluation of Pipeline Integrity Using Risk Based Inspection: A Case Study of Liquefied Natural Gas Pipeline in Nigeria

Ikechukwu Chijioke Onyenekwe, Barinyima Nkoi, and Elemchukwu O. Isaac.
Department of Mechanical Engineering, Rivers State University, Port Harcourt, Nigeria.
princeiyk1@yahoo.com +2348034913007

ABSTRACT
This research work evaluated pipeline integrity using risk-based inspection on Liquefied Natural Gas Pipeline in Nigeria. The pipeline hazards addressed include; mechanical failure, failure due to corrosion, operational failure, third-party activity and natural hazard. Quantitative and qualitative risk analysis methods were employed to evaluate the integrity of the pipeline. Broad based results revealed that for the total risk measure in Naira at every segment for leaks, holes and ruptures, the second segment (km-2) of the proposed pipeline is poised with the highest risk at N 5,720,670/year and the seventh segment (km-7) of the proposed pipeline is poised with the lowest risk at N 426,589/year. The total risk value determined for the entire 8km pipeline is N 21,422,146/year. Based on the analyzed probability and consequences of failures, the first and seventh segments (KP1 and KP7) of the pipeline were classified as low-risk segments while pipeline segments (KP2, KP3, KP4, KP5, KP6 and KP8) were classified as medium risk segments. The total failure rates for leaks, holes and rupture in the pipeline were 2.63 x 10^{-4}, 1.25 x 10^{-4} and 2.29 x 10^{-5}/yr.km respectively. The individual risk experienced by a segment in a year was lower than 10^{-6}/yr. ANOVA analysis performed on the risk measures at every segment for leaks, holes and rupture showed that the risk values are statistically significant as the p-value gotten was less than the 0.05 significant level. A framework that evaluates the integrity of the pipeline using risk-based inspection was established ultimately.

KEYWORDS: Risk based inspection, Risk priority, Probability of Failure, Consequences of failure.

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1.0 INTRODUCTION
Risk analysis is often used as a decision tool in the pipeline industry. Methods can be divided into two main categories: qualitative structure and quantitative risk analysis. The consequences of a pipeline breakdown are usually specified by the following parameters: Total cost as a measure of economic loss; Death as an indicator of life risk; and the remaining emissions as an indicator of long-term environmental impact.

Several studies show that the issue of evaluating pipeline integrity through risk-based management is receiving considerable attention. Many authors have been professionally involved in quantifying pipeline risk in underground tunnels and controlling pipeline integrity and pipeline analysis (Weipeng *et al.*, 2019; Ronsky & Trefanenko, 2002; Hill, 2012). Kishawy and Gabbar (2010) analyzed the integrity of the pipeline, while Lee *et al.* (2017) studied how to quantify the risk of submarine instability. In the study of Breton *et al.* (2010) used the stochastic Bayesian method to determine the types of defects in corrosive pipelines. Achebe *et al.* (2012) published an analysis of pipeline defects in the oil and gas industry in the Niger Delta, Nigeria. Da Cunba (2016) provided an overview of risk quantification in onshore pipelines, while Shan *et al.* (2018) investigated the probability assessment of gas pipelines based on historical error data and correction factors. Bonvicini *et al.* (2018) assessed the risk of environmental damage after major accidents in onshore pipelines, and Det & Veritas (2010) published an energy report containing recommended levels of failure for pipelines. None of the extant research work reviewed evaluated pipeline integrity using risk-based inspection by ranking different segments of the pipeline with respect to priority for increased maintenance which this study focused on.

Pipeline Integrity Assessment
The risk-based integrity assessment includes the following key elements:

i. Data collection and integration- Facilitates risk assessment. • Hazard

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Identification-Identify hazards that may cause tears, leaks, or loss of function. In general, the risks are as follows: corrosion; Third-party land disturbances; Manufacturing defects; Wrong work, etc.

ii. Evaluate Results-The consequences of interruptions, churn, or loss of performance are evaluated. Consequences may include death or injury, pollution; loss of income; property damage; and reputation damage; etc.

iii. Site selection-The pipeline system is divided into areas where the risks or consequences are related to other areas and different areas. For example, onshore and offshore pipelines are usually evaluated separately.

iv. Risk Analysis-The probability of a risk error and the result of this error are multiplied together to give a risk assessment for each risk. The risks of each risk can then be combined to provide an overall assessment of the level of risk in each section.

v. Risk Assessment-Identify high risk areas/pipelines/risks by comparing expected risks to acceptable risk levels or targets or reference values.

vi. Mitigation-risk management plan is drawn up. This is an important step and must be clearly linked to the risk.

vii. Review and Update-The process is in progress and inspection and maintenance results need to be re-analyzed.

The risk management process is graphically shown in Figure 1. Pipeline risk assessment is used in a variety of systems.

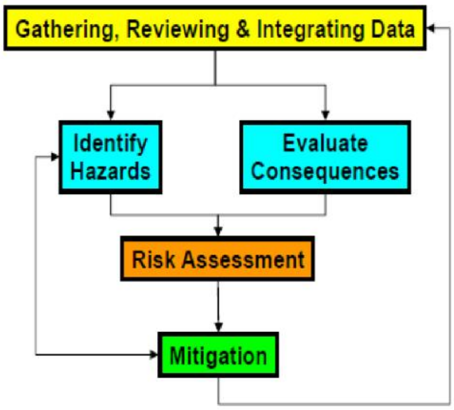

Figure 1: The Risk Management Process (Singh & Markeset, 2009)

2. MATERIALS AND METHODS

The Niger Delta is in southern Nigeria and is the third largest wetland in the world. It has considerable biodiversity and contains most of Nigeria's proven oil and gas reserves. There are about 606 oil fields in the area, of which 355 are land and 251 are offshore (Fig. 2).

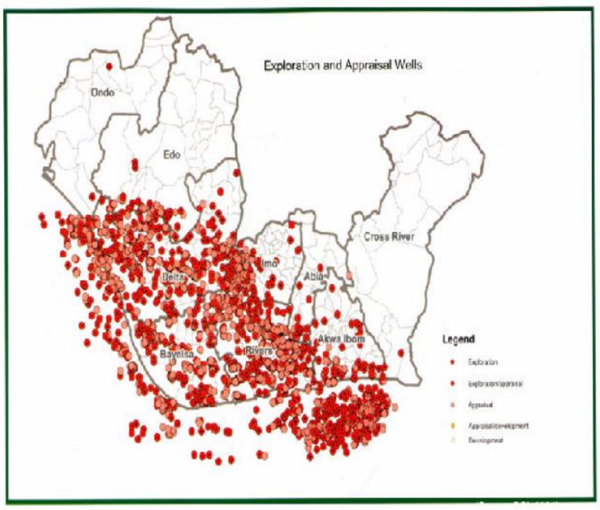

Figure 2: Niger Delta Showing the Distribution of Onshore and Offshore Oil Fields (Source: NDRDMP, 2006)

About 5,084 oil wells have been drilled, and more than 7,000 km of oil and gas pipelines pass through the entire territory to seven export terminals. The distribution of the pipelines indicated by their operators, length, and diameter, in the Niger Delta region of Nigeria is shown in Table 1.

Table 1: Crude Oil Pipelines in the Niger Delta in Nigeria

link	Owner/Operator	Length (Km)	Diameter (cm)
Nkpoku/Bomu	Shell	47	61
Apara/Nkpoku	Shell	11	20
Ramuekpe/Bonny Terminal	Shell	108	71/51/61
Alakiri/Bonny Terminal	Shell	34	61
Ramuekpe/Nkopku	Shell	35	51
Nembe Creek/Cawthorne Channel	Shell	82	61/71
Bonny Terminal/Offshore platform	Shell	27	122
Kwale/Ogoda	Agip/NNPC	81	25/36
Ramuekpe/Ogoda	Agip/NNPC	23	36
Ogoda/Brass Offshore Terminal	Agip/NNPC	127	61/91
Azuzama/T ebidaba	Agip/NNPC	35	30
Clough Creek/Tebidaba	Agip/NNPC	52	25
Tebidaba/Brass manifold	Agip/NNPC	45	46
Obama/Brass manifold	Agip/NNPC	26	4
Brass Manifold/Brass Offs.Terminal	Agip/NNPC	37	61/91
Etim/Odoho	Mobil	26	33/36
Utue Ekpe/ldoho	Mobil	32	41/41/51
Idoho/Qit	Mobil	21	61
lyakb/lyaka/Ekua	Mobil	14	33/46
Unamb/Ubit F	Mobil	3	33

Source: Department of Petroleum Resources (DPR), Shell petroleum Development Company (SPDC), Port-Harcourt, 2018

Causes of Pipeline Failures in the Niger Delta Area of Nigeria

The causes of pipeline faults have been analyzed according to the globally accepted naming system as follows: (NNPC, 2018):

Table 2: A Summary of the Various Causes of Oil Pipeline Failure in the Niger Delta Region of Nigeria

Types of failure	Causes of Failure
Mechanical Failure	Construction, Material and Structural
Corrosion	Internal, External
Operational Failure	System, Human
Third-party Activity	Accidental, Malicious (Sabotage), Incidental and Acts of Vandalism
Natural Hazard	Subsidence, Flooding and Others

(Source: Pipeline Oil Spill Prevention and Remediation in NDA, NNPC, 2018)

The causes of pipeline failures were analyzed in accordance with the internationally accepted nomenclature as follows (NNPC, 2018):

2.1 Method for Risk based Inspection

Risk based Inspection makes uses of qualitative and quantitative risk analysis to prioritize the process piping, by calculating likelihood and ... of

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Characteristics of Risk Factors

Threatening events considered are oil spills. The environmental risk factors (Cs) are listed in Table 3 and Table 4.

In Risk based Inspection methodology, the failure is defined as loss of primary containment, and the risk of failure is calculated using Equation (1).

$$Risk(t) \;=\; POF(t)\ x\ COF \qquad (1)$$

Table 3: Environmental risk elements

Variable	Definition	Explanation
C1	Surface Water Sensitivity	Very High=10, High=7, Medium=5, Low=3 and Not Sensitive=1 Weight=1
C2	Ground Water Sensitivity	Very High=10, High=7, Medium=5, Low=3 and Not Sensitive=1 Weight=1
C3	Terrestrial Ecological Resource	Very High=10, High=7, Medium=5, Low=3 and Not Sensitive=1 Weight=0.75
C4	Land Use	Very High=10, High=7, Medium=5, Low=3 and Not Sensitive=1 Weight=0.75
C5	Archaeology	Very High=10, High=7, Medium=5, Low=3 and Not Sensitive=1 Weight=0.25

As base of four, the risks are classified as Not Sensitive = 0, Low = 2, Medium = 2, High = 3 and Very High =4.

Table 4: Qualitative values of environmental risk for the segments

KP (km)	Surface Water Sensitivity	Ground Water Sensitivity	Terrestrial Ecological Resource	Land Use	Archaeology
1	Not Sensitive	Not Sensitive	Very High	Not Sensitive	Not Sensitive
2	Not Sensitive	Not Sensitive	Very High	Medium	Not Sensitive
3	Not Sensitive	Not Sensitive	Very High	Medium	Not Sensitive
4	Low	Not Sensitive	Very High	Medium	Not Sensitive
5	Not Sensitive	Not Sensitive	Very High	Medium	Not Sensitive
6	Not Sensitive	Not Sensitive	Very High	Medium	Not Sensitive
7	Not Sensitive	Not Sensitive	Very High	Not Sensitive	Not Sensitive
8	Not Sensitive	Not Sensitive	Very High	Not Sensitive	Not Sensitive

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Where:
POF = Probability of Failure and is a function of time, t
COF = Consequence of Failure (losses incurred in Naira)

Risk matrix is the most direct way to show the risk distribution of different pipeline segment. The recommended values for the probability level and consequence categories are shown in the following Table 5.

3. RESULTS ANS DISCUSSION

The risk analysis is conducted for a proposed the length of the liquefied natural gas (NLNG)

Table 5: Recommended Values for the Probability Level and Consequence Categories for the Segments

POF Ranking		**Consequences of Failure (COF)**				
5	**>0.1**	**Medium**	**Med-high**	**Med-high**	**High**	**High**
4	**<0.1**	**Medium**	**Medium**	**Med-high**	**Med-high**	**High**
3	**<0.01**	**Low**	**Low**	**Medium**	**Med-high**	**High**
2	**<0.001**	**Low**	**Low**	**Medium**	**Medium**	**Med-high**
1	**<0.0001**	**Low**	**Low**	**Medium**	**Medium**	**Med-high**
COF Ranking		**A**	**B**	**C**	**D**	**E**
COF Types	**Personal safety**	**No injury**	**Minor injury**	**Major injury**	**Single fatality**	**Multiple fatality**
	Environment	**No pollution**	**Slight Effect**	**Minor local effect**	**Major local effect**	**Significant environmental effect**
	Economic loss(N)	**0 - 100K**	**100K - 1M**	**1M - 10M**	**10 – 100M**	**>100M**
	Impact area (m^2)	**0 – 10**	**10 – 100**	**100 – 1000**	**1000-10000**	**>100000**

(Source: Pipeline Oil Spill Prevention and Remediation in NDA, NNPC, 2018)

To determine the consequences of failure, the kinds of consequences considered are: the consequence on personal safety, the consequence on the operating environment, the impact area and also and the consequences of economic losses.

Probability of Failure (POF)

As shown in the Equation (2) the risk is also a function of time. The Probability of failure could be calculated based on the Equation (2):

$$POF(t) = \frac{1}{Time\ To\ Failure(TTF)} \qquad (2)$$

pipeline is 8 km. The pipeline construction material (MOC) is plain carbon steel, and the pipeline is smooth. In addition to hydrocarbon liquids, pipelines contain small amounts of condensed moisture and soluble CO_2 and H_2S. The proposed part of the pipeline is on the island of Bonny in the Niger-Niger Delta, has surface water topographic boundaries, and groundwater is within the available land and land resources.

Risk analysis was required to develop guidance for risk-based inspection systems.

The pipeline section is characterized by the following data:
I. Inner diameter = 1200mm
II. Section length = 8 km.
iii. Pressure = 70 bar
iv. Pump flow = 140.4 kg/s

Specific dropouts are shown in the table. 6.

Table 6: Leak Sizes

z	HOLE	RUPTURE
Leak Area (cm2) 0.2	Leak Area (cm2) 20.0	Leak Area (cm2) full bore

The values for the total frequency of leaks (leaks, holes and ruptures) from various hazardous events are determined using Equation (3) and (4):

$$f = \sum_{i=1}^{n} f_i \quad (3)$$

Where,
fi = leak event of i,
n = number of leaks or

Or

$$f = f_{mo} + f_{co} + f_{ih} + f_{ai} + f_{nh} \quad (4)$$

Where:
f_{mo} = leak frequency from material mechanical and operational faults,
f_{co} = leak frequency from corrosion,
f_{ih} = leak frequency from intentional hostile action,
f_{ai} = leak frequency from accidental / incidental action,
f_{nh} = leak frequency from natural hazards.

The cumulative level of error from leaks, holes and breaks in the pipeline are: 2.63 x 10-4, 1.25 x 10-4 and 2.29 x 10-5 / km respectively.

Risk matrix is the most direct approach to indicate the distribution of risks and variable priorities pipeline segment is used to classify and qualify the risk value associated with various segments of the pipeline for leaks based on the probability and consequences level provided in Table 5.

The results of the risk analysis as presented in Table 7 shows that attacks on the entire pipeline segments (KP1, KP2, KP3, KP4, KP5, KP6, KP7, and KP8) have a low probability of leaks occurring and could cause a minor injury to personal safety, slight effect on the surrounding environment with economic losses in Naira ranging between **N**100, 000 and **N**1 Million. The area of impact for the attacks associated with the entire pipeline segments is within the range 10 to 100 m^2.

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Table 7: Risk Classification at Every Segment for Leaks

POF Ranking		**Consequences of Failure (COF)**				
5	>0.1					
4	<0.1					
3	<0.01					
2	<0.001		KP1, KP2, KP3, KP4, KP5,KP6,KP7,KP8			
1	<0.0001					
COF Ranking		**A**	**B**	**C**	**D**	**E**
COF Types	Personal safety	No injury	Minor injury	Major injury	Single fatality	Multiple fatality
	Environment	No pollution	Slight Effect	Minor local effect	Major local effect	Significant environmental effect
	Economic loss(**N**)	0 – 100,000	100,000 - 1M	1M - 10M	10M – 100M	>100M
	Impact area (m^2)	0 - 10	10 – 100	100 – 1000	1000-10000	>100000

However, none of the pipeline segments had neither medium nor high probability of leaks occurring and could only cause minor injury to personal safety, slight effect on the surrounding environment with economic losses in naira not less than **N**10 Million.

As mentioned earlier, the most forward approach to display the risk distribution and priority for different pipeline segments, the risk matrix is used to classify and determine the risk values associated with different pipeline segments for holes based on the recommended probabilities
value. The levels and results, are shown in Table 8.

The results of the risk analysis as shows that attack on the pipeline segments (KP1, KP6, KP7, and KP8) have a low probability of holes occurring and could cause a minor injury to personal safety, slight effect on the surrounding environment with economic losses in Naira ranging between **N**100, 000 and **N**1 Million as shown in Table 8. The area of impact for the attacks associated with the pipeline segments (KP1, KP6, KP7, and KP8) is within the range 10 to 100 m^2.

However, pipeline segments (KP2, KP3, KP4 and KP5) have medium probability of holes occurring and could cause a major injury to personal safety, minor local effect on the surrounding environment with economic losses in Naira between **N**1 Million and **N**10 Million. The area of impact for the attacks associated with the pipeline segments (KP2, KP3, KP4, and KP5) is within the range 100 to 1000 m^2.

The risk matrix, the most direct method of showing the risk distribution over different sections of the pipeline, is used to classify and assess the importance of the risks associated with different sections of the pipeline for crime according to their recommended values, the level of probability and outcome

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Table 8: Risk Classification at Every Segment for Holes

POF Ranking		**Consequences of Failure (COF)**				
5	>0.1					
4	<0.1					
3	<0.01					
2	<0.001		KP1, KP6, KP7, KP8	KP2, KP3, KP4, KP5		
1	<0.0001					
COF Ranking		**A**	**B**	**C**	**D**	**E**
COF Types	Personal safety	No injury	Minor injury	Major injury	Single fatality	Multiple fatality
	Environment	No pollution	Slight Effect	Minor local effect	Major local effect	Significant environment al effect
	Economic loss(₦)	0 – 100,000	100,000 - 1M	1M - 10M	10M – 100M	>100M
	Impact area (m^2)	0 - 10	10 – 100	100 – 1000	1000-10000	>100000

The results of the risk analysis shows that attacks on the pipeline segments (KP1, KP3, KP4, KP6, KP7, and KP8) have a low probability of rupture occurring and could cause a minor injury to personal safety, slight effect on the surrounding environment with economic losses in Naira between ₦100, 000 and ₦1 Million as shown Table 9. The area of impact of attack for the pipeline segments (KP1, KP3, KP4, KP6, KP7, and KP8) is within the range 10 to 100 m^2. The graphical illustration in Figure 3 indicates the total risk measure in naira at every segment for leaks. From the graph, the second segment (km-2) of the proposed pipeline is poised with the highest risk of leaks at N772, 905/year and the seventh segment (km-7) of the proposed pipeline is poised with the lowest risk at N113,735/year

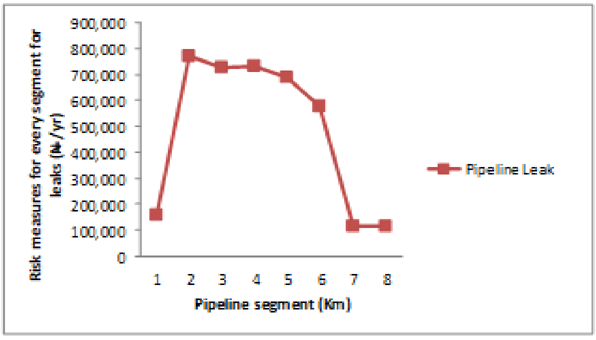

Figure 3: Total Risk Measures in Naira at every segment for Leaks

Similarly, the graphical illustration in Figure 4 indicates Overall measure of the Naira risk of each segment for the holes.

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Table 9: Risk Classification at Every Segment for Ruptures

POF Ranking		Consequences of Failure (COF)				
5	>0.1					
4	<0.1					
3	<0.01					
2	<0.001		KP1, KP6, KP7, KP8	KP2, KP3, KP4, KP5		
1	<0.0001					
COF Ranking		**A**	**B**	**C**	**D**	**E**
COF Types	Personal safety	No injury	Minor injury	Major injury	Single fatality	Multiple fatality
	Environment	No pollution	Slight Effect	Minor local effect	Major local effect	Significant environmental effect
	Economic loss(**N**)	0 – 100,000	100,000 - 1M	1M - 10M	10M – 100M	>100M
	Impact area (m^2)	0 - 10	10 – 100	100 – 1000	1000-10000	>100000

.
From the graph of Figure 4, the second segment (km-2) of the proposed pipeline is poised with the highest risk of leaks at N2,536,070/year and the seventh segment (km-7) of the proposed pipeline is poised with the lowest risk at N173,601 /year.

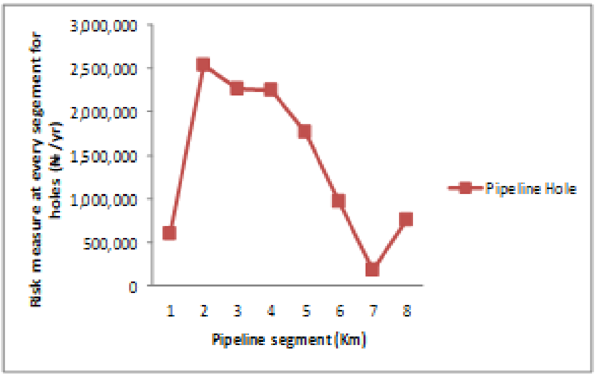

Figure 4 Total Risk Measures in Naira at every segment for Holes

The graphical illustration in Figure 5 indicates Total risk measurement in Naira of each segment for ruptures.

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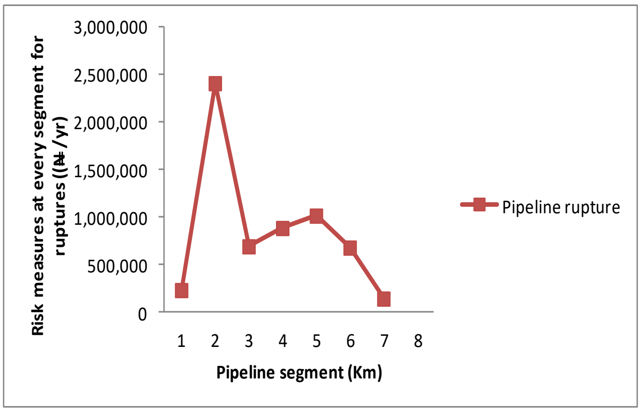

Figure 5 Total Risk Measures in Naira at every segment for Ruptures

The frequency values of various events were analyzed and represented in Figure 6.

From Figure 6, the attack event with the highest frequency and probability of occurrence is mechanical failure & operational failure. Natural hazard has the least risk frequency and probability of occurrence.

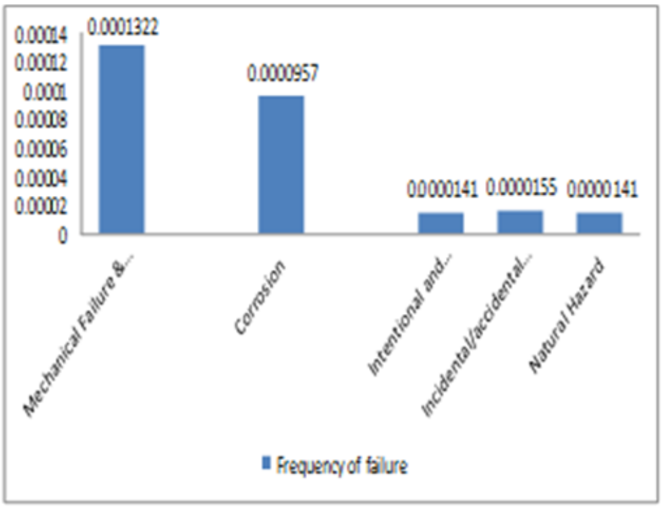

Figure 6 Frequency Values of Various Events

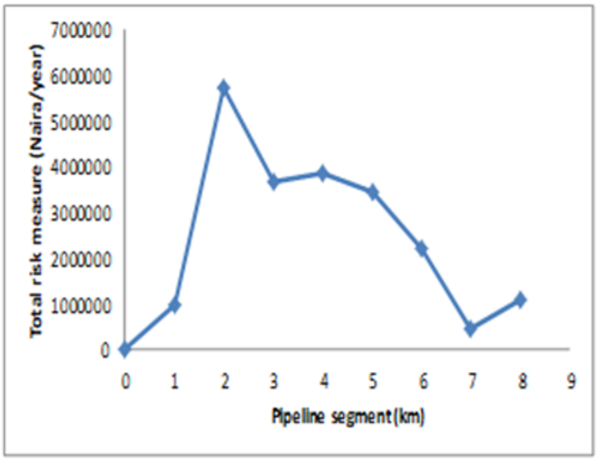

Figure 7 Total Risk Measures in Naira at every segment for Leaks, Holes and Ruptures

From the graph in Figure 7, the second segment (km-2) of the proposed pipeline has the highest risk with N 5,720,670/year and the seventh segment (km-7) of the proposed pipeline has the lowest risk with N 426,589/year. The total risk impact determined for the entire 8km pipeline is N 21,422,146/year.

Analysis of Variance (ANOVA) Result for Total Risk Measure in Naira at every segment for Leaks, Holes and Ruptures

The results for the ANOVA analysis performed using SPSS Computer Software for the total risk measure in Naira at every segment for leaks, holes and ruptures is presented in Table 10, in order to determine whether the risk values for leaks, holes and ruptures are statistically significant or not. The significance level chosen for the ANOVA analysis is 0.05 confidence level. The p-value was used to determine whether the differences between some of the risk values for leaks, holes and ruptures are statistically significant, and if the p-value is less than or equal to the significance level, the null hypothesis that the risk measure in Naira at every segment for leaks, holes and ruptures are not statistically significant, is rejected and this implies that not all of the population values are equal.

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Table 10 ANOVA results for Risk Measure in Naira at Every Segment for Leaks, Holes and Ruptures

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
KP (Km)	9	36	4	7.5
Pipeline Leak (N /yr)	9	3888520	432057.8	1.05E+11
Pipeline Hole (N /yr)	9	11289281	1254365	9.25E+11
Pipeline Ruptur (N /yr)	9	6244345	693816.1	5.43E+11
Total Risk (N /yr)	9	21422146	2380238	3.67E+12

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	3.04E+13	4	7.59E+12	7.236972	0.000175	2.605975
Within Groups	4.2E+13	40	1.05E+12			
Total	7.23E+13	44				

From the result of the ANOVA analysis presented in Table 10, the p-value (0.000175) is less than the significance level (0.05), the null hypothesis that risk measure in Naira at every segment for leaks, holes and ruptures are not statistically significant, is rejected and this implies that the values are statistically significant; hence, the alternate hypothesis is accepted.

4. CONCLUSION

This white paper used a case study to assess the integrity of the pipeline through risk-based inspection in the Niger Delta, Nigeria. A risk analysis model was used to assess pipeline integrity to effectively control pipeline costs for oil and gas companies operating in the Niger Delta region of Nigeria. The first objective of this study was to identify potential hazards and risks associated with crude oil pipelines, and case studies and malfunctions occurring in pipelines in the Niger Delta region, Nigeria, were investigated in a case study, as shown in Table 2, including; Mechanical disturbances, corrosion, operational disturbances, third party activities and natural disasters. Data for the second objectives, which was to analyze different segments of the pipeline with respect to priority of risk impact on the case study, was analyzed using descriptive statistics for risk classification.

Measures to mitigate these risks: errors due to mechanical stress are significant, for example in the Niger Delta (Fig. 6), which improves the coverage and safety of the cathode, creating an effective regulatory and monitoring mechanism for the operation of pipelines in the country. Longer service life polyethylene and multi-layer coating to prevent external corrosion and enforcing effective oil spill detention procedure and framework for risk-based optimization of pipeline integrity maintenance, to arrest the severity of oil spill within the study area.

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