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Asset Integrity Management in Mitigating Oil and Gas Pipeline Vandalism in the Niger Delta Region—Deep Burial Solution

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Abstract

Pipelines, as means of transportation of water and hydrocarbon have been considered "effective, safe and reliable". Over the years, pipeline failures in Niger Delta region of Nigeria have resulted in loss of lives, water pollution, soil contamination, air pollution, destruction of infrastructures and aquatic lives, and other losses. The study area, Niger Delta region is located on Latitude 4˚50'00"N, longitude 6˚00'00"E and comprised of nine coastal states of Nigeria (about 70,000 km^2). Failure data were collected using: Questionnaires administered to experienced pipeline engineers in the International oil and gas companies (IOCs), Personnel interviews, and reports from the Department of Petroleum Resources, Nigerian National Petroleum Corporation (NNPC). This study assessed the strategies employed by four IOCs to mitigate pipeline failures in the process of asset integrity management. Design and construction methods detailing pipelines laying to infiltration discouraging-depth were studied. The results obtained showed that vandalism is presently the major cause of pipeline failures. Deep burial solution was therefore explored as a vandalism mitigation approach and its cost of implementation for a typical Φ20" × 15 km trunkline in the region showed 9.627% (≈809.3 million Naira) rise compared to the normal burial option, and this difference accrued mainly from equipment and personnel cost. This is a paltry sum compared to the huge losses due to vandalism. Finally, this study posits that the available regulatory framework is now inadequate for pipeline design, construction, and operations due to this challenge and requires urgent amendment in favour of deep burial option.

Keywords

Pipeline Integrity, Integrity Management, Pipelines Vandalism, Pipeline Risk

Analysis

1. Introduction

Describing the important function of pipelines, Kishawy & Gabbar [1] likened it to that of a human blood vessel and said: "Pipelines function as blood vessels serving to bring life-necessities such as water or natural gas and to take away life waste like sewage". "And they are considered to be the most favored mode of transportation of gas/liquid in large quantities". Most Nigerians and indeed other people of the world use oil and gas every day. These energy sources are often concentrated in areas other than where they would be needed. Pipelines transport hydrocarbons over long distances, from producing wells and regions to export terminals, refineries, and fuel depot. This means of transporting petroleum products comes with its risk and challenges. Pipelines fail in operation because of defects such as cracks, corrosions, dents, punctures, etc.; leading to damage and leaks on the pipeline resulting to huge downtime, cost, and environmental hazards. These problems have huge environmental, economic, health and safety implications on the pipeline operators and host communities alike. The operating condition determines the design of the pipeline system. According to Gabbar & Kishawy [2], the system to be put in place depends on whether the pipeline would be subjected to high pressure/high temperature or low pressure/low temperature in operation.

Tragic onshore and offshore accidents attributed to pipeline failures are major concerns for operators, regulators, and the public [3]. These incidents have huge environmental, economic, safety, and security implications. These pipeline incidents translate to huge economic loss and massive environmental pollution. On many occasions they have resulted in loss of lives for workers and host communities with over 2500 lives lost in a period of 10 years [4]. Oil companies need to carryout proper hazard identification of the operation they perform whether these are man-made or natural, and manage their risks using appropriate technology to ensure safe working practices. Ipingbemi [5], stated that oil spill which has occurred in several areas of the Niger Delta has impacted negatively on both the soil pH value of and hydrocarbon content of water, the consequence of which is the migration of people to other areas for greener pasture. Ugochukwu *et al.* [6] discussed the various impacts that oil production has had on the biodiversity of the Niger Delta. Okolo & Etekpe [7], reiterated that the discovery of oil in the Niger Delta in 1956 did not and has not ushered in the needed sustainable development in the region.

One of the biggest problems facing the pipeline industry is the fact that the world's pipeline infrastructure is ageing. According to Achebe *et al.* [8], 41% of Nigeria's pipeline network is more than 30 years old. The widespread of pipelines combined with their multifarious range of operations, sizes, materials, age, and environmental effects contribute to the hazards associated with the pipeline industry. Often, these cumulative hazards make oil and gas pipeline safety a very complex process. It therefore is necessary to perform root cause failure analyses of these pipelines whenever they occur to save cost, life and environment.

2. Methodology

Failure data were collected using: 1) structured Questionnaires administered to experienced pipeline engineers in the International oil and gas companies (IOCs), 2) personnel interviews, and 3) reports from the Department of Petroleum Resources, Nigerian National Petroleum Corporation (NNPC). This study assessed the strategies employed by four IOCs to mitigate pipeline failures in the process of asset integrity management. The design and construction methods detailing pipelines laying for pipeline burial depths in the swamp/creek operations with a view to proposing a most acceptable method that will curb and/or ameliorate the most prevalent pipeline failure.

3. Results

3.1. Pipeline Failures and Vandalism

Figure 1 shows the frequency (number) and causes of pipeline failures from 2014 to 2018. It shows that vandalism remains the major cause of spill. From this Figure 1, 2014 witnessed the highest incidents of vandalism, followed by 2015, 2018, 2017, and 2016 (in that order). There was a decline from 2015 to 2016 due to increased security surveillance and reactive attention. From the results obtained, spills attributed to vandalism were 65.1%, 63.0%, 44.0%, 52.4%, and 46.2% of total spill for 2014, 2015, 2016, 2017, and 2018, respectively. The data for causes of spill from 2010 to 2013 are not available.

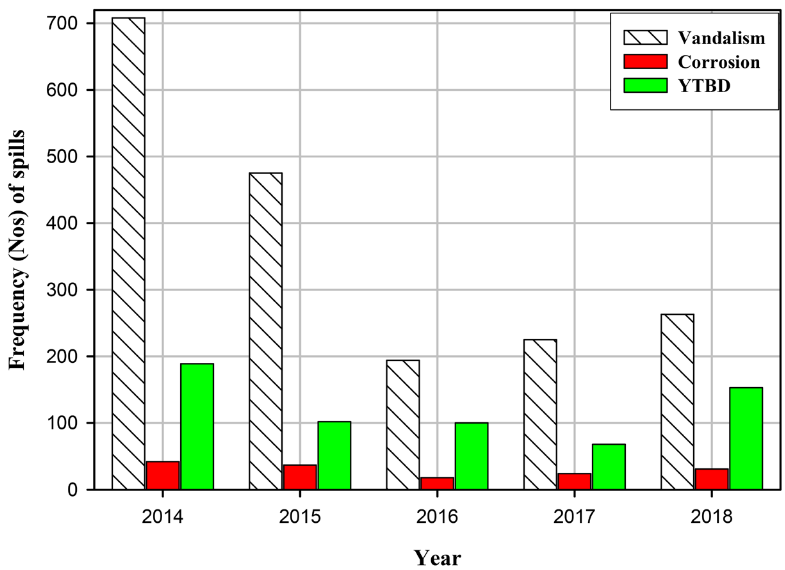

Figure 1. Failures due to Vandalism, Corrosion and Yet-to-be-determined (YTBD) factors.

After 2016, there has been a steady but gradual increase in vandalism incidents, which has not abated till date. Expectedly, this **Figure 1** showed that corrosion related failures remained flat (constant), which to a reasonable extent is a testimony to the effectiveness of the integrity management systems in IOCs surveyed. **Figure 1** also shows that a major number of failures were attributed to "Yet-to-be-determined (YTBD)" factors. The reports also showed that spills attributed to Yet-to-be-determined (YTBD) factors were 17.3%, 13.5%, 23.0%, 15.85%, and 26.88% for 2014, 2015, 2016, 2017, and 2018 respectively. Experience shows that these YTBD factors are disputed vandalism issues. The spill inspectors probably could not agree to attribute them to vandalism. There is therefore a need for policy paradigm shift to accommodate vandalism as a major pipeline integrity problem in Nigeria.

Figure 2 highlights the effect of other causes of pipeline failures (Equipment, Human factor, Natural accidents, and operations/maintenance failures). Failure due to factors that could be regarded as internal to the pipeline operating companies is high in comparison with failure due to natural accidents. This means that the pipeline operating companies must continue to ensure the diligent implementation of their pipeline integrity management systems, as well as invest in technological/instrumentation improvements.

From **Figure 3** and **Figure 4**, year 2015 witnessed the most expensive annual spillage cost, followed by 2014, 2018, 2017 and 2016 (in that order). However, these costs and hence volume represented 65.1%, 63.0%, 44.0%, 52.4% and 46.2% of the annual spill cost for 2014, 2015, 2016, 2017 and 2018, respectively.

From **Figure 5**, it can be observed that the spill frequency progressively increased (unabated) from 2010 to a crescendo in 2014 without the IOC or the joint venture partners classifying the immediate or remote causes of pipeline failures.

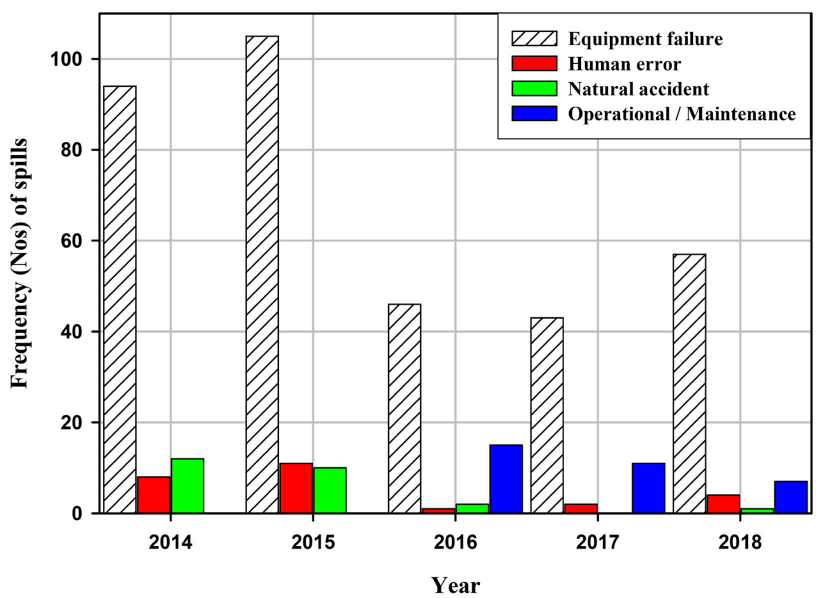

Figure 2. Failures due to Equipment Failure, Human Factor, Natural Accident and Operation/Maintenance.

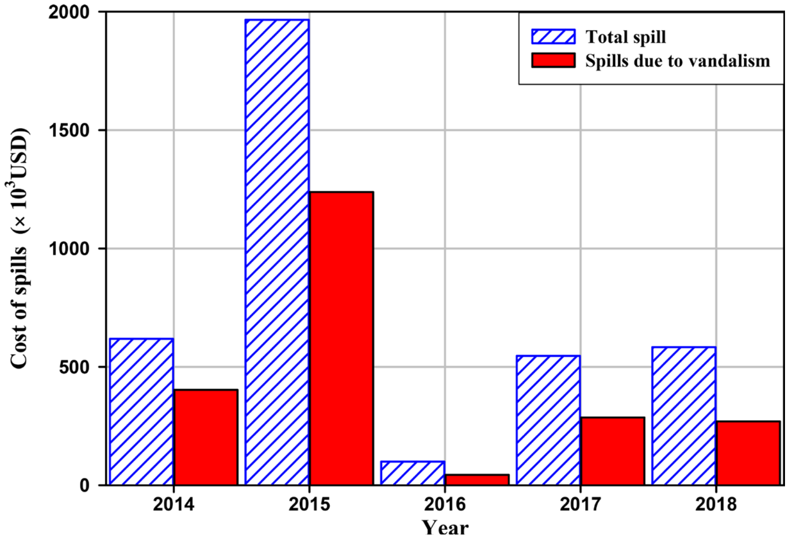

Figure 3. Total cost of spillage with cost of spillage due to vandalism.

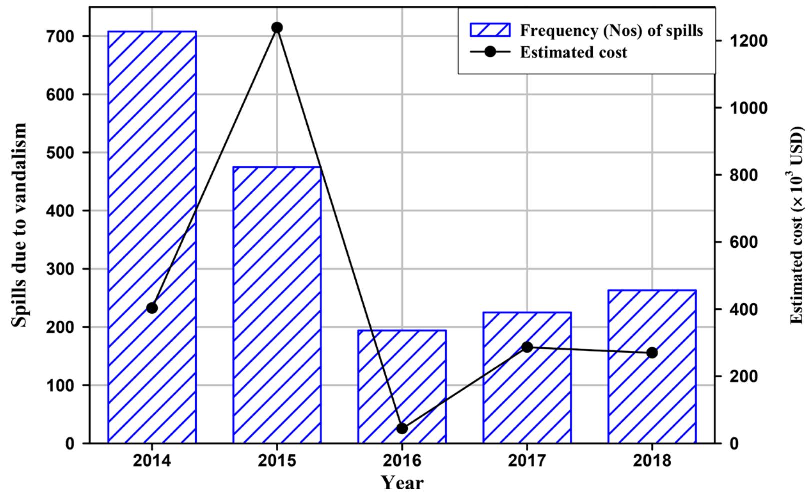

Figure 4. Estimated Cost and frequency of spills due to Vandalism.

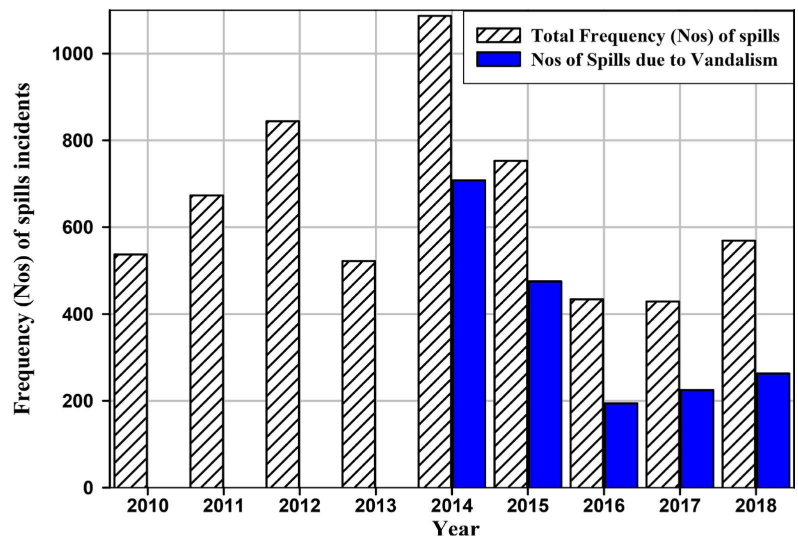

Figure 5. Total number of oil spill incidents and No of spill incidents due to vandalism.

Little attention was paid to root cause analyses of pipeline failures before 2014. It is obvious that the issue of vandalism had been ongoing being reported in the pre-2014 period. Attempts to nip the trend in the bud in 2013 were resisted by a fight back which shot the peak frequency of 1087 in 2014.

From **Figure 6**, it can be observed that though 2014 witnessed the worst spill frequency (1087) its volumetric loss and hence cost was actually low (10,302.16 barrels). The worst spill loss was however recorded in 2011 with a frequency of 673 but a total spill loss of 66,906.84 barrels. The best spill scenario of frequency 434 and spill volume 1658.98 barrels was recorded in 2016 due to improved surveillance and technology.

The following evidence/incidents among others corroborate the results of **Figures 1-6**. Over the years there has been notable occurrence of pipeline failures/incidents around the world and in Nigeria which has led to oil/gas leakages and spills. Kadafa [9], quoting the Punch newspaper of February 2012 reported thus: "a total of 2796 oil spill incidences were recorded between the periods of 1976-1990 leading to 2,105,393 barrels of oil spilled". Kadafa [9] further reported that: "The UNDP [10] report stated that there was a total of 6817 oil spills between 1976 and 2001, leading to 3 million barrels of oil lost". Spills that occur in areas that are populated often have huge environmental impacts as they spread out over vast area, destroying aquatic life and agricultural products that are valuable to man for his survival. Umar *et al.* [11] lamented the frequent attacks by Niger Delta militants on oil and gas pipelines, describing it as worrisome, "due to its devastating effects on the environment". They stressed that: "Factors such as poor management, poor governance, weak legal system, and environmental degradation are among factors that encourage crude pipeline vandalism in the Niger Delta".

Babatunde [12], stated that "Oil exploration and pollution harms water resources and fuels conflict in the Niger Delta region". Weli [13] sought the support of all

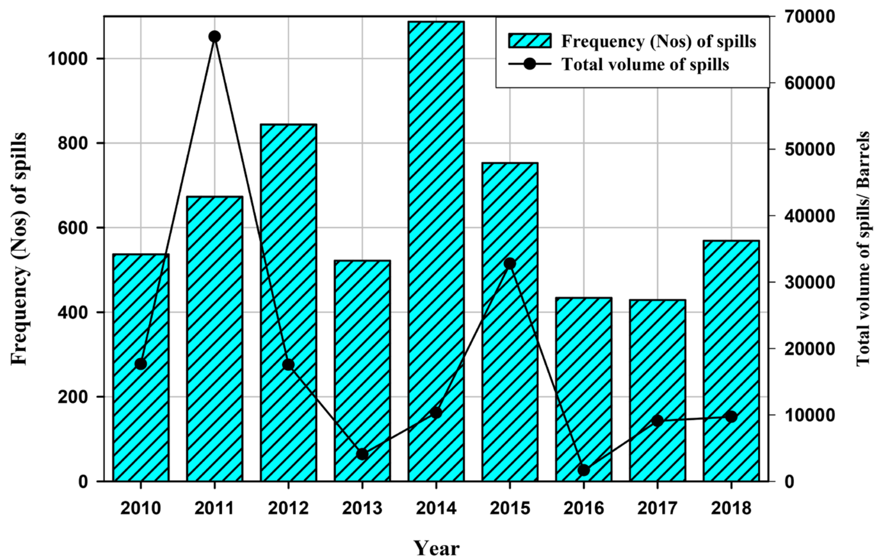

Figure 6. Volume of oil spillage and frequency of spill.

stakeholders to curb pipeline vandalism, informing that "Since 2017, sabotage spill rate has risen steeply and crude oil theft from Shell Petroleum Development Company of Nigeria (SPDC) Joint Ventures pipeline network averaged 11,000 barrels per day in 2018, an increase of about 20% over previous year. Ofualagba & Ejodomi [14] informed that: "Between 2010 and 2012, about 2787 line breaks were reported on pipelines belonging to the Nigerian National Petroleum Corporation (NNPC) resulting in loss of 157.81 metric tons of petroleum products worth about 12.53 billion Naira".

1) According to the 2013 annual report of Nigeria Extractive Industry Transparency Initiative (NEITI), Nigeria lost $10.9 billion to oil theft from 2009 to 2011 [15].

2) The Nigerian National Petroleum Corporation (NNPC) reported in June 2019 that 106 points were vandalized in its network of pipelines, representing a 79% rise in cases of pipeline vandalism over the figure for May of the same year (60 points).

3) In June 2020, for example, Shell Petroleum Development Company of Nigeria (SPDC) [16] reported 17 vandalized points on some of its pipelines, namely:

a) 28" Bomu-Bonny pipeline at Owokiri—1 point;

b) 14" Okodia-Rumuekpe pipeline at Edeoha—5 points;

c) 28" Nkpoku-Bomu pipeline at Ula-Ikata—1 point;

d) 20" Kolocreek-Rumuekpe pipeline at Odau—2 points;

e) 12" Imo river-Ogale pipeline at Umuololo—5 points;

f) 36" Nkpoku-Ogale at Rumukrusi—1 point.

4) Obaseki [17], confirmed that NNPC reported that Nigeria in 2019 recorded a loss of 22.64 million barrels of crude oil valued at $1.35 billion for the half year and $2.7 billion for the full year at $60.0 per barrel. According to Obaseki [17], the Nembe-Cawthone Channel Trunkline (NCTL) suffered the most vandalism attack during this period. The following pipelines suffered debilitating vandalisms in the period:

a) Nembe-Cathone Channel Trunkline (NCTL)—9.2 million barrels;

b) Trans Niger Pipeline (TNP) —8.6 million barrels;

c) Trans Forcados Pipeline (TFP)—3.96 million barrels;

d) Trans Excravos Pipeline (TEP)—877,000 barrels.

The above examples represent a fraction of the economic and health hazard suffered by Nigeria on a continuous basis yearly, derived from pipeline attacks. These attacks occur on pipelines carrying crude as well as those transporting refined products for everyday use. These product pipeline vandalism has resulted to several explosions in the past, leading to preventable loss of lives and environmental degradation. The following incident reports [18] are worth mentioning.

a) 2020 pipeline explosion at Soba area of satellite town Lagos;

b) January 19, 2020 Abule-Egba pipeline explosion, Lagos;

c) August 30, 2019 Abura crude line at Otu-Jeremi, Ugheli, Delta State;

d) October 12, 2018—Umueze community of Abia State;

e) June 09, 2016—Sanoni creek, Ogidigben Warri, Delta State;

f) May 18, 2014 NNPC jetty at Okrika, Rivers State;

g) January 12, 2013 At Arepo, Ogun State.

Olisah [19] reported an account by NNPC General Manager public affairs that vandalism of its pipeline network across the country rose by a phenomenal spike of 50%. Furthermore, Olalekan [20] reported that at the 2019 Nigeria Extractive Industry and Transparency Initiative (NEITI) inaugural dialogue in which NNPC claimed that between 2001 and 2019, an 18-year period, about 45,347 vandalism incidents were recorded on its pipeline network. Okoli & Orinya [21] claimed that "vandalism mostly take place in poor courtiers because international oil companies often fail to bury or protect their pipelines as they would have to by law in rich countries". "The easily accessible pipes which often run through slums and informal settlements are tempting to desperately poor communities". They recommended stringent penalties for perpetrators as well as adequate protection and surveillance.

The fast-changing nature of problem and the increasing sophistication of pipeline vandals have necessitated the application of measure that will not only discourage pipeline vandalism but can lead to its long-term elimination. The need to stamp out pipeline vandalism can therefore not be over emphasized. It is imperative to do this both for the economic, quality, health, safety, and environmental wellbeing of Nigeria. The deep burial concept is hereby proposed as a technical approach to eliminate pipeline vandalism.

3.2. Deep Burial Solution

3.2.1. Philosophy

The deep burial concept is the burial of welded pipeline into the ground deeper than the minimal acceptable standard of 1 m below ground surface level. This concept can only be achieved in swamp locations as the constructed pipe will be buried at minimum depth of 4.5 m with a cover of 1 m above the buried pipe using part of the excavated material and concrete slab. The remaining 3 m of the ditch depth will be filled with water thereby creating a navigable water way that will be used by both commercial, company and private boats. The combination of the pipeline depth and the navigability of the right-of-way (ROW) make it difficult for vandals to access the constructed pipe since it will be deeper than normal, the pipeline will no longer be remote, and security can easily access any point the vandals will be trying to carry out their nefarious act. Accessing the deep buried pipe by vandals will require mobilization of expensive construction and diving equipment. It is not an activity that can be done in few hours that government security will not be able to know and intervene since the ROW is now navigable by boats.

3.2.2. Design

The ditch design will be 4.5 m depth by 10 m width at the top while the ditch bottom width will be 6 m. The design of 4.5 m depth is a minimum and a decision of equipment availability, considering the minimum allowable depth that can be achieved after 1 m cover. The length of the boat propellers was also put into consideration. The ditch is slanted to give stability to the ditch to avoid collapse, for easy navigation with boats, tugboats, and lay barge.

3.2.3. Construction

A step-by-step process for deep burial method of pipeline construction is shown in Figure 7. The critical path in the deep burial construction process is the ditch excavation. Excavation follows the sequence in the flowchart in Figure 8 in other to achieve the designed profile. After the initial excavation, expansion of the ditch (ROW) was done to a width and depth of 10 m and 3 m, and finally to 4.5 m depth respectively. All the swamp-buggies involved in the operation were

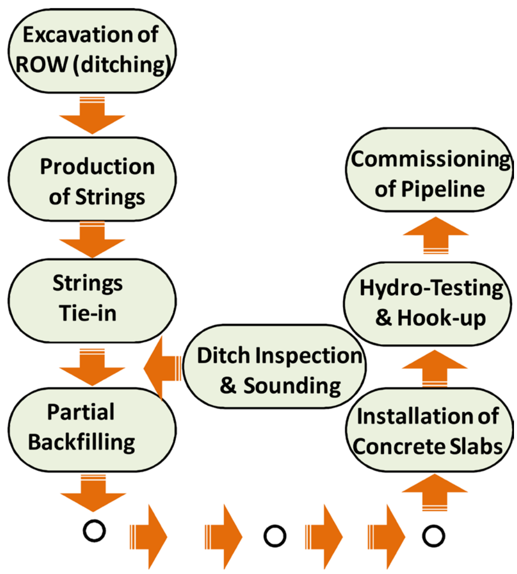

Figure 7. Pipeline deep burial construction flowchart.

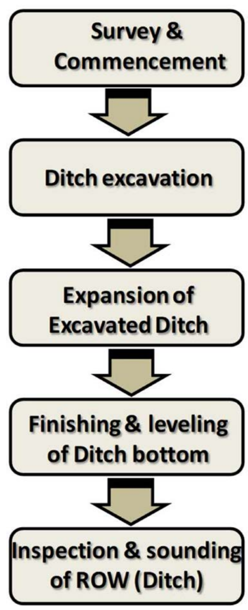

Figure 8. Ditching (Right-of-Way) excavation operation process.

positioned 2.5 m away from the edge of the excavation and on one side of the ditch. The ditch is kept full of water to provide additional support to the trench sides against collapse. The material excavated from the ditch were stacked on one side of the ROW at a 6.5 m distance away from the sides of the ditch to prevent liquefied materials from running back into the ditch and where possible to allow machine access along the pipeline ROW.

The ditch expansion/widening and finishing and leveling of ditch bottom (Figure 9) was followed by both longitudinal and cross echo-sounding of the completed trench to accurately determine the depth and width of the trench-bottom respectively.

As shown in Figure 9, on completion of rough ditching the long boom excavator is further deployed to level and smoothen the ditch to the designed profile of 10 m wide at the top, 6 m wide at the ditch bottom and to a depth of 4.5 m.

Ditch depth will be confirmed by the installation of timber tide-gauges marked with numbered graduations corresponding to the graduations marked on the dipper-arm of the excavators. The survey team will set these gauges to correspond to the design ditch depth. Following the completion of a trench segment, the survey team will manually probe the depth to provide fairly accurate estimates of achieved depth. This will be followed by both longitudinal and cross echo sounding of the completed trench to accurately determine the depth and width of the trench-bottom, respectively.

3.2.4. Comparative Cost of Pipeline Normal and Deep Burial Solutions

The summary of the cost for deep burial and normal burial construction methods for a typical 20" × 15 km pipeline project in the Niger Delta region is presented in Table 1.

For apple-to-apple construction cost comparison, deep burial is about 9.6% higher than normal shallow burial, translating to about 809.3 million Naira. If an additional cost of 1 billion Naira is incurred to construct a pipeline with a lifespan of about 25 years in other to save a possible loss of 27 billion dollars annually,

Figure 9. Finishing/leveling of ditch bottom (Source: NESTOIL [22]).

Table 1. Trunkline construction cost for 20" × 15 km pipeline using Deep burial and Normal burial.

S/Nos	Item Description	Amount (Naira)	
		Normal burial	Deep burial
1	Allow for provisional sum for engineering works	280,000,000.00	280,000,000.00
2	Procurement (20" × 15 km CWC coated pipes)	4,128,000,000.00	4,128,000,000.00
3	Personnel	244,255,947.38	290,807,344.30
4	Equipment	2,372,601,800.00	3,135,344,800.00
5	Welders and fitters cost per joint for 15 km	131,040,000.00	131,040,000.00
6	Allow for provisional sum for community stipend	135,000,000.00	135,000,000.00
7	Allow proviisional sum for NDT	126,000,000.00	126,000,000.00
8	Allow provisional sum for HYDRO-TEST	120,257,061.30	120,257,061.30
9	Allow provional sum for Tie-in	60,008,569.71	60,008,569.71
	Total (Naira)	**7,597,163,378.39**	**8,406,457,775.31**

this additional cost becomes insignificant, hence our recommendation for its adoption.

3.3. Re-Engineering the Pipeline Burial Policy Framework

The burial depth of pipelines as contained in Department of Petroleum Resources (DPR) [23] guidelines: (Guidelines and procedures for Construction, Operation and Management of Oil and Gas pipelines) issued pursuant section 31 of the oil pipeline act CAP 338 of the law of Nigeria 1990, ranges between 1.0 m to 2.0 m for all terrains.

Present day realities clearly show that this policy is no longer adequate to address the major area of pipeline failure currently. It becomes imperative that further policy framework backed-up by legislation is required, especially to address the issue of pipeline vandalism.

1) The minimum soil cover should be increased to 4.5m; the pipeline should be buried to a minimum depth of 4.5m below ground level. Besides, the designed lifespan of every installed pipeline must be strictly respected, and replacement planned.

2) Modify policy to remove the requirement for block valves installation on the upstream side of major river crossings and pump stations, as these have become the easiest access point for the pipeline vandals and economic saboteurs.

If local companies indigenous to the area of operation are empowered to invest in and operate the pipelines, it will enhance the economic wellbeing of people of the area by also creating more employment opportunities. It will also give these indigenes greater responsibility to ensure that their source of income and livelihood is protected.

4. Conclusion

The negative impacts of pipeline failures are enormous. It results in fire disasters, which destroy cash crops which could have been harvested and sold for income. Oil companies in Nigeria need to comply with internationally accepted standards. Standards relevant to pipeline integrity and management, such as: the API standards for High Consequence Areas which requires more hazard analysis and risk assessment, and the API guideline standards for Area Susceptible to damage from third parties (vandalism, terror attack, illegal bunkering, theft, etc.) are prime examples of standards to follow to improve safety and environmental standards. The human, cultural and operational factors that affect effective safety management system in the Nigeria pipeline industries should be approached in the right way with the help of Nigerian government because it would be a waste of resources if not done in an organized and effective way. The Nigerian government needs to explicitly tackle these threats by implementing corrective procedures and measure performance against clearly identifiable standards. In Nigeria, most of our pipelines are buried, and continue to be buried at depths detrimental to the achievement of the pipeline objectives. It is therefore imperative that existing policy frameworks should be reviewed, and a comprehensive regulatory framework with effective enforcement and monitoring systems that can help to maintain proper safety management systems should be introduced and implemented to curb the vandalism incidents and associated pipeline failures.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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