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Application of Geographical Information Systems to Oil and Gas Assets Management in Nigeria

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ABSTRACT: Over the decades, the petroleum industry has relied on traditional practices and procedures in the management of pipeline oil and gas assets. This has had some consequences in terms of pipeline and storage facility planning and mapping. Multiple hurdles, such as natural disasters, equipment malfunctions, vandalism, data processing, and human mistakes, could not be avoided because Conventional means were unable to generate survey maps and plans necessary for "real time" applications. Geographic Information System (GIS) technology is being introduced into the petroleum industry has led to a fast modifications and enhancements in the energy sector of the economy' activities in terms of evaluation, exploration, production, and product transmission from the depots to customers. In this study, digital maps of petroleum depots, oil and gas pipelines, and other relevant features such as Temperature, soil types, vegetation, and terrain were created. Pipeline attributes such as pipeline coating, thickness, diameter, maintenance information and date of installation were used to create a relational database model. Queries operations on the database displays the essential information, such as the next date of pipe maintenance, sabotage-prone areas, locations with specific pipe diameters. Other maps produced include the Temperature, soil, elevation and rainfall maps were produced to determine how they will affect the location of the pipelines to aid decision making. The study recommended that oil and gas companies implement GIS for accurate and effective asset management.

KEYWORDS: Assets management, GIS, oil and gas, Nigeria, gas pipeline network

I. INTRODUCTION

Nigeria is rich in natural resources, the most important of which are petroleum resources. The country is Africa's largest oil producer and one of the 10 biggest oil producing nations (Olokesusi, 2005). In 2004, the oil and gas industry contribute to approximately 80% of total government income, 90-95 percent of export revenues, and more than 90% of foreign exchange revenues (Aluko, 2004). The problems associated with oil and gas asset management are common in most oil-producing countries around the world, and Nigeria is no exception. Moreover, the transmission of petroleum products is flawed with abnormalities, resulting in petroleum product downtimes, absurdly high product prices, and disagreements over product fuel prices. The Niger Delta area, which is currently defined by the political boundaries of nine states: Akwa-Ibom, Ondo, Abia,Cross-River, Imo Bayelsa, Delta, Edo and Rivers, produces the majority of the oil and gas. Nigeria's oil and gas operations include assets and infrastructure that encompass the country, creating a network connecting the country's 22 petroleum storage depots. The four refineries are located in Warri, Kaduna and Port-Harcourt (I & II) as well as off-shore terminals in Escravos and Bonny, and jelties in Okirika, Alas Cove, Calabar, and Warri (Onuoha, 2007). These developments frequently necessitate the reclamation or dredging of a significant portion of the wetland. Oil and gas production has had a significant impact on the environment on approximately 1,500 settlements in

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the Niger Delta region where oil venture partners of the Nigerian National Petroleum Corporation (NNPC) operate.

Petroleum pipelines network in Nigeria run the entire length of the country's geopolitical zones, from rain forest and swamp forest to savannah grasslands, and are subjected to a variety of soil and climatic conditions, with varying ramifications such as seepages and leakages of petroleum products, which are harmful to Environment and towns and cities (Agbazie, 2004; Ekwo, 2011). Pipelines for oil and gas are pivotal to the economy of Nigeria according to Nnah and Owei (2005). The petroleum pipeline is a crucial method of transport and also a highly technical infrastructure. Nigeria currently has a petroleum pipeline network that spans over 7,000 kilometers (Agbazie, 2004; Nigerian National Petroleum Cooperation, 2002).

Natural disasters caused by earth movement, fire, and flood, as well as the ignoring oil and gas producing areas, are other sources of concern in oil spillage. It is difficult to prevent such events if the placement of the infrastructure is not understood ahead of time. GIS and spatial analysis can aid in predicting where these attacks will happen in the future. This makes a significant contribution to fewer potential attacks as well as better performance in responsiveness when theft or an attacks occurs. The aim of this paper is to propose a GIS pipelines geodatabase and toanalyse the locations of pipelinesto aid decision making and mitigation of environmental hazards like oil spillage and pipelines vandalism. If implemented, the system will aid oil and gas companies in reducing pipeline system crash and loss and responding quickly if any occur through selecting the best location to lay different types of pipelines.

1.1 OIL AND GAS ASSETS

Critical Petroleum Assets, like the high-pressure pipelines and deports, are critical to the global supply of volatile products (Hopkins, 2008). Operators must assert the integrity of their assets while also assessing and reducing risk in a setting that effectively addresses stakeholder interests, such as those involved in and directly impacted by the asset's construction and operation (Metcalfe and S. Sastrowardoyo, 2013; Hopkins, 2008; BSI Standards Publication, 2013). The total capacity of the Refineries is 445,000. A "pipeline system" includes booster stations, pumps, mainline pipes, Compressor and other transmission system facilities.

The Nigerian National Petroleum Company's pipelines are an example of a CPA with difficult socioeconomic and political issues affecting the pipeline's integrity andsafety. The issue of interdiction and sabotage is at the heart of this problem (Anifowose, 2012; Ambituuni, 2015). For example, in 2011, NNPC identified a total of 2,787 line breakdowns, 2,768 of which were resulted by interceptors and 19 by component deterioration. Researches like (e.g., Ambituuni, 2016; Omodanisi, Eludoyin, and Salami, 2014) exemplifies the dynamic causal aspects of such pipeline infiltrations, such as theft by well-equipped actors and intentional sabotage as a result of Nigerian mineral and petroleum politics. Ogwu (2012) acknowledged that these causes had been confronted by local community and were associated to the surface visibility of the pipelines.

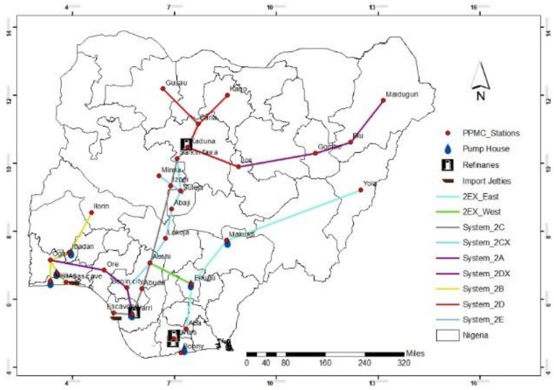

Figure 1: Nigerian map with pipeline system and oil and gas storage facilities
Adapted from: NNPC, 2021

1.2 PETROLEUM PIPELINES ACCIDENTS IN NIGERIA

Indeed, we have seen a number of pipeline failures linked to sociotechnical shortcomings, insinuating a fault in social and technical integration. The December 26th, 2006 pipeline blast in Ilado-Odo, Nigeria, which burned to death more than 250 people, was faulted on a pipeline breakage and blast caused by material irregularities and woefully inadequate disaster response (Omodanisi, Eludoyin, and Salami, 2014). Similarly, on October 15, 1998, a pipeline rupture and blast in the Jesse neighborhood resulted in widespread pollution and the deaths of more than 1,500 persons (Emeseh, 2006).The question then becomes, how can pipeline prone to failure and their possible repercussions implications be identified and mapped out to notify managerial practice with actionable actions using a geographical information system? As a result, the study's goal is to identify and map Critical Petroleum Assets (CPA) in Nigeria, such as high-pressure pipelines and deports, pipeline networks, and failure hotspots and frequency, and to create a geodatabase of the critical petroleum assets.

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1.3 GIS IN OIL AND GAS ASSETS MANAGEMENT

In the progression of infrastructure information, the Geographical Information System (GIS) can provide a general geospatial blueprint. GIS combines computer technology and geographic data from space (San and Suzen, 2005). Application of a gas pipeline GIS can significantly affect the efficiency and operational performance of pipeline network information management, resulting in more operational strategies and decision - making process, quality performance for users, and the ability for the venture to grow.The geographical information system (GIS) for the gas network is becoming a driving force behind the development of all big oil companies to achieve scientific management. Thermal imaging, according to Roper and Dutta (2005), is impactful for pipeline tracking because it can Pipelines can be recognized at night due to thermal conduction among pipelines and the ground. As a result, this application makes use of the GIS system to collect all necessary details on oil pipelines, as well as other valuable information, in order to display the following:

i. A map of the petroleum pipelines and transmission system, along with submersible pumps and equipment, with all essential information.

ii. Data on the quantity of oil and gas stored in each storage facility across the country.

iii. A map depicting the location and network of pipeline equipment as well as various flow stations.

iv. Relevant data on oil and gas network pipelines, such as category, dimensions, depth, construction contract number, installation date, road surface, and so on.

II. STUDY AREA

Nigeria is located in Western Africa, between longitudes 3 and 14 degrees and latitudes 4 and 14 degrees. It covers 923,768 square kilometers of land. Nigeria has a multi-cultural geography, with condition from drylands to humid equatorial. Its most diversified feature, however, is its people. Among the multitude of languages and dialects are Hausa, Yoruba,Tiv, Edo, Igbo,Ibibio, Fula and English.The country is rich in natural resources, exceptionally large deposits of oil and natural gas. The nation's 800 kilometers of shoreline endows it with maritime power potential. Nigeria has an abundance of land for farming, industrial production, and commercial activities. Nigeria is bordered by Benin Republic to the west Niger Republic to the north, Cameroon and Chad to the east and the Atlantic Ocean's Gulf of Guinea to the south. Nigeria is not only the largest country in Africa, but it is also the most populous(Ajayi, et al., 2022).

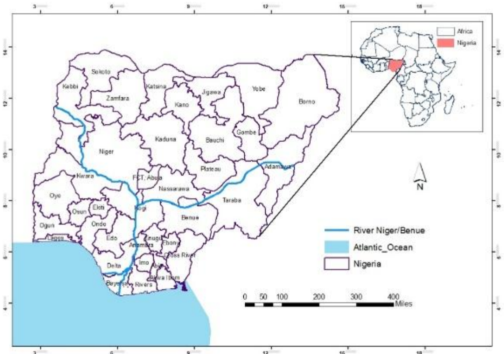

Figure 2: Map of Nigeria

Source: Adopted from Administrative Map of Nigeria, 2022

III. METHODOLOGY

3.1. Data Creation and Conversion

Data for this study was obtained from the PPMC (Pipeline Product Marketing Company of Nigeria), the NNPC (Nigeria National Petroleum Company), the PPPRA (Petroleum Products, Pricing Regulatory Agency), the NEITI (Nigeria Extractive Industry Transparency Initiative), and extensive Web searches.

3.2 Types of data needed

The table below comprises of the relevant data needed to carry to carry out the research

Table 1: Type and sources of data

SN	TYPE OF DATA	SOURCE
1	Pipelines Data	PPMC
2	Pipelines Vandalism data	Nigeria National Petroleum Company (NNPC)
3	Rainfall and Temperature data	Nigerian Metrological Agency (NIMET)
4	Elevation	United states Geological Survey
5	Soil typei.e.Digital soil map of the world	Food and Agricultural Organization of the United Nations (FAO)
	Water bodies & water lines	http://www.diva-gis.org/Data

Source: Author's, 2022

3.3The oil and gas assets data model

Methods for storing geospatial data A geographic information system's data is classified

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into two types: geographic data and attribute data. Spatial data describe the spatial position of the target, geometric shapes, and the spatial relations of other objects, such as a dot, line, or face. Numbers, pipeline material, names, diameter, length, and other data with no direct relationship to space position are examples of attribute data. Attribute and spatial data are inextricably linked and cannot be separated (Xiaoling, 1999). The data in the pipeline network is classified into two types: terrain map data and pipeline data, with each type further subdivided into graphic data and attribute data. As a result, in order to meet the system's function requirements, we must organize data logically.

3.4 procedure for map production

The Procedure for the map production involves digitizing the map obtained from PPRA and inputting the attributes of the various oil and gas critical assets to create a geodatabase. These attributes include coating type, Diameter, Depth of the pipeline in the soil, thickness and date of maintenance. Geometric Rectification was also carried out to make sure the facilities are in their true position. The pipelines were also over layer upon the soil, elevation, temperature and rainfall map to create the thematic maps.

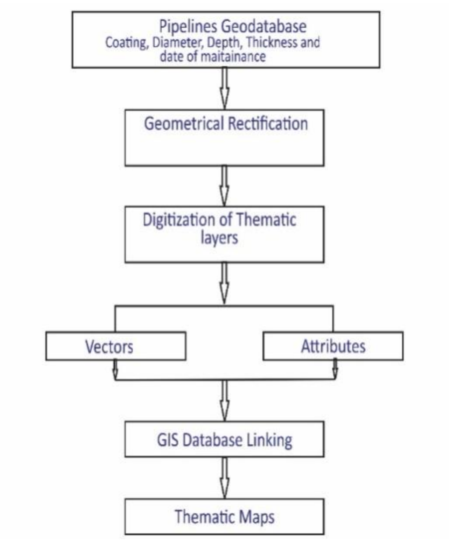

Figure 3: Procedures for map production
Source: Author's Analysis, 2021

There are three methods for integrating spatial and attribute data in general. The first is that attribute data is included in spatial data; the second is that attribute data or rather spatial data is viewed as a whole; and the third is that attribute data and spatial data are only organized. The advantages of this approach include the capabilities for spatial data and attribute data to handle their corresponding objects, which can create conflict between spatial data and attribute data, particularly during updating. Because of the massive amounts of data in the pipelines system, the third method is used. Map files store spatial data, whereas relational databases store attribute information.

IV. PRESENTATION OF RESULT AND ANALYSIS

4.1 Pipelines Geodatabase

After digitizing the pipelines individually, they were merged using Merge tool in geoprocessing in order to create a single shapefile that could be used to create the database. To facilitate data entry and analysis, attributes were categorized and keyed. Columns were also added to the attribute table to the merged shapefiles for the attributes of the respective pipelines to be entered against each pipeline. The columns are Depth, Diameter, Coating, Thickness and Maintenance date.

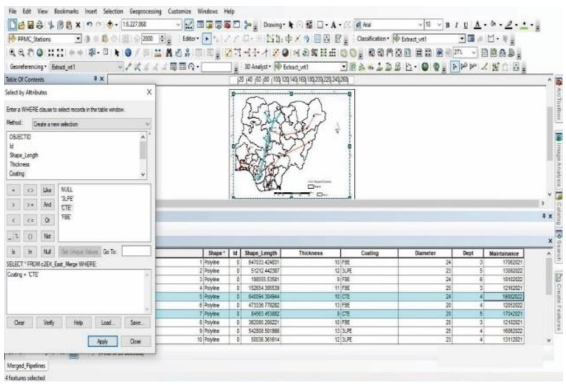

Figure 4: Geodatabase Query operation
Source: Author's Analysis, 2021

The above picture shows a query carried out of the coating characteristics of the pipelines. The database contains three types of coating, namely; Fusion bonded Epoxy (BPE), Three Layer Poly Ethylene (3LPE) and Coating Tar Enamel (CTE) coating. From the above, we can see that only four pipelines routes have CTE coating. In addition, in case of emergencies like oil spillage, the maintenance team can know in advance what type of materials.

4.2 Cases of Pipeline vandalism

The table below shows a 5 – Year Pipeline Incidences of pipelines vandalism and rapture as captured by the NNPC. The Port Harcourt zone has the highest number of cases at 4120 followed by Mosimi 1874 and Kaduna 552. Warri zone had 337 cases, while Gombe zone had 194. These cases have

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been observed to be prevalent in the Niger Delta Region, where militants used to undertake irregular attacks on pipeline systems operated in the region in an attempt to destabilize the activities of oil companies while also attracting government and global attention (llagaha, 2007).

Table 2: Number of pipelines vandalism and rupture (2016-2020).

S/N	ZONE	VANDALISM	RUPTURE
1	Port Harcourt	4120	39
2	Warri	337	25
3	Mosimi	1874	33
4	Kaduna	552	81
5	Gombe	194	2
	TOTAL	**7077**	**99**

Source: NNPC Annual Statistical Bulletin (ASB), 2020

The above data can be used by the respective stakeholders to enhance security especially in the area that has more cases of pipeline vandalism to avoid future occurrence. Furthermore, Vidal (2011) identified a number of factors as causative and predisposing factors of oil pipeline vandalism in Nigeria:

(i) an excessive desire to accumulate wealth
(ii) a lifestyle of crime impunity and thievery in Nigeria
(iii) Inadequate surveillance of pipelines
(iv) political opposition, as in the case of Niger Delta militancy, and
(v) enormous economic inequality of rural and urban residents.

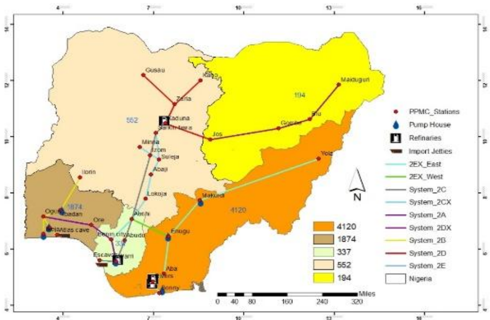

Figure 5: Map showing pipelines vandalism
Source: Author's Analysis, 2021

Figure 6: Pipeline vandalism
Source: NNPC, 2019

4.3 Rainfall Intensity

Heavy precipitation can affect rate of soil erosion (Meyer, 1981), and it is commonly discovered to play one of most important role in determining erosion (Reid et al., 1999; Nichols and Sexton, 1932; Holz et al., 2009). Raindrops' kinetic energy increases as rainfall intensity increases, increasing soil separation and transfer (Quansah, 1981; Ellison, 1944). The kinetic energy of a raindrop is affected by its velocity and mass; as acceleration and mass increase, so does kinetic energy (Stuart and Edwards, 2006).

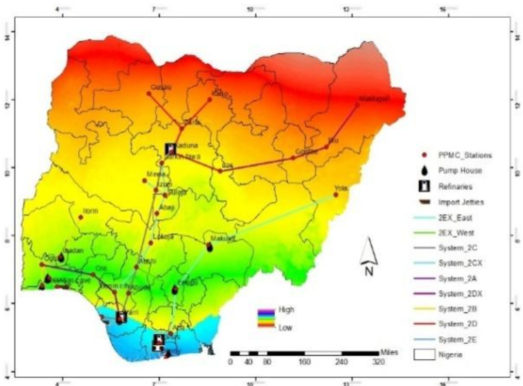

Figure 7: Nigeria's Rainfall Map
Source: Author's Analysis, 2021

The southern part of the country witness more rainfall than the northern part therefore determines the type and coating needing for the pipelines in the respective regions. Having knowledge of the rate of rainfall in an area will also determine the type of pipelines, depth and coating to use.

4.4 Vegetation Type

For a time, the construction of a gas pipeline alters the land's surface by discarding the vegetative layer and exposing nutrient soil. Erosion and sedimentation may increase as the mineral soil is revealed. Linear disruptions can have an

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immediate impact on adjacent plant communities, establishing gaps and modifying plant structure (Sousa 1984; Hansen and Clevenger 2005), as well as an indirect effect by changes in the environment such as light and water barriers (Parendes and Jones 2000; Hansen and Clevenger2005).Near road networks, a few vegetation was more sensitive to non-native species invasion than heavily forested ecosystems (Hansen and Clevenger 2005). Linear disturbances, such as pipelines and roads, influence vegetation differently than secluded disruptions (Daniel 2015; Jones et al. 2014).

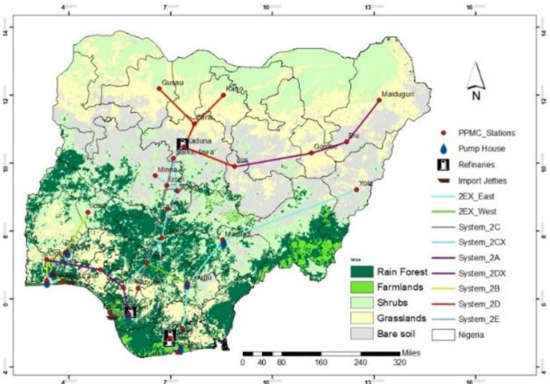

Figure 8: Vegetation Cover
Source: Author's Analysis, 2021

There are two broad vegetation types that correspond to the precipitation patterns, with a wetter southern half and a drier northern half: forested areas and grasslands. Each has three variants that run as roughly parallel bands east to west throughout the country. Forests, Savanna, Swamp of saline water, Savanna of Guinea, Swamp of fresh water, Sudan Savanna and Sahel Savanna which is a tropical (high) evergreen savanna.

4.5 Soil Type

Pipelines, on the other hand, may have a significant impact on native grasslands ecosystems. Pipelines on the right of way (ROW) can modify soil characteristics such as electrical conductivity, pH, salinity, soil water content, composition, and temperature through processes such as topsoil and subsoil integrating (De Jong and Button 1973; Naeth 1985; Ivey and McBride 1999; Olson and Doherty 2012; Shi,*et al.,* 2014; Xiao *et al*., 2014; Xiao et al. 2016). Trenching, welding, and vehicular traffic can all result in elevated metal concentrations (Shi,*et al.*,2014).

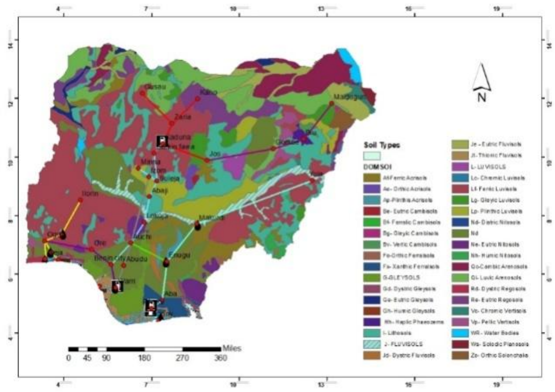

Figure 9: Soil Map
Source: Author's Analysis, 2021

Soil type can help in determination of the depth of the pipelines to prevent them to being exposed easily. Smaller particle soils (silt and clay) have a larger surface area than larger sand particles, and a greater surface area allows a soil to hold more water. In other words, fine soil has a higher water-holding capacity than soil with a high percentage of clay and silt particles. Oil spills have a negative impact on the environment by destroying life, destroying fertile soil, polluting the air and water, and harming the host communities' ecosystems (Aghalino, 2000). Brownish vegetation and soil erosion have been observed as a result of oil spillage, as have diminishing natural ecosystem resources and an adverse effect on people's lives, health, and economies (Abii and Nwosu 2009).

The oil film on the topsoil acts as a barrier between both the air and the soil, influencing physicochemical properties such as composition, nutrient content, temperature and soil ph. Crops with oily shoots, such as peppers and tomatoes, can sometimes wilt and die as a direct result of stomatal obstruction, which restricts photosynthesis, transpiration, and respiration. Crop germination, growth performance, and yield are all hampered by oil spills (Aghalino 2000).In their study, Bello and Anobeme (2015) concluded that the comparatively small increase in soil acidity of the soils investigated could be credited to the high Sulphur composition of the oil-spilled substances.

4.6Temperature Determination

Heat transmission analysis in oil and gas pipelines is essential for predicting and preventing the formation of paraffinic deposits and hydrates, which can interrupt oil and gas flow and cause significant financial losses. The map below depicts the observed average mean temperature in Nigeria for the year 2020. The coldest recorded temperature is 25.10^{oc} in Cross River state South-South Region while the hottest was 28.79^{oc} experienced in Sokoto

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state Northwestern Nigeria.

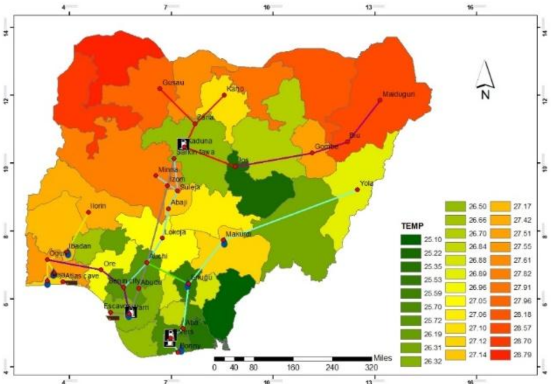

Figure 10: Mean Annual Temperature
Source: NiMET

Temperature has an impact on several aspects of gas distribution, including pipeline transport capacity and compression energy costs, natural gas hydrate formation and hydrocarbon condensation, and thermal stress on pipeline material, permafrost, and thawing. Heat transfer in a circumferential direction, heat rapid expansion in the surrounding soil, and the Joule-Thomson effect all have an impact on gas temperature in a pipeline.
The temperature change caused by a gas expanding without producing work or transferring heat is known as the Joule-Thomson effect. Compression tends to add heat to the gas, causing the temperature of the compressed gas to rise.

4.7Water Bodies

Appraisal of stormwater direction and areas where water can influence heating performance for heavy crude conveyed via pipe by causing drop in temperature, which is absolutely essential in fuel management used in the pipeline heating process. Numerous drinking water sources in Ogoniland, Niger Delta, are highly contaminated, according to the United Nations Environment Programme (UNEP), with life - threatening complications.Crude oil and refined products have also been discovered in land areas, sediments, and mangrove swamps, negatively impacting vegetation and aquatic life. Rivers Niger, Benue, Rima, and Kaduna are among these waterbodies. Nigeria has 13,000 square kilometres of water. Nigeria has an abundant water that covers a varied landscape, but it is distributed throughout the nation (WHO/UNEP, 1997).

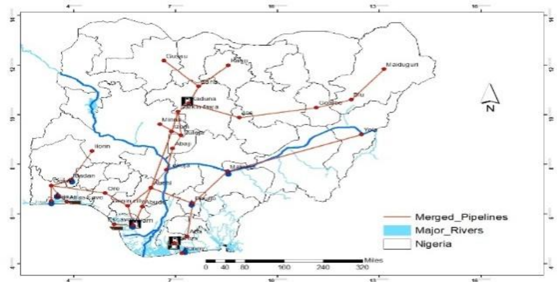

Figure 11: Map showing Waterbodies
Source: Author's Analysis, 2021

Okoro*et al.*, (2011) discovered in their research that the amounts of benzene in drinking water from the Wells at NisusiokenOgale of the Ogoni land in the Niger Delta area are 900 times higher than World Health Organization guidelines. According to Yakubu (2017), in addition to a lack of livelihood for many in the Niger Delta's Ogoni land area, there has been exposure to toxic substances from environmental pollution, which has serious health consequences such as cancer, respiratory issues, and miscarriage among women. Because of extensive pollution, most rivers are devoid of aquatic life, and most agricultural lands have become counterproductive. Climate change, which has impacted agricultural production in many parts of the world, including Nigeria, may exacerbate the situation (Shiruet al., 2018; Ahammed, *et al.,* 2019; Salman *et al.,* 2020).

4.8Elevation

Flow assurance is among the most pressing matters for the oil and gas industry, and it may be one of the most difficult challenges to the global expansion of pipeline networks. Pipeline construction and laying require a thorough understanding of the terrain. The pressure at a specific point in a pipe is affected by the fluid's elevation changes as it flows through a pipeline system where pipes rise and fall, changing elevation.

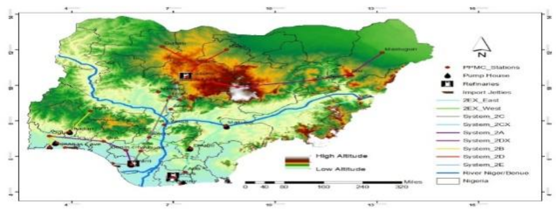

Figure 12: Elevation Map
Source: Author's Analysis, 2021

The majority of Nigeria's elevation pattern consists of a gradual rise from the coastal plains to the northern grasslands areas, reaching an altitude of 600 to 700 meters. Relatively high elevations of more than 1,200 meters are only found in remote areas of the Jos Plateau and parts of the eastern highlands along the Cameroon border. The coastal extends about ten kilometres inland and increases to an elevation of forty to fifty meters above sea level at its northern boundary. The Niger Delta, which spread over an area of about 10,000 square kilometres, separates the eastern and western segments of the coastal plain. The Cameroon Highlands, which run along the centre of the country's eastern border, contain the country's highest point (2,042 meters). Elevation declines below 300 meters in the Sokoto Basin in the northwest, in the far northwest and northeast, and the Chad Basin in the far northeast (Helen,1991).

V. CONCLUSION

Pipelines are a cost-effective and safe way to transport fluids such as crude oil and natural gas cover vast distances and terrain. However, because they are man-made systems, they can and do fail, occasionally catastrophically. Proper maintenance, as well as environmental remediation, can be very expensive, especially in sensitive spots.

An operator can visualize his pipeline in its environmental and safety specific situation using GIS-based technology, allowing him to instantly simulate high-risk areas and the need for possible class location upgrades. In an emergency, GIS can also direct you to a particular location, such as a main line valve. In this study, GIS is used to provide a compact space where all types of data relating to Area, such as images, maps, documents, and images, can be stored digitally. Data has already been organized in such a way that it can be used in advanced data procedures as well as fully integrated into presentations such as maps, tables and charts.

Subsequent studies can be used to inform future decisions about planning, design, and site management. The combined effect of GIS and pipeline operation data can also provide greater assurance of safety to the community in buffered pipeline routes near dwellings. As a result, the NNPC and other oil corporations can even use the system to manage assets more accurately and effectively. Simultaneously, the framework has an excellent advancement character for laying the groundwork for system exploitation. To use GIS technology, a massive GIS database of geographical features must be created. Creating such a database is a time-consuming process that may include data collection, verification, and organization.

VI. RECOMMENDATIONS

i. Oil spillage or soil pollution by petroleum products should be avoided as much as possible because it has such adverse effects on the biochemical properties of soils in relation to the crops or vegetation in the surrounding area.
ii. Because the activities of microorganisms, particularly beneficial microorganisms, are so important to release of nutrients to crops/vegetation grown on a specific soil, it is crucial to avoid soil pollution and contamination.
iii. Security should be increased in areas noticed to have frequent cases of vandalism
iv. The type, depth and coating of pipelines should be considered while laying them at various location to protect the natural ecosystem and biodiversity because different locations have different characteristics.
v. The Indigenous communities, leaders and environmental activist should be involved in the process of environmental mitigation and prevention. Pipelines vandalism should also be discouraged by the community leaders and the government.

VII. DECLARATIONS

Author contribution statement
YUSUF Y. Y., AHMED. A. H., andYAU. A.: Conceived, designed the study and Wrote the paper. ALIYU B.M, andMOHAMMED, A. S.: Analyzed and interpreted the data.

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Data availability statement
Data will be made available on request.

Declaration of interest statement
The authors declare no conflict of interest.

Additional information
No additional information is available for this paper.

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