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Research article

Environmental and socioeconomic impacts of pipeline transport interdiction in Niger Delta, Nigeria

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ABSTRACT

Over the years, pipelines have been the most economic medium for transporting crude oil to production and distribution facilities in the Niger Delta area of Nigeria. However, damages to the pipelines in this area by interdiction have hampered the continuous flow of crude oil to the facilities. Consequently, the revenue of the government dwindles, and the environment is severely degraded. This study assesses the economic and environmental impacts of pipeline interdiction in the Niger Delta region. Data from National oil spills detection and response agency, Nigeria is used to map spatial distribution of oil spills using Kernel Density Estimation with Geographic Information System. Literature was assessed to synthesize the historical, socioeconomic, and environmental impacts of oil spills and pipeline interdiction. Soil samples were collected from study area to determine the types of hydrocarbon pollutants and their concentrations in comparison with uncontaminated sites in the area. Results show that the range of concentrations of total petroleum hydrocarbon (TPH) for the impacted soil (IMP) was 17.27–58.36 mg/kg; remediated soil (RS) was 11.73–50.78 mg/kg which were higher than the concentrations of 0.68 mg/kg in the control samples (CS). Polycyclic aromatic hydrocarbons (PAH) concentrations were in the range of 0.43–77.54 mg/kg for IMP, 0.42–10.65 mg/kg for RS, against CS value of 0.49 mg/kg while BTEX ranged between 0.02 – 0.38 mg/kg for IMP, 0.01–2.7 for RS against CS value of 0.01. The values of the PAH were higher than the limits of the Department of Petroleum Resources, Nigeria. This study also revealed that pipeline interdiction has affected the livelihood of the inhabitants of the study area and the revenue of the Nigerian government. The major hotspots for oil spills in the Niger Delta region are Bayelsa, Rivers and Delta states.

1. Introduction

Pipeline networks play important roles in efficient transportation of oil from production wells to oil refineries. They also facilitate convenient and uninterrupted supply of finished petroleum products to dependent industries and other end users. However, over the years, pipelines have not only been exposed to incessant attacks but also remained potential targets for socioeconomic sabotage and sources of environmental degradation (Phil-Eze and Okoro, 2009; Sojinu et al., 2010; William and Benson, 2010). There are various causes of oil spills including operational failure, third-party damages and unknown causes (Kandiyoti, 2012). In many parts of the world, accidental third-party damages of crude oil pipelines have become increasingly common especially during excavations, but recently, pipeline interdiction and oil bunkering have been reported in countries like Columbia, Mexico, Middle East as well as Asia and Africa (Steiner, 2010; Mohamed et al., 2012).

"Interdiction" is a term used to describe a hostile situation whereby a certain commodity or goods is prevented from movement from one place to another by certain aggrieved individuals. As such, it is an intentional act of sabotage, vandalism or attack (Alawode and Ogunleye, 2011; Anifowose et al., 2012). This type of act has become common in Nigeria in recent times. Shell Petroleum Development Company (SPDC) and other oil companies operating in the country report about 200 oil spill incidences relating to pipeline interdiction annually since 2005 (Akpomuvie, 2011; Shell Petroleum Development Company, 2018). Since there is correlation between energy production/consumption and economic development of any country (Manoharan and Srivastava, 2020), pipeline interdiction affects the process of oil and gas production and

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transportation, thereby affecting the state of the economy of any nation where it is prevalent. This may trigger unscheduled repairs or maintenance of oil facilities, which is a setback for oil production and transportation (Motamed and Majrouhi, 2018).

In Nigeria, the revenues from oil and gas play vital socioeconomic development roles as they contribute 80–90 percent to the government's revenue and 40 percent of gross domestic product (GDP) (Ambituuni et al., 2014). Thus, any disruption in the production and supply chain of oil and gas in the country has devastating impacts on the already fragile economy. The major cause of pipeline interdiction in the Niger Delta area of Nigeria is the agitation for the cleanup of the severely polluted environments of the area. After several calls by the affected communities for the clean-up of the contaminated environment by the Nigerian government and the multi-national companies operating in the area yielded no results, militancy began in order to get the attention of the government and companies. This subsequently created the opportunity for bunkering, which was found to be profitable by many, particularly the youths who have lost their sources of livelihoods to environmental degradation. The increase in the level of oil pipeline destructions by the militants resulted in further environmental degradation and economic hardship in the region. It is estimated that approximately 546 million gallons of crude oil were spilled into the environment from 1958 to 2010 (Francis et al., 2011) with about 50,000 acres of mangrove forest disappearing between 1986—2003.

According to the statistics released by an Italian Multinational Oil Company (ENI) and Amnesty International, more than 550 oil spill incidences were reported in the Niger Delta within the span of one year. On the other hand, there were only 10 spills per annum in the whole of Europe between 1971 and 2011. However, apart from pipeline interdictions, spillage due to ageing pipelines also contributes to the degradation of the agricultural lands, water resources and biodiversity of the of the affected communities in the Niger Delta (Steiner, 2010; Benedict, 2011). For example, most of the water bodies used for fishing, irrigation, domestic and industrial uses are often polluted whenever oil spills occur. In addition, many farmlands have become unproductive and there is lack of fish in many rivers, exacerbating the economic hardship in the region. Audrey Gaughran, Global Issues Director, Amnesty International in 2011 stated that "in any other country, this would be a national emergency. Surprisingly, in Nigeria, it appears to be the standard operating procedure for the oil industry because the government that should protect the environment and the citizens appears complacent of the long-term implications of the current unsustainable oil and gas exploitation framework". As noted by Amnesty International (2015), "The human cost is horrific – people living with pollution every day of their lives". These emphasize the need for extensive investigation and cleanup of the region in order to enforce a more sustainable oil and gas exploration and exploitation in the Niger Delta.

Therefore, to properly address the incessant pipeline vandalization, proactive measures need to be taken by the government and other stakeholders. It is important to understand the historical and geographical distribution of the oil spills as well as the possible contaminants present in order to adopt appropriate remediation strategy as well as prevent further spills in the area. The overall aim of this study is to use geographical information system (GIS) approach to map the pattern of interdiction and to collect soil samples from an area in the region to assess the presence of hydrocarbon contaminants. The results generated from the GIS analysis and soil samples investigation are combined with economic data to assess the economic and environmental impacts of pipeline interdictions in the area. This will undoubtedly help in addressing environmental pollution and safeguarding agricultural land and water bodies. In particular, the following objectives shall be pursued in order to achieve the overall aim of the study:

1. Explore the historical pattern of the pipeline transport interdiction in the Niger Delta area of Nigeria.
2. Map the pollution hotspots and collect soil samples for analysis of hydrocarbon contaminants in the study area.
3. Assess the economic and environmental impacts based on findings from the study.

The major contribution of this study is to adopt a forensic approach to provide an in-depth analysis of the oil spills occurrences as well as explore the links between the interdictions resulting in oil spills and the economic, health and environmental impacts on the study area. The finding from this study can be of importance to the Nigerian government in gaining insights into the impacts of pipeline interdiction on the inhabitants of the region and the need for an urgent action to clean up the environment and improve the living conditions through infrastructural development in the region. In addition, this study will be useful for countries experiencing oil pipeline interdictions and countries that would exploit oil and gas reserves for socioeconomic development.

So far, the background problem, aim and objectives of the study have been presented. Henceforth, Section 2 presents the description of the study area. Section 3 presents the historical backgrounds of pipeline interdiction in Nigeria. Section 4 outlines the research method and approach while Section 5 presents the results. A critical discussion is made in Section 6 while the conclusions from the study are presented in Section 7.

2. Description of the study area

Figure 1 shows the nine states in the Niger Delta region in Nigeria where significant oil and gas production is currently taking place. Niger Delta region is made up of nine states, hosting about 1500 communities and different oil and gas companies. The region is located between latitudes 4° 10′ to 6° 20′ north and longitudes 2° 35′ to east of the equator. It projects towards the Gulf of Guinea on the Atlantic coast of West Africa. This delta is the second largest delta in the world with the coastline stretching about 450km up to the entrance of Imo River (Awosika, 1995). It also covers the coasts of Ondo, Delta, Bayelsa, Rivers, Akwa Ibom to Cross Rivers states (Tunde Imoobe and Iroro, 2009). The Niger Delta region in Nigeria covers about 70,000 km^2 wetland and it has been named as one of the top ten wetlands and deltaic ecosystems in the world (Achebe et al., 2012; Hooper et al., 2002; Phil-Eze and Okoro, 2009).

The stagnant swamp in the region covers about 8600 km^2, while rivers, creeks, and estuaries cover about 2,370 km^2. The mangrove swamp is the largest swamp in Africa and it spans about 1900 km^2 (Awosika, 1995). There are myriad of species of plants and animals in the Niger Delta. These include timber species, edible vegetables, fruits, nuts, seeds, medicinal plants, palm trees, tannis, bamboos and grasses among others, while the different species of fauna inhabiting the Niger Delta region includes monkeys, apes, mongoose, otters, squirrels, antelopes, elephants, reptiles as well as 33 different species of birds; insects and invertebrates (World Bank, 1995; Ebeku, 2005; Kuenzer et al., 2014).

The region has few major towns with several rural communities. General standard of living is very low as majority of the population lives below a dollar per day and rely on agricultural activities and fishing for survival (Watts et al., 2004). Crude oil was discovered in large quantities in Oloibiri in Bayelsa State in the 50's. Niger Delta's crude oil made Nigeria the biggest petroleum producing nation in Africa and sixth in the world (Yakubu, 2008). Nigeria started the exportation of crude oil at low production rate of about 5100 barrels per day (bpd) in the year 1958 (Ubani, 2016). It has been estimated that about 6800 oil spills incidence occurred between 1971 to 2001 releasing approximately 3,000,000 barrels of oil in the region (UNDP, 2006). Similarly, about 256 and 418 oil spills were released between 2007 and 2008. These several oil spill incidences in the region have affected many sectors including water resources, agriculture, health and the environment of the region. This has consequently resulted into loss of agricultural lands, loss of aquatic lives, unpotable water resources and several health problems in the area.

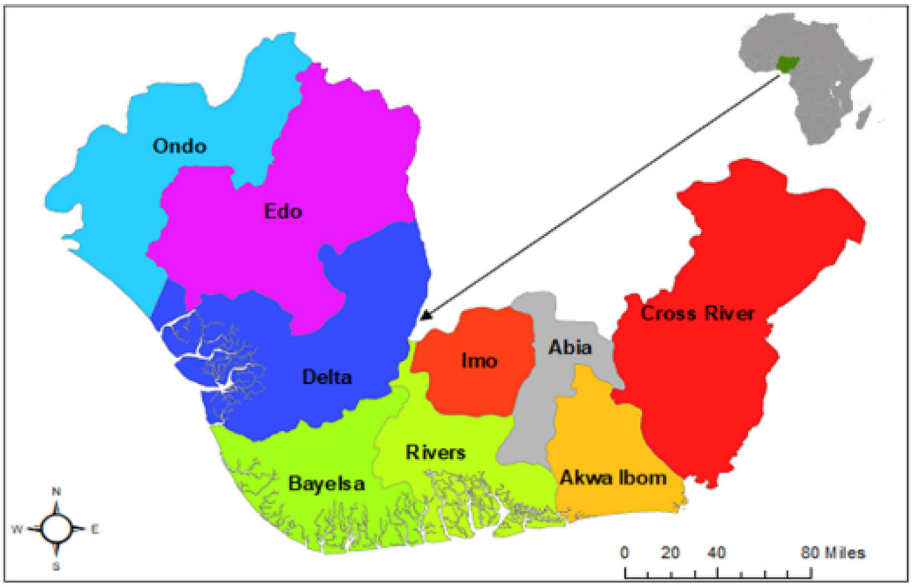

Figure 1. Map of the study area showing Africa, Nigeria and the Niger Delta.

3. History of pipeline transport interdiction in the Niger Delta

For close to half a century, the oil rich Niger Delta faced series of agitation, protests and struggle against what they called "injustice, marginalization and neglect" by the Nigerian government. It was thought that the protest would be curtailed since governments around the world have the capacity to avert uprising as quickly as possible (He et al., 2016; Talukdar, 2018). Contrarily, the government of Nigeria ignored environmental activists, who sometimes get into trouble with the government. For example, an activist from the Niger Delta region Ken Saro-Wiwa was executed by the then military government over his activism. Apart from ecological catastrophe, political marginalisation, social deprivation, the 40 years of oil exploration and exploitation in the Niger Delta have brought no noticeable development to the people of the region (Watts, 2008; Ikelegbe, 2010). The government continued to use force to ensure that the supply chain and logistics of oil and gas continued. Eventually, the situation escalated, and the region slipped into series of attacks from the insurgence (Ikelegbe, 2010). The attacks became more frequent with many locals in the area supporting the attackers if they can attract the attention of the government or/and the international community on their plight. The upsurge of violence tremendously increased between 2004 and 2009 when militants started incessant attacks on pipeline installations, kidnapping of oil workers, taking hostages and engaging in oil bunkering.

The acts of pipeline vandalization and other vices in the Niger Delta stems from the belief that there was no fairness in resource allocations to the Niger Delta region which contributes the major part of revenue of the government. According to OPEC's statistics, Nigeria was the seventh largest exporter of petroleum and fifth largest crude oil supplier to the U.S. Yet, the people of the Niger Delta did not get the full benefit of the natural endowments considering the level of poverty, environmental degradation, underdevelopment and poor infrastructure in the region. Conflicts over resources control in the Niger Delta have claimed over 10,000 lives and thousands have lost their lives through pipeline vandalism fire outbreaks (Adamu et al., 2015).

3.1. Key actors and their motivations

In this study, the key actors identified to cause pipeline transport interdiction that leads to oil spillage are classified into three. They are: sophisticated bunkerers, amateur bunkerers and vandals. Table 1 shows the interrelation among the three groups of interdiction actors. Each of them is further discussed in order to understand their mode of operation.

3.1.1. Interdiction by sophisticated bunkerers

This category of individuals or group of individuals have experiences in bunkering and they are well equipped and connected (DPR, 2010). Their major motivation is to make economic gains by illegally obtaining oil from pipelines. However, they always seek collaborations with security agents and oil workers to siphon reasonable quantities of crude oil directly from pipelines that supplies the various refineries (Onuzurike, 2008). Even though the operation is at a smaller scale compared to the main refineries, spills are unavoidable due to inability to regulate the flow, usually from illegal fittings, installations and control valves. While they sometimes receive supplies from amateur bunkerers, they often operate on their own. They make use of rubber hoses to load the crude oil on to series of smaller boats and move through various creeks for onward transfer to bigger boats or barges before loading the oil onto the ship for sale at the international markets (Katsouris and Sayne, 2013). Figure 2 shows seized locally fabricated boats for loading stolen crude oil within Ogoniland creeks.

3.1.2. Interdiction by amateur bunkerers

This group uses crude methods such as hacksaws and local fittings to steal crude oil from pipelines. The group constitutes the large percentage of unemployed youths in the Niger Delta region. The motivation of this

Table 1. Relationship among causers of oil spills through pipeline interdiction.

Actors	Relationship with bunkerers	Motivation
Vandals	None to bunkerers	Agitated
Amateur bunkerers	With sophisticated bunkerers. They supply oil to barges for sophisticated bunkerers	Economic gain
Sophisticated bunkerers	With amateur bunkerers, they receive oil from amateur bunkeres through barges to be loaded on ships at sea.	Economic gain

Figure 2. Seized boats used in transporting stolen crude in the Niger Delta.

group is to earn economic benefit from bunkering for survival. Most members of the group after having lost their sources of income from fishing and agriculture, found the bunkering business as an option. In this group, crude oil is usually transported on canoes and loaded to barges to be sold to the sophisticated bunkerers. Sometimes they also refine the crude using crude and local methods and sell to the local communities. There are several artisanal refineries scattered in and around the Niger Delta area (Overall, 2008). Regrettably, this group of individuals care less about spills caused, as they always leave the broken pipes discharging crude in the environment.

3.1.3. Interdiction by vandals

These categories of persons are interested in sabotage and vandalization unlike the first two categories that interdict for economic benefits. Vandals normally show their grievances towards the government and multinational oil companies through sabotaging their operations. They attack fully armed and with explosives, breaking pipelines that supplies oil to various companies and refineries. This group works closely with the community leaders in order to send signals to the government and multinational companies on the need to provide social amenities for the areas (Benedict, 2011).

The activities of the different categories of groups carrying out pipeline interdiction significantly affect oil production and distribution. This often have significant socioeconomic and environmental impacts and can drastically reduce the GDP of the country. Therefore, it is imperative that the government ensures improved living conditions for the inhabitants of the Niger Delta area and take urgent measures to clean up the polluted environment.

4. Research method and approach

In order to achieve the objectives stated in Section 1, specific approaches adopted are presented in this section. Figure 3 presents the methodological flow chart of the study. This study involves the collection of all available oil spills data covering the entire Niger Delta region from 2007 to 2019 from the National Oil Spills Detection and Response Agency (NOSDRA) which keeps a database of official oil spills in Nigeria and SPDC, a multinational oil company that has operated in Nigeria for several decades. The data had been compiled by both Shell and NOSDRA via a process of joint investigation visits (JIV), and reports by oil companies.

Information on the database which is updated as soon as any spill incidence occurs encompasses dates, time, causes, magnitude, and GPS coordinates of spills. In this study, the oil spill data were used in ascertaining the extent of each oil spill, and the frequency of spills at different locations. The methods applied in the study are discussed in the following sections.

4.1. Spatial analysis of oil spills hotspot map

Researchers from different background have used varying approached and methods for identifying significant hotspots in spatial

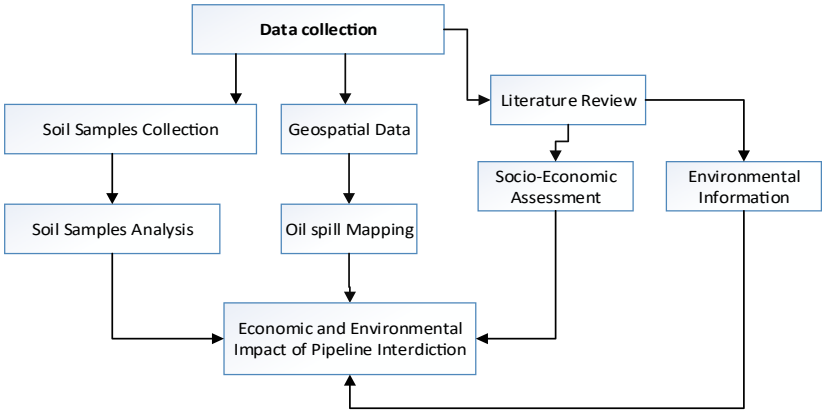

Figure 3. Methodological flow chart of the study.

data (Anderson, 2009; Benedek et al., 2016; Chicas et al., 2016). Most popular among the methods includes Kernel Density Estimation (KDE). Even though, the application of Kernel density estimation was developed purposely for epidemiological studies, it has been successfully extended to areas of transport and other related fields (Xie and Yan, 2013). This study therefore applied kernel density estimation to show the hotspots where oil spills are prevalent in the Niger Delta area. Colour Ramp is used to show the concentration of spills from higher spots to lower spots.

To perform the spatial analysis of the hotspots of the oil spills in the study area, oil spill dataset was added in the ArcMap environment. ArcGIS constitutes an important tool having the ability of providing varying ways of displaying an event spatially on a map (Umar et al., 2018). The oil spills data was georeferenced using the geo-referencing tool of ArcMap to align to UTM zone 32N. After this, the geoprocessing tool of the ArcMap was chosen from the arc tool box to reveal the spatial analyst tools. From the spatial analyst tools, the density option was chosen which revealed the kernel, line, and point densities. The kernel density option was then chosen for the estimation of the spatial distribution of the contaminants within the study area. The socioeconomic realities and environmental impacts analysis in this study considered the density of the spatial distribution of the hotspots.

4.2. Soil samples collection and analysis

A composite samples consisting of several subsamples were taken at the study sites, homogenizad and a portion was placed into clean sampling container (PD ISO/TS 22939:2019). Soil sample collection and analysis comply with the ISO 18400-206. Soil sampling, hand-held auger drill was used for the collection of soil samples at depths of 0–15 cm, 15–30 cm, and 30–45 cm intervals below the sub surface. The locations of samples collections were based on proximity to the oil pipelines within the study area and on suspected contaminated sites. In order to establish fair representativeness of the samples collected, random sampling method was employed to collect samples from communities that had been polluted by spills. Using geographic positioning system (GPS) and oil spill data from NOSDRA, the actual locations of spills were identified and samples were collected. Soil samples from non-polluted areas and remediated soils were collected as soil concentration reference for the contaminated soils. Composite samples were made from the samples collected at 0–15 cm, 15–30 cm and 30–45 cm depths in order to obtain the representative sampling of all the samples collected. The samples were later taken to the laboratory, well labelled in sterilized amber bottles. The soil samples were preserved in the field at 4 °C to avoid the breakdown of the biological and chemical processes which changes when the soil is removed from its natural ecosystem and Environment (Rayment and Lyons, 2011). Hydrocarbon Analysis conducted on the soil samples are: Total Organic Carbon (TOC), Total Oil and Grease (TOG), Total Petroleum Hydrocarbon (TPH), and Benzene-Toluene-Ethylbenzene-Xylene (BTEX).

5. Results

The socioeconomic impacts of oil spills are intricately intertwined with the environmental impacts. In this section, the impact of oil spillage through interdictions and its national economic and local socioeconomic and environmental impacts are discussed.

5.1. Oil spill by interdiction

Although some of the oil spills result from the failure of equipment and operational error, pipeline interdiction accounts for most of the spills that occur in the Niger Delta region (Shell Petroleum Development Company, 2007). The activities of Niger Delta militants whose intention is to fight for the plight of the people of Niger Delta have resulted into tremendous environmental degradation, mainly through attacks on pipelines that transport crude oil to various refineries in the region and elsewhere. They siphon unrefined crude oil and refine it locally for local or international markets, and because of this, large volume of crude oil is spilled, causing significant damage to the entire ecosystem (NOSDRA, 2016). Presently, there are 600 oil fields in the Niger Delta, with onshore field occupying 360 while offshore has 240 and the region is believed to have over 3000km of pipelines crisscrossing the entire land and water ways. These pipelines transport and distribute crude oil to about 275 flow stations across the area.

Figure 4 shows map of the Niger Delta with oil spills hotspots across the states. The hotspots evidently showed that the cluster of oil spills is higher in Bayelsa, Delta, Rivers and Imo states.

Table 2 shows that the total volume of spill by interdiction is almost twice that of operational failure and much higher than other spill occurrences within the period of 9 years. Other spills mostly were as a result of undocumented figures due to either remoteness of the location or security threat from the Niger Delta avengers. The table further suggest that a total of almost 90 million barrels of crude oil was spilled within the 9 years' period and year 2011 and 2014 recorded the worst pipeline spills making up more than a quarter of the total amount spilled. According to NOSDRA (2016), there are other causes of spills, but record less quantity compared to aforementioned.

From Figure 5, the number of pipeline spills has increased significantly over the period of 13 years and pipeline interdiction accounted for about 60% of the spill occurrences between 2013 and 2019. However, significant drop in pipeline interdiction was seen in 2015 and this is largely due to government policies that address some of the challenges in the Niger Delta. Such policies include amnesty granted to the militants by the government which saw many of the militants dropping their weapons to embrace the peace process. Niger Delta Development Commission was established to address the socioeconomic development of the region. This includes building of physical infrastructures and youth empowerment through specialised trainings and scholarship awards.

Three out of nine states were severely affected. This has been demonstrated in Figure 6 which shows high hotspots around Rivers, Bayelsa and Delta states, respectively. Additionally, most of the affected areas lies within coastline and creeks and this has made it very difficult for security agencies to mount effective patrol and easier for the bunkerers to steal crude oil and whisk it away easily. Crude oil pipelines in the Niger Delta crisscross almost all the urban areas which makes it an easy target, while spills from the broken pipelines expose the settlers to contamination, causing severe environmental, social, health and economic degradations across the region (Yakubu, 2017).

5.2. Economic impact assessment of pipeline transport interdiction

The incessant pipeline transport interdictions by the three groups identified in this study have had serious impacts on the lives, safety, environment, and economy of the Niger Delta region. Whenever the community members learn that there is an unrepaired pipeline transport interdiction, they usually rush down with buckets and cans to scoop oil, whether it is refined or not. They use local means to refine the crude if the interdicted flow is of crude. Unfortunately, fire outbreaks have been reported to have occurred in the process because of the flammability of the oil. This usually lead to death of the people involved and innocent people close by. Between 2009 and 2011, Nigeria earned about $143.5 billion in equity from crude sales, taxes and bonuses as well as from royalty. At the same period, the country lost over 136 million barrels of oil estimated at $109 billion to oil stealing, sabotage, and militancy (The New Diplomat, 9 May 2016). The report further revealed that about 10 million barrels of oil valued at an estimated cost of $894 million were also lost due to pipeline vandalization (NEITI-EITI Core Audit Report of Oil and Gas, 2009–2011).

Prior to the middle of 2016, the country was the largest producer of petroleum in Africa and among the top five member nations of organization of Petroleum Exporting Countries (OPEC) (Kandiyoti, 2012). However, incessant pipeline vandalism brought the country out of this position in the continent. For example, in the first quarter of 2013, the

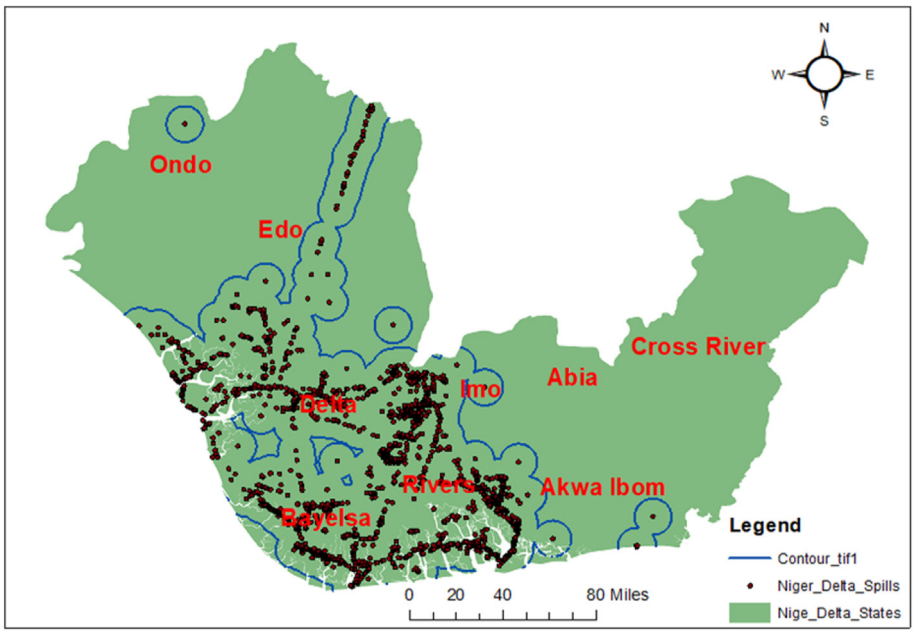

Figure 4. Oil spill hot spots in different parts of the Niger Delta.

Table 2. Volume of oil (Litres) spilled from pipeline interdiction and operational errors (2007–2019) Source: NOSDRA.

S.N0	Year	Operational	Sabotage	Others	Total
1	2007	2,040,659	8,746,906	468,963	11,256,527
2	2008	2,042,381	12,853,084	490,508	15,385,973
3	2009	1,826,455	3,655,121	428,862	5,910,437
4	2010	1,682,112	4,313,584	1,477,306	7,473,003
5	2011	7,118,230	4,178,088	319,673	11,615,991
6	2012	584,149	5,634,026	378,245	6,596,421
7	2013	849,686	3,935,630	318,174	5,103,490
8	2014	5,627,638	6,848,192	59,149	12,534,978
9	2015	468,901	8,172,893	88,068	8,729,863
10	2016	773,030	6,127,050	79,659	6,979,739
11	2017	294,196	5,099,599	138,722	5,532,517
12	2018	871,799	3,377,854	39,221	4,288,873
13	2019	934,075	6,010,422	20,921	6,965,418

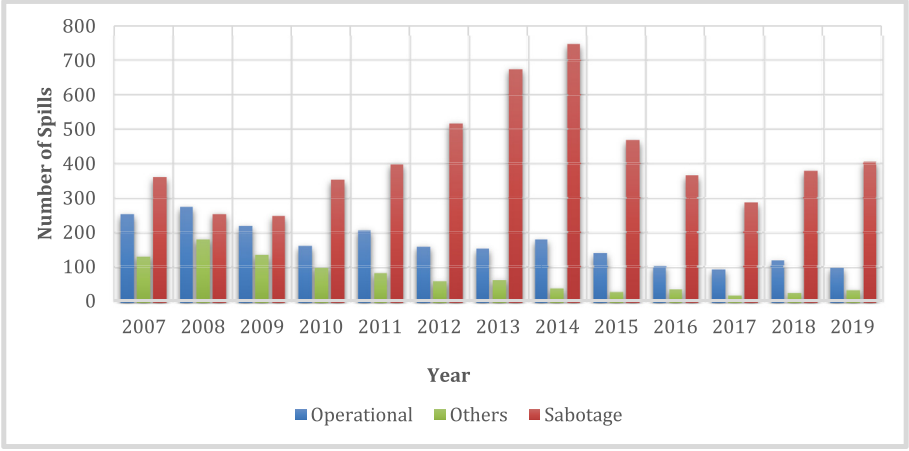

Figure 5. Frequency of oil spills caused by operational errors, sabotage, and others.

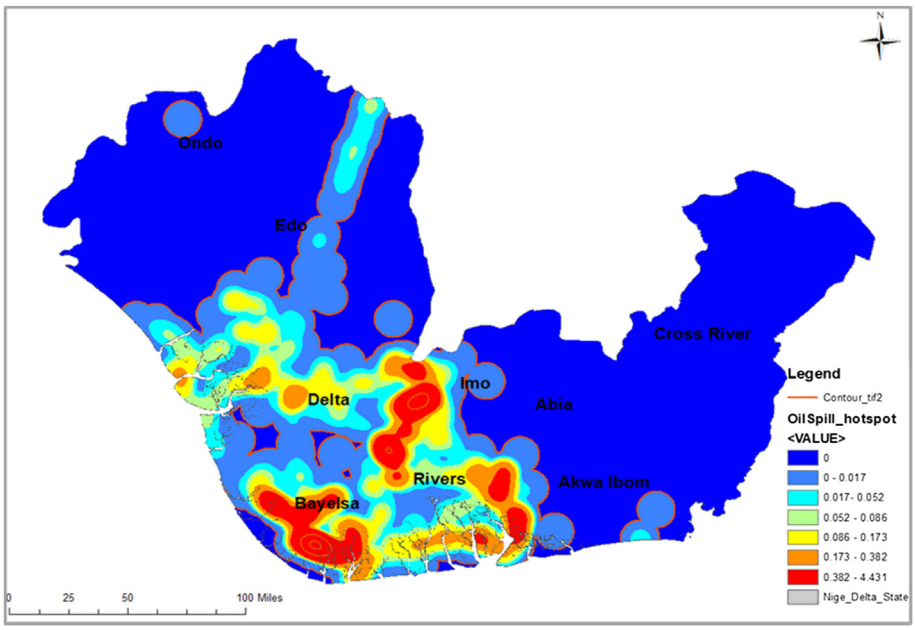

Figure 6. Oil spills hotspots in the Niger Delta using kernel density estimation.

country's production capacity was between 1.86 and 2.1 million barrels per day against the expected estimates of 2.48 million barrels per day. According to OPEC monthly report dated March 2017, Angola assumes the first position as the continent's largest producer as Nigeria's production capacity fell below 156,900 barrels per day. The report further stated that 1.269 million bpd was produced in March, 2017 as against 1.426 capacity in February the same year (Okere, 2017). Additionally, the country lost about 300,000 bpd out of 400,000 bpd supplied from Forcados pipeline that transports the product to the biggest export terminal in western Niger Delta known as Forcados external terminal (The New Diplomat, 9 May 2016). Another pipeline vandalism was reported by Chevron in 2016. The company claimed that about 35,000 bpd of crude oil has been lost which hitherto to that its production capacity was about 240,000 bpd (Ordonez, 2016). However, it was generally estimated that pipeline interdictions almost took place daily; with blown up pipelines around five to seven times daily including submerged pipelines in the region (Onuzurike, 2008).

To buttress the assertion, the Minister of Petroleum Resources was quoted as saying "between 2015 to 2016, the country's production capacity dropped by 800,000 barrels per day in 2016 as against 1.4 million bpd in 2015" (Premium Times, 2017). As a guest speaker on the 2016, Fiscal liquidity assessment committee, the Group Managing Director of Nigerian National Petroleum Cooperation (NNPC) noted that the production capacity lost in 2016 alone would have been sufficiently enough to produce 7,000 MW power plant, 1, 700 km pipelines and could finance about 30% of the country's national budget (The Nation Newspapers, 2017). Figure 7 presents the crude oil production and spill volume in Nigeria between 2010 and 2017 (see Figure 7). Figure show that there has been decrease in production due to spills as a result of vandalization.

There are other consequences of third-party pipeline damage apart from direct impact on the economy. During their aggressive attacks on the pipelines, the militants use local hacksaw or dynamites to break the pipes and siphon refined or unrefined petroleum products and leave the contents to spill into the environment continuously until authorities get to know about it and gets it repaired at huge costs. The spilled products destroy the ecosystem and require huge costs for clean-up. According to Adati (2012), incessant attacks on oil pipelines in the Niger Delta cost Nigeria more than what it is losing from production and clean ups. The irony of pipeline interdictions in the Niger Delta is that the continuous

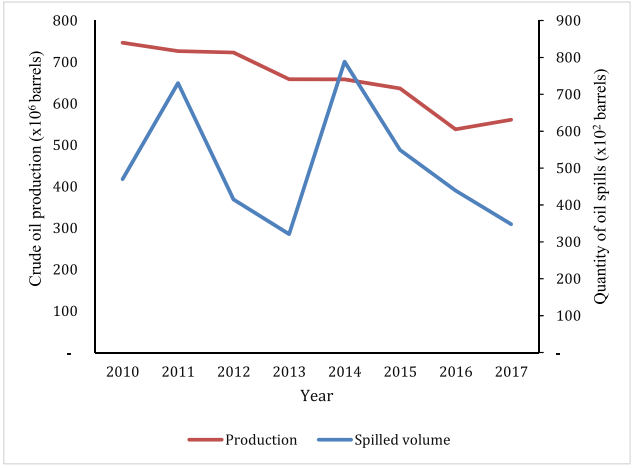

Figure 7. Crude oil production and quantity of oil spills in Nigeria between 2010 and 2017 Sources: (Production: Data obtained from DPR, 2017; Spilled volume: Data obtained from NOSDRA, 2017).

destruction of farmlands and rivers in the Niger Delta emanates from its people who are supposed to protect the environment.

The Federal Government of Nigeria, through the security agencies, continues to ensure that interdictions are eliminated in the Niger Delta to achieve stable economy. The report of 2013 prepared by the multinational joint task force indicated that about 3,778 artisanal refineries were destroyed, eight vessels fully loaded with 120 barges, 178 pumps, 878 boats, 5238 surface tanks, 606 pumping machines and 626 outbound engines were confiscated (Franklin et al., 2018). Pipeline interdiction has remained a major threat to the Nigeria's economic prosperity, a major concern to the oil companies operating there, and a huge environmental problem to the people living in the region.

5.3. *Environmental impacts of pipeline transport interdiction*

Undoubtedly, there is a huge environmental cost of oil spills into the environment due to pipeline interdiction. This include damages to farmlands, swamps, groundwaters, vegetation, and animals. There is also

Table 3. Concentrations of hydrocarbon pollutants in soil samples. Values are average of triplicates for TOG×103, TPH×102 and TOC×10.

	Chemical compound				
	TOG (mg/kg)	TPH (mg/kg)	PAH (mg/kg)	BTEX (mg/kg)	TOC %
Oshie IMP Soil 01	19.84	42.81	0.43	0.1	2.37
Oshie IMP Soil 02	17.96	31.97	33.53	0.38	5.14
Ukperede IMP Soil 01	16.37	41.39	54.56	0.22	4.84
Ukperede IMP Soil 02	21.75	58.36	77.54	0.14	6.04
Akinima Soil IMP 01	14.92	19.44	43.02	0.09	2.17
Akinima Soil IMP 02	15.69	17.27	6.99	0.19	4.15
Ihereke Soil IMP	16.09	46.73	5.48	0.02	3.37
Oshie RS	24.67	50.78	0.42	0.01	1.14
Ukperede RS	16.75	24.78	0.43	0.15	8.11
Akinima RS	14.86	11.73	10.65	2.7	7.18
Ihereke RS	12.71	28.42	2.4	0.38	2.74
Control Soil CS	0.27	0.68	0.49	0.01	0.318
DPR Limits	5000	5000	40	246	2

DPR–Department of Petroleum Resources; **EPA**–Environmental Protection Agency; **TOG**–Total Oil and Grease; **TPH**–Total Petroleum Hydrocarbon; **PAH**–Polycyclic Aromatic Hydrocarbon; **BTEX–**Benzene, Toluene, Ethylbenzene and Xylene; **TOC**–Total Organic Carbon.

human health-related issues due to the interaction with polluted wáter, soil and air in the Niger Delta area. From the results in this study, analyses of the soil simples show that hydrocarbons are present in the soil samples collected from a location in the region shown in Table 3. Total, organic carbon found in the soil samples at the impacted and remediated area has a concentration that ranges from 8.109 - 1.135., This range of values is higher than the concentration at the control area of 0.318. The values are also higher than the 2% stated as the acceptable value by the DPR. The value of TOC for Oshie, which is a remediated site, indicates that significant quantity of the hydrocarbon has undergone appreciable decomposition or degradation. Usually, organic matter content increases when carbonaceous substances, hydrocarbon fuels or condensates are added to the soil (Polyak et al., 2018). There are two decomposition processes that are of significance to this study. First is the decomposition of the soil organic matter and the other is the decomposition of the added petroleum hydrocarbons. They are, however, at the prerogative of heterotrophic organisms that are present in the soil. In particular, the total organic matter in soil represents humus which is the stable end product of the decomposition of organic matter in the soil matrices. This finding implies that a significant decomposition of the petroleum hydrocarbons has taken place in the remediated site which may have been facilitated by different factors of decomposition.

The results of the analysis of the soil samples for impacted soil (IMP), remediated soil (RS) and the control soil (CS) are presented in Table 3. The analysis of the soil samples were conducted according to the American Society for Testing and Materials for TOG, TPH, PAH, and BTEX while that of TOC was conducted according to the Environmental Protection Agency (EPA) method. The results were compared to the limits of the Department of Petroleum Resources (DPR) of Nigeria. Concentrations of TPH ranges from 58.36 - 11.73 mg/kg from both impacted and remediated soils as shown in Table 3, while oil and grease in samples from both impacted and remediated sites were significantly higher with values ranging from 24.67 - 12.711 mg/kg than those from the control site of values of 0.27 mg/kg. Also, the levels of total PAH ranges from 54.56 - 0.42 mg/kg and BTEX with 0.38 -0.1 mg/kg obtained in the impacted and remediated sites were higher than in the control samples. When compared with the DPR limits, TPH, PAH and BTEX were all in compliance, with the exception of Ukperede Impacted Soil 01, Ukperede Impacted site 02 and Akinima impacted sites 01 with the PAH values of 54.56 mg/kg, 77.54 mg/kg and 43.02 mg/kg respectively. These values suggest high petroleum hydrocarbon impact exceeding the background values for petroleum hydrocarbon presence in soils.

6. Discussion

The environmental and socioeconomic impacts of third-party interdictions affect the sustainable production of oil and gas in the Niger Delta. The spill data analysed in this study revealed that interdiction is the major cause of about 60 percent oil spill quantity in the region. This finding debunked the notion that multinational oil companies were solely responsible for pollution incidences in the region. Although, interdiction claimed most of the spill incidences, operational failure by multinational oil companies has also contributed significantly to environmental degradation in the region. Failure to adhere strictly to the standards of maintenance and slow responses to spill incidences are responsible for spills due to operational failures. Other spills category labelled as “others” have prompted many researchers and stakeholders to call on government to fortify security and improve the level of response to threats and demand higher environmental management practices by companies in the region. The total amount of oil spills in the Niger Delta within the period of 13 years presented in Table 2 is adequate to cause significant damage to human health and ecosystem. This has equally affected Nigeria's economic growth, increased poverty level, unemployment and underemployment as well as discouraged foreign investors.

Compared to other countries, pipeline interdictions are more common in Nigeria due to the cultural, socioeconomic, geopolitical and environmental perceptions of the people and the government. However, there are pipelines interdictions occur in other regions including South America, Asia and Middle East. It is important for countries like Ghana, Sierra Leone, Guyana, Suriname, Mauritius and Mozambique where oil has been discovered recently to learn from Nigeria's experience and use different pipeline installation approaches like deeper installations or/and offshore installation pipeline transport networks. In addition, it is imperative to prevent environmental pollution or conduct appropriate and efficient cleanup when they occur to avoid agitations from the communities hosting the oil companies.

Kadafa (2012) reported that about 24,000 barrels of oil from a pipeline at Ogada Brass near Etiama Nembe community of the Niger Delta polluted freshwater swamp forest and brackish water mangrove swamp in the year 1995. According to the United Nations Environmental Programme (UNEP) (2011), many drinking water sources in Ogoniland of Niger Delta are widely polluted and have serious health impacts. It was also found that crude oil and refined products were found in land areas, sediments and swamplands constituting major damage to vegetation and aquatic lives. The study also found that at Nisusioken Ogale community

of the Ogoni land in Niger Delta area, the levels of benzene in drinking waters from the Wells are 900 times above the World Health Organization guideline. Okoro et al. (2011) analyzed soil samples from Orere-Oluba area of the Niger Delta after 33 months of spillage and clean-up. The study revealed that the TPH was 581.02 mg kg $^{-1}$, oil and grease was 492.55 mg kg $^{-1}$, and polynuclear aromatic hydrocarbons PAH, 20.41 mg kg $^{-1}$. It was shown that significant correlation exists between TPH, and oil and grease (0.97), TPH and PAH (0.64), TPH and hydrocarbon degrading bacteria (0.72). The values were significantly higher than the uncontaminated (control) soils. It also revealed that there were high levels of diffuse petroleum hydrocarbons in the contaminated area. Ayanlade and Howard (2016) revealed that several health issues like diarrhea, skin irritation and stomach-ache, emanating from consumption of polluted water are common among the people of Tsekelewu community of the Niger Delta. According to Yakubu (2017), aside from the loss of means of livelihood of many in the Ogoni land area of the Niger Delta, there have been exposure to toxic chemicals from environmental pollution which have severe health impacts including cancer, respiratory issues, miscarriage among women. Zabbey et al. (2017) suggested toxicity of root crops and other agricultural products through bioaccumulation of toxic components from hydrocarbon pollution in the Niger Delta area of Nigeria.

While the impacts of environmental pollution due to oil exploration and exploitation affect the local communities of the Niger Delta area, the economic impacts because of the activities of the vandals is beyond the Niger Delta region. These activities usually affect the revenue of the government as the outputs decrease. Environmental pollution has affected the major sources of livelihood, agriculture, and fishing of the local communities. Most rivers lack aquatic lives due to extensive pollution and most agricultural lands have become unproductive. This may be aggravated by climate change which has affected agriculture in many areas of the world including Nigeria (Shiru et al., 2018; Ahammed et al., 2019; Salman et al., 2020). The expected changes in climate variables, mainly rainfall and temperature have also been reported in Nigeria (Oloruntade et al., 2017; Shiru et al., 2019, 2020a). As reported by Okoro et al. (2017), the impacts of climate change are expected to affects yields of agricultural output of a palm oil which is a major agricultural product from the region. Climate change is also expected to affect disaster risks like floods and droughts in many parts of the globe including Nigeria (Sa'adi et al., 2019; Homsi et al., 2020; Shiru et al., 2020b). Immediate environmental management for the mitigation of the combined effects of environmental pollution and climate change in the Niger Delta region is therefore crucial to socio-economic development and peace in the region. A wider applications of renewable energy technologies in Nigeria can help to improve the socioeconomic and environmental standards in Niger Delta and across the country at large (Ogbonnaya et al., 2019a, 2019b, 2019c).

7. Conclusions

This study assesses the environmental and socioeconomic impacts of pipeline interdiction in the Niger Delta region of Nigeria. It uses KDE and GIS to analyse the data from NOSDRA in order to visualize the spatial distribution of oil spills. First, the historical background of the environmental and socioeconomic dimensions of pipeline interdiction in the region were established. Then, soil samples were collected at Ahoada communities to determine the types of hydrocarbon pollutants and their concentrations to compare them with the uncontaminated sites in the area. Results show that the range of concentrations of total petroleum hydrocarbon (TPH) for the impacted soil (IMP) was 17.27–58.36 mg/kg; remediated soil (RS) was 11.73–50.78 mg/kg which were higher than the concentrations of 0.68 mg/kg in the control sample (CS). Polycyclic aromatic hydrocarbons (PAH) concentrations were in the range of 0.43–77.54 mg/kg for IMP, 0.42–10.65 mg/kg for RS, against CS value of 0.49 mg/kg while BTEX ranged between 0.02 – 0.38 mg/kg for IMP, 0.01–2.7 for RS against CS value of 0.01. The values of the PAH were higher than the limits of the Department of Petroleum Resources (DPR) of Nigeria. The study also revealed that interdiction contributes more to the contamination of the environment of the Niger Delta in recent times than other sources. The major hotspots for oil spills in the Niger Delta region are Bayelsa, Rivers and Delta states, respectively. The extensive environmental pollution in the Niger Delta has affected the sources of livelihood and incomes of many inhabitants of the Niger Delta. Pipeline interdiction also affects the revenue of the federal government as it always affects the quantity of crude available for exports. It is anticipated that the challenges of pipeline interdiction can be mitigated through dialogue with the inhabitants of the areas, infrastructural and human development, and implementation of sustainable oil exploitation and environmental management in the area.

Declarations

Author contribution statement

H. A. Umar: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

M. F. Abdul Khanan: Performed the experiments.

C. Ogbonnaya, M. S. Shiru: Analyzed and interpreted the data.

A. Ahmad, A. I. Baba: Contributed reagents, materials, analysis tools or data.

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Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

References

Achebe, C.H., Nneke, U.C., Ansiji, O.E., 2012. Analysis of oil pipeline failure in the oil and gas industries in the Niger Delta area of Nigeria. Hong Kong. In: Proceeding of the International Multi-Conference of Engineers and Computer Sciences, II. IMECS.

Adamu, B., Tansey, K., Ogutu, B., 2015. Using vegetation spectral indices to detect oil pollution in the Niger delta. Remote Sens. Lett. 6, 145–154.

Adati, 2012. Oil exploration and spillage in the Niger delta of Nigeria. Civ. Environ. Res. 2, 38–50. ISSN 2222-1719 (Paper) ISSN 2222-2863 (Online).

Ahammed, S.J., Homsi, R., Khan, N., Shahid, S., Shiru, M.S., Mohsenipour, M., Ahmed, K., Nawaz, N., Alias, N.E., Yuzir, A., 2019. Assessment of Changing Pattern of Crop Water Stress in Bangladesh. Environment, Development and Sustainability, p. 20.

Akpomuvie, O., 2011. Tragedy of commons: analysis of oil spillage, gas flaring and sustainable development of the Niger delta of Nigeria. J. Sustain. Dev. 4, 200–210.

Alawode, A.J., Ogunleye, I.O., 2011. Maintenance, security, and environmental implications of pipeline damage and ruptures in the Niger delta region. Pac. J. Sci. Technol. 12, 565–573. http://eprints.abuad.edu.ng/id/eprint/302.

Ambituuni, A., Amezaga, J., Emeseh, E., 2014. Analysis of safety and environmental regulations for downstream petroleum industry operations in Nigeria: problems and prospects. Environ. Dev. 9 (1), 43–60.

AmnestyInternational, 2015. Nigeria: hundreds of oil spills continue to blight Niger Delta. Available: https://www.amnesty.org/en/latest/news/2015/03/hundreds-of-oil-spills-continue-to-blight-niger-delta/. (Accessed 17 March 2019).

Anderson, T.K., 2009. Kernel density estimation and K-means clustering to profile road accident hotspots. Accid. Anal. Prev. 41, 359–364.

Anifowose, B., Lawler, D.M., Van Der Horst, D., Chapman, L., 2012. Attacks on oil transport pipelines in Nigeria: a quantitative exploration and possible explanation of observed pattern. Appl. Geogr. 32, 636–651.

Awosika, L., 1995. Impacts of global climate change and sea level rise on Coastal resources and energy development in Nigeria. In: Umolu, J.C. (Ed.), Global Climate Change: Impact on Energy Development. DAMTECH Nigeria Limited, Nigeria.

Ayanlade, A., Howard, M.T., 2016. Environmental impacts of oil production in the Niger Delta: remote sensing and social survey examination. Afr. Geogr. Rev. 35 (No. 3), 272–293.

Benedek, J., Ciobanu, S.M., Man, T.C., 2016. Hotspots and social background of urban traffic crashes: a case study in Cluj-Napoca (Romania). Accid. Anal. Prev.

Benedict, A., 2011. Tragedy of Commons: analysis of oil spillage, gas flaring and sustainable development of the Niger Delta of Nigeria. J. Sustain. Dev. 4 (2).

Chicas, S.D., Omine, K., Ford, J.B., 2016. Identifying erosion hotspots and assessing communities' perspectives on the drivers, underlying causes and impacts of soil erosion in Toledo's Rio Grande Watershed: Belize. Appl. Geogr.

Department of Petroleum Resources (DPR), 2010. "Role in the Oil and Gas Industry". Guideline for Bunkering. www.dpr.nigeria.

Department of Petroleum Resources (DPR), 2017. 2017 Nigerian oil and gas industry annual report [Online] Available at: https://www.dpr.gov.ng/oil-gas-industry-annual-reports-ogiar/. (Accessed 24 October 2020).

Ebeku, K.S.A., 2005. Oil and the Niger Delta People in International Law. Resource Rights, Environmental and Equity Issues, OGEL Special Study, p. 5.

Francis, P., Deirdre, L., Rossaiasco, P., 2011. Securing development and peace in the Niger delta: a social and conflict analysis for change. Available: https://www.wilsoncenter.org/publication/securing-development-and-peace-the-niger-delta-social-and-conflict-analysis-for-change. (Accessed 2 January 2020).

Franklin, O. Okorodudu, Philip, O. Okorodudu, Lawrence, O. Atumah, 2018. A Monitoring System for Petroleum Pipeline Vandalism in the Niger Delta Region of Nigeria.

He, G., Mol, A.P.J., Lu, Y., 2016. Public protests against the Beijing–Shenyang high-speed railway in China. Transport. Res. Part D 42, 1–16.

Homsi, R., Shiru, M.S., Shahid, S., Ismail, T., Harun, S., Al-Ansari, N., Chau, K.-W., Yaseen, Z.M., 2020. Precipitation projection using a CMIP5 GCM ensemble model: a regional investigation of Syria Engineering applications of computational fluid mechanics. Eng. Appl. Comput. Fluid Mech. 14, 90–106.

Hooper, R.J., Fitzsimmon, R.J., Grant, N., Vendeville, B., 2002. The role of deformation in controlling depositional patterns in the south-central Niger Delta, West Africa. J. Struct. Geol. 24 (4), 847–859.

Ikelegbe, A., 2010. Oil, Resource Conflicts and the Post Conflict Transition in the Niger Delta Region: beyond the Amnesty. Ambik Press, Benin City, pp. 1–80. ISBN: 978-978-8400-76-9.

Kadafa, A.A., 2012. Oil exploration and spillage in the Niger delta of Nigeria. Civil Environ. Res. 2 (2). ISSN 2222-1719 (Paper) ISSN 2222-2863 (Online).

Kandiyoti, R., 2012. Pipelines Flowing Oil and Crude Politics. I.B. Tauris & Co Ltd, London.

Katsouris, C., Sayne, A., 2013. Nigeria's Criminal Crude: International Options to Combat the Export of Stolen Oil. Chatham House, London. ISBN 978 1 86203 295 8.

Kuenzer, C., van Beijma, S., Gessner, U., Dech, S., 2014. Land surface dynamics and environmental challenges of the Niger Delta, Africa: remote sensing-based analyses spanning three decades (1986-2013). Appl. Geogr. 53, 354–368.

Manoharan, R., Srivastava, A., 2020. Rational hybrid analytical model for steel pipe. Rack Quantification Oil Gas Ind. 6 (No. 4), 649–658.

Mohamed, Y., Werr, P., Cooney, P., 2012. Blast rocks Egypt's gas pipeline to Israel, Jordan. Reuters. Available: http://www.reuters.com/article/2012/07/22/us-egypt-pipeline-idUSBRE86L00T20120722. (Accessed 4 January 2020).

Motamed, P., Majrouhi, J., 2018. A framework to select the best strategy for Iran's entry into the repair and maintenance market of oil drilling rigs. Civil Eng. J. 4 (No. 11), 2702–2718.

National Oil Spill Detection and Response Agency (NOSDRA), 2016 [Online] Available at: http://www.nosdra.org/foreward.html. (Accessed 24 March 2019).

National Oil Spill Detection and Response Agency (NOSDRA), 2017. Nigerian oil spill monitor. https://nosdra.oilspillmonitor.ng/.

Ogbonnaya, C., Abeykoon, C., Damo, U.M., Turan, A., 2019a. The current and emerging renewable energy technologies for power generation in Nigeria: a review. Therm. Sci. Eng. Prog. 13, 100390.

Ogbonnaya, C., Turan, A., Abeykoon, C., 2019b. Novel thermodynamic efficiency índices for choosing an optimal location for large-scale photovoltaic power generation. J. Clean. Prod. 119405.

Ogbonnaya, C., Turan, A., Abeykoon, C., 2019c. Energy and exergy efficiencies enhancement análisis of integrated photovoltaic-based energy systems. J. Energy Storage 26.

Okere, 2017. "Nigeria Loses Africa's Top Producer Position to Angola. Internets.guardian.ng/news/Nigeria-loses-africas-top-oil-producer-position-to-angola/.

Okoro, D, Oviasogie, P.O, Oviasogie, F.E, 2011. Soil quality assessment 33 months after crude oil spillageand clean-up. Chemical speciation and bioavailability 3 (1). https://doi.org/10.3184/095422911X12963991543492.

Okoro, S.U., Schickhof, U., Boehner, J., Schneider, U.A., Huth, N., 2017. Climate impacts on palm oil yields in the Nigerian NigerDelta. Eur. J. Agron. 85, 38–50.

Oloruntade, A.J., Mohammad, T.A., Ghazali, A.H., Wayayok, A., 2017. Analysis of meteorological and hydrological droughts in the Niger-South Basin, Nigeria. Global Planet. Change 155, 225–233.

Onuzurike, V.T., 2008. Thesis Titled "Oil Bunkering in Nigeria's Niger Delta Region (1990 – 2007), Trend, Practice and Economic Implication".

Ordonez, I., 2016. Nigeria: Chevron loses 35,000 b/d to attack in Chevron-operated Okan platform. Sweet Crude: A Rev. Niger. Energ. Ind. 5. The Vanguard, 8 May.

Overall, R., 2008. "Buying Knowledge" Published in World Bunkering Issue 62.

Phil-Eze, P.O., Okoro, I.C., 2009. Sustainable biodiversity conservation in the Niger delta: a practical approach to conservation site selection. Biodivers. Conserv. 18, 1247–1257.

Polyak, Y.M., Bakina, L.G., Marina Chugunova, V., Mayachkina, N.V., Gerasimov, A.O., Bure, V.M., 2018. Effect of remediation strategies on biological activity of oil-contaminated soil - a field study. Int. Biodeterior. Biodegrad. 126, 57–68.

Premium Times, 2017. Vandals cut Nigeria's oil production by 800,000 barrels per day. Internet: http://www.premiumtimesng.com/news/top-news/203515-vandals-cut-nigerias-oilproduction-800000-barrels-per-day-kachikwu.html. (Accessed 16 May 2017).

Rayment, G.E., Lyons, D.J., 2011. Soil chemical methods: Australasia. CSIRO publishing 3.

Salman, S.A., Shahid, S., Afan, H.A., Shiru, M.S., Al-Ansari, N., Yaseen, Z.M., 2020. Changes in climatic water availability and crop water demand for Iraq region. Sustainability 12, 3437.

Sa'adi, Z., Shiru, M.S., Shahid, S., Ismail, T., 2019. Selection of general circulation models for the projections of spatio-temporal changes in temperature of Borneo Island based on CMIP5. Theor. Appl. Climatol.

Shell Petroleum Development Company, 2007. Environmental Performance: Oil Spills and Managing Our Facilities. Published by Shell Companies in Nigeria: Shell Petroleum Development Company, Shell Nigeria Exploration and Production Company, Shell Nigeria Oil Products and Shell Nigeria Gas Ltd.

Shell Petroleum Development Company, 2018. Oil Spill Data. Shell Petroleum Development Company. http://www.shell.com.ng/environment-society/environment-tpkg/oil-spills.html.

Shiru, M.S., Shahid, S., Alias, N., Chung, E.-S., 2018. Trend analysis of droughts during crop growing seasons of Nigeria. Sustainability 10, 13, 871.

Shiru, M.S., Shahid, S., Chung, E.-S., Alias, N., Scherer, L., 2019. A MCDM-based framework for selection of general circulation models and projection of spatio-temporal rainfall changes: a case study of Nigeria. Atmos. Res. 225, 1–16.

Shiru, M.S., Chung, E.-S., Shahid, S., Alias, N., 2020a. GCM selection and temperature projection of Nigeria under different RCPs of the CMIP5 GCMS. Theor. Appl. Climatol.

Shiru, M.S., Shahid, S., Dewan, A., Chung, E.-S., Alias, N., Ahmed, K., Hassan, Q.K., 2020b. Projection of meteorological droughts in Nigeria during growing seasons under climate change scenarios. Sci. Rep. 10, 10107.

Sojinu, O.S.S., Wang, J., Sonibare, O.O., Zeng, E.Y., 2010. Polycyclic aromatic hydrocarbons in sediments and soils from oil exploration areas of the Niger delta, Nigeria. J. Hazard Mater. 174, 641–647.

Steiner, R., 2010. Double Standard Shell Practices in Nigeria Compared with International Standards to Prevent and Control Pipeline Oil Spills and the Deepwater Horizon Oil Spills. Milieu Defensie the Netherlands, Amsterdam.

Talukdar, R., 2018. Sparking a debate on coal: case study on the Indian Government's crackdown on Greenpeace. Cosmopolitan Civil Soc. J. 10 (No. 1), 47–62.

The Nation Newspapers, 2017. FG lost N2trn to militancy, pipeline vandalism in 2016. Internet: http://thenationonlineng.net/nigeria-lost-n2tn-militancy-pipeline-vandalism-nnpc-2/. (Accessed 28 October 2016).

The New Diplomat, 2016. Apprehension as Nigeria Crude Production Drops by 67,000 Bpd 25, pp. 1–2. April—May 9, 2(15).

Tunde Imoobe, B.O., Iroro, T., 2009. Ecological restoration of oil spill sites in the Niger delta, Nigeria. J. Sustain. Dev. Afr. 11 (2), 54–65.

Ubani, C.U., 2016. Overview of the performance of the Nigerian. Oil and Gas Sector 1 (2), 76–92 (1981-2014).

Umar, H.A., Abdul Khanan, M.F., Umar, D.A., Shiru, M.S., Isma'il, M., Mohd Salleh, M.R., Abdul Rahman, A., Ahmad, A., Okoli, E.A., 2018. Mapping potential habitats for arthropod vectors of trypanosomiasis infection in Northern Nigeria: an introductory synthesis. Int. Arch. Photogram. Rem. Sens. Spatial Inf. Sci. XLII-4/W9, 147–152.

United Nations Development Programme, 2006. Niger Delta Human Development Report. United Nations Development Programme, Lagos.

United Nations Environment Programme, 2011. Environmental assessment of Ogoni land, Nairobi, p. 262. Available: https://postconflict.unep.ch/publications/OEA/UNEP_OEA.pdf. (Accessed 18 March 2020).

Watts, M., 2008. The Rule of Oil: Petro-Politics and the Anatomy of an Insurgency: in the Nigerian State, Oil Industry and the Niger Delta. International Conference Organized by the Department of Political Science, Niger Delta University in Collaboration with the Centre for Applied Environmental Research, University of Missouri, Kansas City, At Yenagoa, Nigeria. March 11–13.

Watts, M., Okonta, I., Kemedi, D.V., 2004. Economies of Violence: Petroleum, Politics and Community Conflict in the Niger Delta, Nigeria. Niger Delta: Economies of Violence. Institute of International Studies, University of California, Berkeley; The United States Institute of Peace, Washington DC; Our Niger Delta, Port Harcourt, Nigeria.

William, A.B., Benson, N.U., 2010. Interseasonal hydrological characteristics and variability in surface water of tropical estuarine ecosystems within Niger delta. J. Environ. Monit. Assess. 165 (1-4), 399–406.

World Bank, 1995. Defining an Environmental Management Strategy for the Niger Delta. Report Prepared by Jasdip Smigh, David Moffat and Olof Linden. Industry and Energy operations division, West African Department, World Bank, Washington D. C.

Xie, Z., Yan, J., 2013. Detecting traffic accident clusters with network kernel density estimation and local spatial statistics: an integrated approach. J. Transport Geogr. 31.

Yakubu, L., 2008. Nigeria Loses N5.8b Daily to Gas Flaring. The Guardian News Paper: an online version,, 5th August.

Yakubu, O., 2017. Addressing environmental health problems in Ogoniland through implementation of United nations environment program recommendations: environmental management strategies. Environments 4 (2), 28.

Zabbey, N., Sam, K., Onyebuchi, A.T., 2017. Remediation of contaminated lands in the Niger Delta, Nigeria: prospects and challenges. Sci. Total Environ. 586, 952–965.