Assessment of Seismic Survey Line Cutting on Mangroves in the Kalabari Region of River State, Nigeria

[1]Akpomrere R., [1]Ogbijara U., [2]Eyo E. & [1]Okwuashi O.
[1]Department of Surveying & Geoinformatics, Delta State University of Science & Technology, Ozoro
[2]Department of Surveying & Geoinformatics, Federal University of Technology, Minna

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Seismic survey line cutting is a common practice in the oil and gas industry. This research, in the Kalabari region of River State, Nigeria, assessed the impact of seismic survey line cutting on mangrove ecosystems from 1996 to 2012/2013. Employing field surveys, visual on-spot analysis, and mathematical calculations, the study showed a significant increase in mangrove tree densities in newer lines, indicating potential facilitated access for harvesting. T-test analysis demonstrated a statistically significant variance in mangrove tree densities cut between the old and new lines. The study reveals that cuts made in 1996 still had visible impacts in 2013, indicating long-term nature of the damage. The surveyed area was divided into grids for assessment, totalling 333.97 km^2, with 4.18 km^2 impacted by seismic line cuts. The findings suggest that 13 square metres of mangroves were destroyed per square kilometre due to these activities, highlighting significant harm to the ecosystems. Understanding these impacts is vital for effective conservation and sustainable management practices. The study recommends extensive revegetation efforts for restoration in the area.

Keywords: Seismic, Survey Line, Mangroves, Effects

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INTRODUCTION

The Kalabari region of River State, Nigeria, is home to a diverse array of mangrove ecosystems that play a crucial role in maintaining the health and stability of the coastal environment. Apart from the global climate change and its effects such as rise of temperature, sea level, atmospheric CO2 etc., their decline is mainly related to human activities. In terms of degradation, major oil spills have occurred that have devastated rivers, killed mangroves and coastal life and affected the health and livelihoods of millions of inhabitants (Amnesty International Australia, 2009; Sun et al., 2024). Also, one pervasive practice within the oil and gas industry is seismic survey line cutting, which poses potential harm to mangroves.

Mangroves perform an integral role in coastal ecosystems, delivering a range of ecological and socio-economic advantages (Alongi, 2002). Mangroves also play a valuable role in supporting fisheries, and in protecting coastal communities and agricultural land from coastal storms and other natural hazards (Gnansounou *et al*., 2024). The United Nations Conference on Environmental and Development (UNCED, 1992), stressed the importance of conserving mangroves forest and developing the renewable resources in a wise and sustainable manner (Anu *et al*., 2024). The implication of this information is that the functions of mangroves, in terms of supply of renewable resources, should not be threatened. Economic operations in or near mangroves must be undertaken in a manner which minimizes, to the greatest possible extent, damages to the mangrove ecosystems. Despite their importance, mangrove vegetations are threatened all over the world by direct and indirect causes (Cui *et al*., 2024).

Seismic surveying, an essential process to offshore drilling, entails the creation of shock waves that are transmitted through the earth's crust, details of which are then analysed to determine the presence, size, and shape of sub-terrestrial oil and gas reserves (Hardisty, 2010). This is usually accomplished using air guns that generate a high-pressure wave, and hydrophones or geophones that pick up the signal bounce back, after reflection off sub-terrestrial strata. A clear line of sight or "shot line" is required for the seismic waves to travel. In terrestrial or semi-terrestrial settings such as mangroves, this often leads to line-cutting, a process that involves clearing a pathway through the vegetation (Alao *et al*., 2020). Seismic survey procedures vary depending on the location and the scale of the operation. In sensitive environments such as mangroves, work is generally carried out on foot using a minimum of equipment. The seismic operational activities involve survey line cutting, drilling, layout of cables and geophones, recording, pickup/clean-up and restoration. All these activities take place in the cleared survey lines. Despite efforts on a global scale to conserve the outstanding biodiversity, climate regulation, and food security values of mangrove forests, the Kalabari region has been subjected to this destructive practice with little reflection on potential environmental implications. Increasingly, scientific literature and findings question the sustainability of such practices, considering their wide-ranging negative impacts on the ecological and hydrological functionality of mangroves (Friess & Webb, 2014). This work is an assessment of the effects of seismic survey line-cutting on mangroves in the Kalabari region, bringing attention to the damage caused to these vital ecosystems and the implications for local communities that rely on them for their livelihoods (Brown *et al*., 2022). By shedding light on the environmental consequences of line-cutting practices, this research hopes to promote greater awareness and conservation efforts to protect mangroves and the benefits they provide to both nature and society.

LITERATURE REVIEW

The growing body of research on the detrimental effects of seismic survey activities on mangrove ecosystems underscores the urgent need for action to protect these valuable coastal habitats. Studies conducted in various regions including the Gulf of Mexico, Indonesia, and Australia have consistently shown the harmful impacts of seismic surveys on mangrove habitats. In the Gulf of Mexico, for example, research by Garcia *et al*. (2017) revealed widespread mangrove deforestation and habitat fragmentation as a result of seismic surveying. The increased noise levels and vibrations from the surveys disrupt the natural processes of mangrove growth and regeneration, leading to long-term ecological impacts.

Similarly, studies in Indonesia by Tan *et al*. (2019) demonstrated that seismic survey activities in mangrove areas led to changes in soil composition and nutrient levels, affecting the overall health of the mangrove forests. In Australia, research by Smithson *et al*. (2020) documented changes in mangrove vegetation structure and dynamics in response to seismic survey operations. The loss of mangrove diversity and resilience in these areas raises concerns about the long-term sustainability of these ecosystems and the need for improved management practices. The disruption in ecosystem functioning caused by seismic surveys has cascading effects on the biodiversity and ecosystem services provided by mangroves, such as coastal protection and carbon sequestration. It is clear that collaboration between researchers, policymakers, and industry stakeholders is crucial to ensure the sustainable management of mangrove ecosystems in the face of increasing anthropogenic pressures. Comprehensive assessments and conservation measures are urgently needed to protect these valuable coastal habitats for future generations. Also, a study conducted by Bakare (2016) indicated that seismic line cutting within these fragile ecosystems leads to habitat fragmentation, consequently resulting in the loss of flora and fauna. He suggests that the ecological balance of mangrove swamps is being affected by various environmental factors such as climate change, pollution, and human activities.

Addressing the cumulative impacts of multiple stressors, including climate change and coastal development, is crucial in developing effective management strategies for mangroves in the face of increasing threats from seismic survey activities (Bosire *et al*., 2015). By incorporating scientific evidence and stakeholder input into policy development and industry practices, a balanced approach can be achieved to mitigate the adverse effects of seismic surveys on mangrove ecosystems while meeting the needs of various stakeholders (Spalding *et al*., 2016). In conclusion, the growing body of research underscores the urgent need for coordinated efforts to protect mangrove forests from the harmful impacts of seismic survey activities. By integrating scientific knowledge, policy interventions, and industry best practices, it is possible to preserve the ecological integrity and ecosystem services provided by mangroves, ensuring their long-term sustainability in the face of unprecedented challenges.

The impacts of seismic survey line cutting on mangrove ecosystems in the Kalabari region of River State, Nigeria, have been investigated by several researchers. Ekundayo and Obuekwe (2000) conducted a study to assess the effects of seismic activities on the mangrove vegetation in this region. Their findings revealed that the seismic survey line cutting resulted in significant damage to the mangrove trees, with up to 60% of the trees being affected (Ekundayo & Obuekwe, 2000).

Omokhehe *et al*. (2015) further examined the long-term impacts of seismic survey line cutting on the regeneration and recovery of mangrove forests in the Kalabari region. The study showed that the disturbed mangrove areas had a reduced species diversity and a lower density of mangrove seedlings and saplings compared to undisturbed reference sites (Omokhehe *et al*., 2015). This suggests that the seismic survey line cutting has hindered the natural regeneration of the mangrove ecosystem.

Additionally, Abowei and Sikoki (2005) investigated the impact of seismic activities on the associated faunal communities within the mangrove forests. They found that the abundance and diversity of benthic invertebrates, crustaceans, and fish species were significantly lower in the areas affected by seismic survey line cutting compared to the undisturbed mangrove areas (Abowei & Sikoki, 2005).

Furthermore, in Osuji *et al*. (2006), a survey and assessment of the mangrove system in seven communities in the Niger Delta (Nigeria) impacted by seismic and production activities provided valuable insights into the environmental changes in the region. The analysis conducted revealed significant alterations in soil composition, sediment structure, and vegetation distribution. Upon closer inspection, it was found that the levels of hydrocarbons in the soil ranged from 0.3 to 1.1 mg/100 g near spill sites and seismic lines. These high levels of hydrocarbons can have detrimental effects on the overall health of the mangrove ecosystem. The mangrove forest in the study area was found to be diverse, with Rhizophora racemosa being the dominant species. However, the construction of seismic lines was observed to disrupt the natural vegetation patterns, leading to the growth of species like Paspalum vaginatum and Acrostichum aureum near dredge spoils. This disruption in vegetation distribution could have long-term consequences on the biodiversity of the area. Various factors such as tidal inundation, substrate mobility, salinity fluctuations, and anoxia were identified as potential contributors to the degradation of plant species near the seismic lines and hydrocarbon sources. These environmental stressors could further exacerbate the existing challenges faced by the mangrove ecosystem in the Niger Delta. In conclusion, the reconnaissance survey and laboratory appraisal of the mangrove system in the Niger Delta highlighted the need for conservation efforts and sustainable management practices to protect the fragile ecosystem from further degradation. Collaborative efforts from government agencies, local communities, and industry stakeholders are essential to ensure the long-term health and resilience of the mangrove ecosystem in the region.

MATERIALS AND METHODS

Study Area

The Kalabari region is located in Rivers State, which falls within the Niger Delta in the Southern part of Nigeria. The Kalabari region is chiefly the mangrove forest type, typified by the Red and White Mangroves (Rhizophora racemosa, R. mangle, and Avicennia germinans), and accompanied by thick, dense growths of Nypa palms (Nypa fruticans) in brackish water parts of the delta (Akegbejo-Samsons, 2008). This region experiences heavily sediment-laden rivers that form complex systems of channels and creeks, creating islands and an interwoven network of estuaries. These water bodies have significantly influenced the vegetation of the region, making it suitable for various species of fishes, crustaceans, mollusks, mammals, and birds. The inhabitants are primarily involved in activities such as fishing and farming. The region is host to numerous oil and gas companies, which have significantly contributed to the economic growth of Nigeria (Osuji, 2004).

The study area is located in Oil Mining License (OML) 40, covering parts of four local government areas (Akuku- Toru, Asari-Toru, Degema and Emohua) of River State, Nigeria. The prospected regions lie within longitude 475000E-490000E and latitude 65000N-95000N, with an estimated area of about 331.97km^2 (Figure 1).

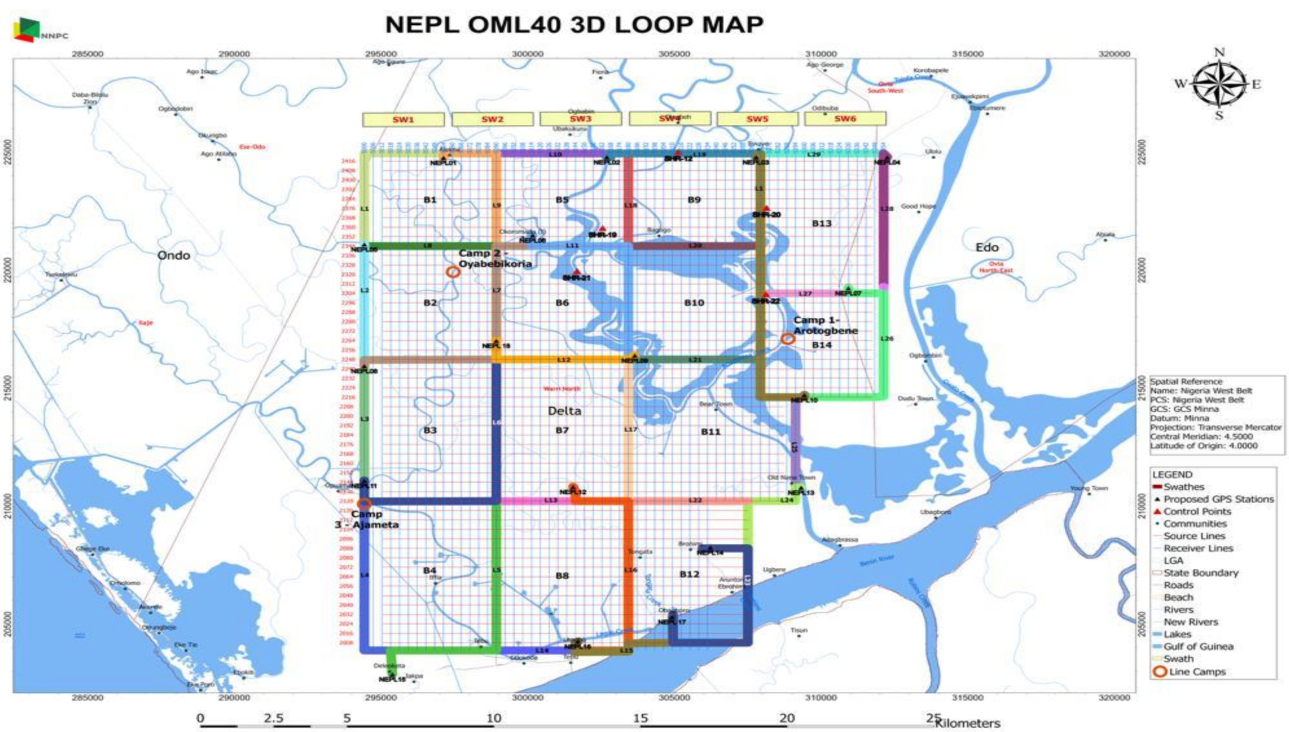

Figure 1: Area of prospect used for the study (BGP/CNPC, 2012)

OML 40, (study area) fell in the regions lying close and far from the Sambreiro River that are subjected to the upper inter-tidal area, with extensive channel and creek system but no major freshwater inputs.

Seismic Survey Procedure

The seismic operational activities involve survey line cutting, drilling, layout of cables and geophones, recording, pick-up/clean-up and restoration. All these activities take place in the cleared survey lines. A seismic survey line is a pre-determined route that is cut, cleaned and traversed. The lines are set out to define point positions unambiguously for the use of the Drills and Recording sections. A 3D seismic operation in forested mangroves areas entails cutting straight lines through the mangroves to acquire seismic data. These seismic lines are also access trails along which equipment is carried by hand.

For the prospect, the area was gridded into 41 vertical lines (receivers) and 77 horizontal lines (source). The distance between a receiver line to the next one was 350 metres while the distance between a source line to the next was 400 metres (Figure 1). Also, the distance apart from one geophone peg to another was 50 metres and deep hole drilling of 45 metres was used. Line width varies between 1 and 2metres.The lines must be of sufficient width to safely transport man-portable drills, cables and equipment along their length. For 3D seismic operations shot points or holes are drilled with man-portable drills of depths ranging from 10 metres to 20 metres. Figure 2 shows a fresh 1.5m wide cut and cleansed seismic line.

Figure 2: A fresh seismic line in 2012

Figure 3: A seismic line of 1996

Materials and Methods

The method used in this study was on- the - spot observation of seismic survey operation and counting of cut trees between the new prospecting area 2012/2013 and those of 1996 as shown in Table 1. The field research observations were undertaken in six old seismic survey lines (3 receiver and 3 source) cleared in 1996 (Figure 3), sixteen years before the re-shoot prospect of 2012 and six new other lines (three sources: 1513, 2025 and 2505 and three receivers: 5771, 5967 and 6191). Of these lines, some were cleared August 2012, (which is about sixteen years to that of 1996), January 2013 (six months from August 2012) and three months later in April 2013. Figures 2, 4 and 5 show the cleared lines of August 2012, January 2013 and April 2013 respectively. The seismic lines studied have length of 30.40 km for the receivers and 10.92 km for the sources. These lines cut across numerous creeks and speed boat was used to ferry the crew members across the creeks. Some parts of the lines chosen were closed to fishing camp communities while others were far from human settlements. The study area was reached in speed boats and work was carried out on foot using the seismic lines. Each seismic line was traversed by at least six separate work crews (minimum crew numbers are given in brackets): surveyors and line cutters (8) carrying a Total

Station and its accessories, 3 tripods, 3 ranging poles and 5 machetes defined the line and cleared vegetation; drilling crews (8) took a generator, pipes and compressed air hose down the line and drilled holes for seismic charges; pre loading crews (5) laid charges; recording crews (10) laid geophones; shooting crews (5) laid detonators, possibly travelling the lines more than once to resolve problems; and, after firing, removal crews (10) cleared the area of equipment. Figure 3 shows a seismic line where all seismic survey parties have worked.

Table 1: Number of mangrove tress cut

Line type	Mangroves cut above 15cm girth	
	Living	**Dead**
Source (new)	10	3
	15	5
	18	2
Receiver (new)	12	2
	16	3
	9	3
Source (old)	3	3
	1	2
	2	2
Receiver (old)	2	2
	1	3
	2	3

Figure 4: A worked upon seismic line in 2013

Figure 5: Seismic line 2013 (at high tide)

It can thus be assumed that the seismic lines were 'walked' a minimum of 92 times (in and out) and, where lines were long and otherwise inaccessible, as is probable in larger areas of mangrove, crews may have again traversed ground they had already worked on in order to progress. This would have resulted in sections of line being walked 184 or 276 times if two or three passes were made. In addition, at 50 m intervals, drilling crew drilled shot holes, which then became the focus of subsequent work crews resulting in further trampling.

Coverage computation

The prospected area of study was gridded into 41 parallel receiver lines of 30.40 km each and 77 parallel source lines of 10.92 km each (Figure 1)

Assumptions:

Total area of study was covered with mangroves.

Maximum width of seismic line cut and cleaned was 2m.

Formulation:

Area from Receiver Lines (Ar) = (Lr x W)/1000x Nr (km^2)

Area from Source Lines (As) = (Ls x W)/1000x Ns (km^2)

Total Area from Cleared Lines = Ar + As (km^2) and

Total Area of Study = (Lr)(Nr) x (Ls)(Ns) (km^2).

Where,

Lr is length of receiver line

Ls is length of source line,

W is width of line

Nr is number of receiver lines

Ns is number of source lines.

RESULTS AND DISCUSSION

Results

Computed areas

The total area of study was 333.97 km^2. Area from Receiver Lines (Ar) was 1.68 km^2 and area from Source Lines (As) was 1.68 km^2. The total area from cleared lines was 4.18km^2.

Differences in mangrove post-seismic survey recovery

Total tree densities (including living and dead trees) differed between the two periods of 1996 and 2012/ 2013 under consideration. The mean (13.33)/(1.83) and standard deviation (3.69)/(0.69) for 2012/2013 and 1996 respectively of living and dead mangroves cut above 15cm girth are higher for the new lines compared to the old lines. This suggests that the new lines have had a greater impact on mangroves, leading to more mangroves being cut above 15cm girth. The standard deviation values indicate that the data points are more spread out for the new lines, showing more variability in the impact on mangroves. The range values also support this, with a wider range for the new lines compared to the old lines although there was more gap coverage for the 2012/2013 lines as the prop roots of some mature mangroves had spread to the lines in high dense mangroves regions (Figure 3). The median values for both datasets ((13.5/2) are close to the mean values, indicating that the data is relatively symmetrically distributed.

T-test analysis using $t = (mean_1 - mean_2) / sqrt((s_1^2/n_1) + (s_2^2/n_2))$ with 10 degrees of freedom, the p-value for a two-tailed test is less than 0.001, indicating that the difference between the means is statistically significant at the 99.9% confidence level suggests that there are significant differences in the mean scores of mangroves cut above 15cm girth between the new and old lines.

Discussion

Seismic-related differences in tree density and distribution

Given the nature of seismic exploration in mangroves with its associated removal of all trees in lines approximately 2m wide, the greater number of dead trees in the seismic lines was expected. The mean and median values for living and dead mangroves cut above 15cm girth are higher for the new lines compared to the old lines.

It has been suggested that canopy gaps in mangroves might play an important part in recovery from disturbance by improving survival rates and promoting increased abundance and growth rates (Clarke & Kerrigan 2000, Sherman *et al*., 2000). The pattern of cutting suggests that seismic survey lines have become access routes to the mangroves, facilitating harvesting from previously inaccessible areas. Cutting was highest in regions closed to communities. Some of the Local community people perceived clearance lines as paths, and evidence of firewood collection was observed on the 2012/2013 lines during surveying. From the computed areas it can be inferred that, about 333.97 km^2 of mangroves coverage of the study area, 4.18 km^2 of mangrove coverage had been destroyed by seismic line cutting and the soil laid bared to agent of denudations. This means that for everyone kilometres squared mangroves, approximately thirteen metres squared of it is destroyed from seismic survey line cutting.

Mangroves recovery over time

During surveying, it was noticeable that there were few seedlings and saplings in the immediate area of the seismic lines, despite the time difference in their clearance. Reasons for this are probably the trampling effect when the lines were originally cleared, ongoing trampling, and changes in the soil hydrology due to the loss of trees. Trampling has been shown to break down the mangrove surface root layer and alter the structure of the mangrove sediments, and recovery from such impacts probably takes several years due to the slow growth rate of mangrove root systems (Dye, 2006). This loss of root material can also lead to a reduction in anaerobic conditions, resulting in reduced microbial activity, especially that of sulphate reducers (Alongiand de Carvalho, 2008), and increased levels of (toxic) sulphide, which inhibits seedling and mangrove growth (Hogarth, 2007).

While some level of recovery may have occurred in the sixteen years since seismic surveying of 1996, the surface root layer of the mangroves remained affected. Ongoing trampling and cutting would further hamper recovery by preventing seedling establishment. Trampling also disrupts the surface topography and soil stability of mangrove mud and, combined with the loss of trees, can lead to increased tidal flushing, which slows down mangrove recruitment; seedlings are washed away before they become established if the soil lacks stability (Kaly *et al*., 1997). The seismic line exposes the soil (Fig 4) to flushing which can also result in reduced levels of nutrients (Kaly *et al*., 1997; Alongi & de Carvalho, 2008), and research on the effects of nutrients on Rhizophora mangle seedlings shows that phosphorous is a limiting factor in seedling development and, even when present, water-logged (Figure 3) and anoxic soils render it ineffective (Koch andSnedaker, 1997). This suggests that it may be necessary to artificially maintain soil profiles and increase nitrogen and phosphorus levels in damaged systems to aid their recovery (Kaly*et al*., 1997; Alongiand de Carvalho, 2008).

CONCLUSION

Areas cleared along the seismic survey lines in the study region had been subjected to additional local mangrove cutting. The combined effect of seismic clearing and local cutting was significant. The present study shows that for everyone kilometres squared mangroves, approximately thirteen metres squared of it is destroyed from seismic survey line cutting and the soil laid bared to agent of denudations. Although, the seismic lines surveyed did not show signs of recovery (Fig. 4 and 5), future research should target seedling and sampling abundance and growth in the lines, and soil structure, organic content and nutrient levels. This should elucidate any persistent effects of mangrove clearing and provide the information needed to develop appropriate mitigation measures to facilitate recovery.

An assessment of local use of the mangroves might also establish the degree to which seismic lines are being used as access routes after their creation. Future seismic surveys in mangroves need to incorporate monitoring of forest recovery, activities to promote regeneration, and the prevention of secondary impacts. Current guidelines specify that the area to be cleared should be minimal, line width to be one metre and mature trees should not be cut (the path should go around them by offsetting) and branches should not be trimmed above the line of sight in an effort to retain the canopy. The line cleaners should be supervised to ensure that the lines are not cleared to ground level. By adopting this procedure, vegetation is expected to regenerate within a short period of time.

Vegetation cut during clearance should be left at the side of the lines to acts as barrier, discourage access to the forest and mitigate exacerbation of the environmental impact of their removal and efforts (awareness campaigns, appropriate warning signs etc.) should be made to discourage communities from converting such traverses into access routes.

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