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Severity Risk Analysis Matrix Ranking (SRAMR) for Oil-Spill Contingency Planning: Asemoku-Agip Pipeline in Perspective

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Abstract

One of the down sides of crude oil exploration and exploitation in the developing nations is its impacts on the environment. A major manifestation of poor crude oil management is oil-spillages. Mitigation strategies have been too expensive, but a cheaper recent way of managing crude-spills is by developing a severity risk analysis matrix ranking (SRAMR). The spatial data-sets deployed in this study were acquired from the USGS, Google Earth Pro, and NOSDRA. A buffer zone of 100 - 400 meters was created to characterize the LULC characteristics of the area. Also, this was to help develop a risk sensitivity characteristic. The study found that the vegetal cover was the environmental resource at high risk to crude-spills in the area, while other land-uses were at low risk of crude-spill. It is hoped that the finding from this study informs policy development and planning for crude oil spill incidents.

Keywords

Land-Use/Land-Cover, Asemoku, Crude-Spills, Severity-Risk-Analysis

1. Introduction

Crude oil syphoning has since (1960s) replaced the production of agro products as Nigeria's main export earner (Akpotor, 2019). This black gold has brought to the country many advantages that include infrastructural development, provision of funds for economic stability etc. (Abdulkareem et al., 2021). In the same sweep, in the process of transporting the syphoned crude, serious harm is done to the environment, through spill (Abianji-Menang, 2021). When these spills happen it is pertinent to deploy strategic means to protect the environment, while mitigating the spill effects (Grubesic et al., 2019). Geospatial tech represents one of the contemporary options for managing spills globally (Yekeen et al., 2020).

The use of geospatial has been noted to be very useful and helpful in oil spill assessments and analysis (Akinwumiju et al., 2020). This is because of the ability to access, data, analyse them and then see the spatial aspects of the spill (Zeng & Wang, 2020). This tech (geospatial techniques) allows the investigator, to check the spill for same site or multiple sites at the same time and with minimal time (Ullah et al., 2021). Geographic information systems (GIS) techs allow an investigator to identify the sensitive aspects of the environment to environmental pollutants such as oil spill (Pieri et al., 2018). This makes spills monitoring and sensitivity mapping easy (Jafarzadeh et al., 2021).

Several environmental challenges result from crude oil pollution (Godspower et al., 2023; Okumagba & Ozabor, 2016). These challenges includes, soil degradation (Bhattacharyya et al., 2015), forest fires (Nwagbara et al., 2017), water pollution, with the attendant consequences for aquatic animals (Ushurhe et al., 2024), and even air pollution (Ozabor & Obisesan, 2015). The pollution in the environment has some consequences for man. The infertile lands could impact on the livelihood of the people consequently causing serious migration problem (Hollos et al., 2009). Diseases are also bound to spread (Ozabor & Obaro, 2016). Hunger and food insecurity is another challenge that can happen if adequate steps are not taken to curb oil spill issues in our environment (Babatunde, 2023). Today, it is clear that the global community have taken environmental monitoring seriously, however, the same cannot be said of the developing ones (Litvinenko et al., 2022; Ozabor & Nwagbara, 2018). Deploying Environmental Sensitivity Analysis (ESA) and applying the Environmental Sensitivity Index (ESI), represents a modern step targeted at reducing environmental consequences resulting from crude spill (Wekpe et al., 2024). Very scan attempt have been made to deploy this technique for crude oil spill management in Nigeria (Singh et al., 2012). As a result of that deficiency this study focuses on developing and environmental sensitivity index of the study area, by articulating the risks and sensitivity mapping of the study area with a view to identifying emergency response zones, in the event of oil spill.

2. Materials and Methods

2.1. Study Area

The area where this study was carried out is the Asemoku area, which is located in the Ndokwa East local government area (LGA) of Delta State (Otutu, 2011). The geographic features that surround the area include to the west Isoko North, South by Oshimili South, the north by Aniocha South and to the east the area is bordered by River Niger (see **Figure 1**). Using the coordinates the area lies on latitude 5.55˚ and 5.69˚ North and longitudes 6.40˚ and 6.56˚ East. The extent of crude oil is Lon. X_ 6.5616111, Lat. Y_5.6505833 respectively.

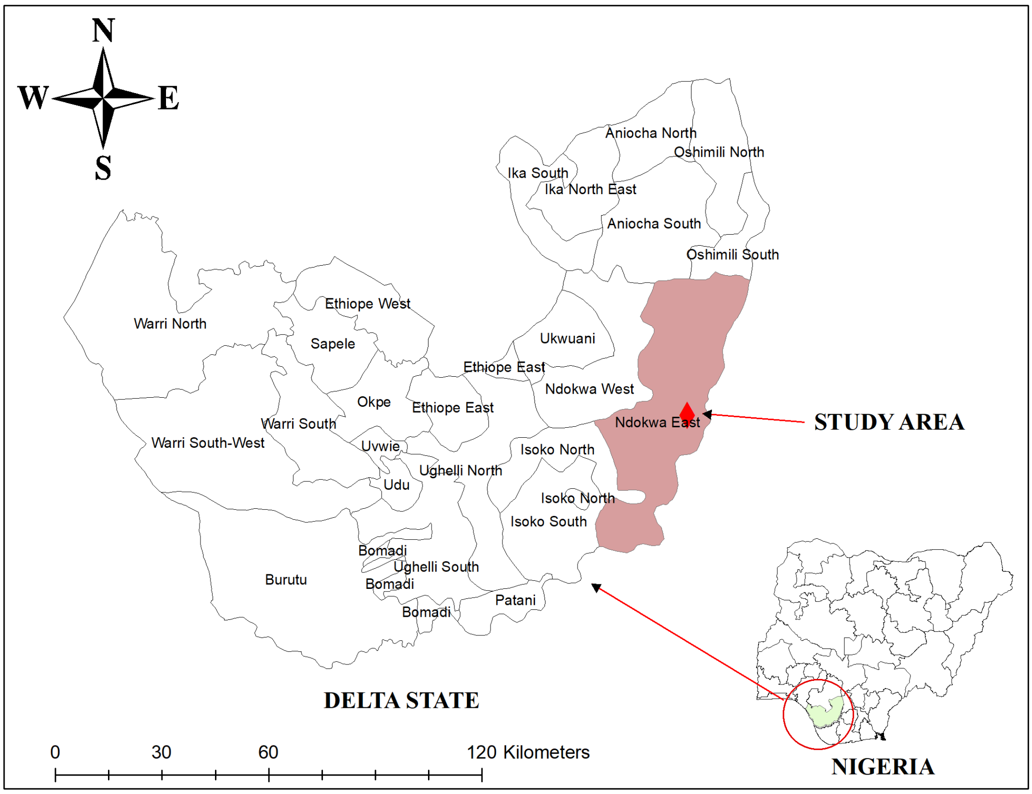


Figure 1. Map of Delta State showing Ndokwa East.

It is also important to itemize the economic activities of the people in the area. The area is situated on the tropical belts based on the Koppens classification. This means that the area enjoys annual rainfall of up to 1600 mm to 2100 mm. The mean annual temperature ranges between 27˚C to 30˚C. This climate type coupled with favourable edaphic factors, encourages agriculture on the area (Ozabor, 2014). This makes most of the locals' agriculturist. Others are farmers, traders and fishermen (Ushurhe et al., 2023). Thus the issues of oil spill do not only affect the vegetation and soils, but also the sources of livelihood of the locals. Hence a study such as this is not only targeting curbing of the spill problems, but also ensuring eco-sustainability and food security (Pisanò, 2024).

2.2. Method

The primary and secondary sources of data as prescribed by D'Affonseca et al. (2023) were deployed for this study (see **Table 1**). The data was collected from both the government agencies and the non-governmental agencies. The spatial data-sets deployed in this study was acquired from the United States Geological Surveys (USGS) (Mays et al., 2012), Google Earth Pro (Taylor et al., 2011), Oil Spill Incident data (Watts & Zalik, 2020) acquired for the data bank of the National Oil Spill Detection and Response Agency (NOSDRA) https://oilspillmonitor.ng/. This is a government owned agency and captures oil spill events across Nigeria (NOSDRA, 2006).

Table 1. The sources and types of ESI data sets and their uses.

DATA TYPE	Landsat Image	Google Earth Pro	Literatures	Pipeline locations
Resolution	**30 m**	Eye altitude between 2.61 km to 6.51 km		
DATE	**2014**	2018		
SOURCE	USGS, NIGERSAT	(c) 2018 Google, (c)	NOSDRA	NOSRA and NNPC data banks
USES	LU/LC classification	LU/LC classification and identification of characteristics	Inland-habitat classification	Location-features coordinates

Source: Authors compilation (2023).

The researchers first conducted a buffer operation (Lee et al., 2010). This ensures that the researchers are able to tell the land-use/land-cover (LULC) that are susceptible to crude-spills in the event of occurrence (Lv et al., 2011). Also, creating a buffer identifies and analyses spatial relationships of features in space. For this study the researchers created a Buffer zone of 100, 200, 300 and 400 meters to carry out this study. This distance has also been deployed by several researchers in the literature (Jaiswal et al., 2002). After processing the image, the ecological classification of 100 - 400 m helped establish the LULC that was susceptible and at risk of the event of a spill (Berisa & Birhanu, 2015) (See **Figure 2**). At the 200 meter buffer the off-set of the pipe line spill-point was established and marked in **Figure 2** in blue, the 300 m buffer zone is marked in purple, while the 400 m buffer zone is marked in light-blue (**Figure 2**). The predetermined buffers helped in the assessment of spread of crude-spills and how the spills could affect susceptible LULC (Smith et al., 1994).

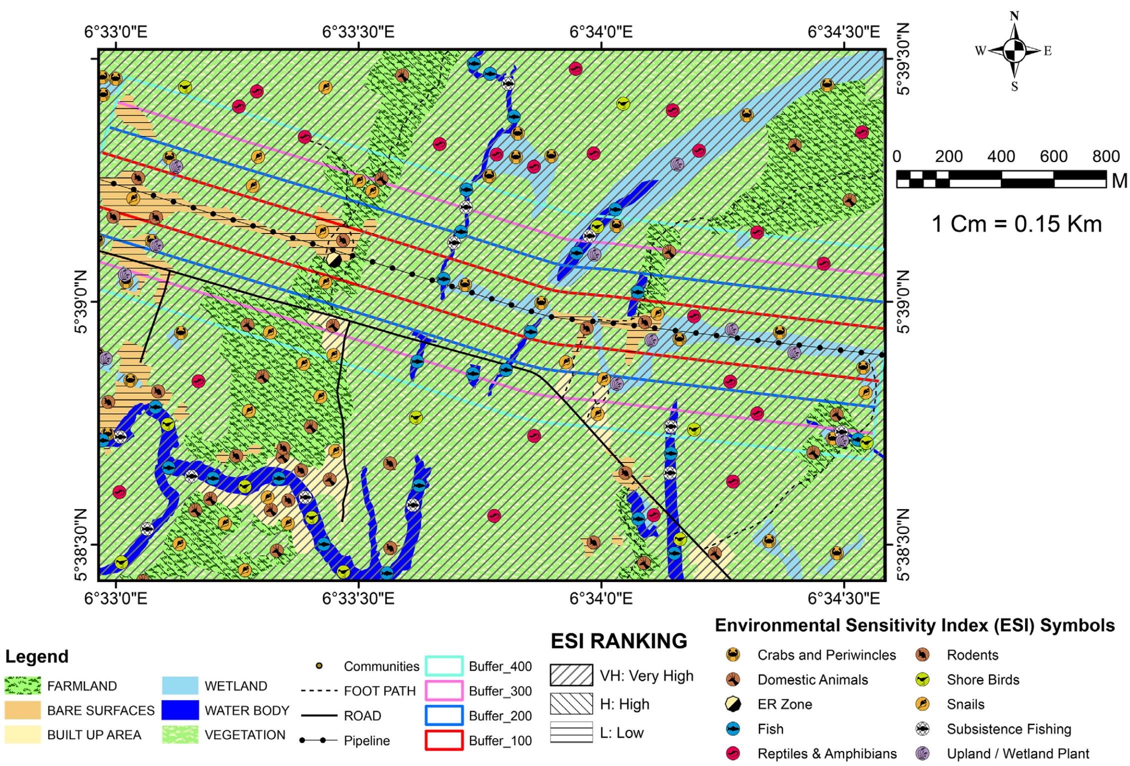


Figure 2. Digitized map of study area.

After the determination of the susceptible assets, the assets were prioritised and ranked based off of the use of the LULC and severity of impact in the event of a spill (Al-Aizari et al., 2024). This was done to point the spill-clean-up team to identifying the area it should concentrate resources first, in the event of a spill (Grubesic et al., 2017).

The sensitivity index ranking method (SIRM) deployed by (Onosemuode et al., 2019) (**Table 2**) was used to characterize a severity risk matrix (SRM) for the study so as to evaluate spill impacts on LULC (Frank & Boisa, 2018).

Table 2. LULC sensitivity ranking and classification.

ESI Classes	VH	H	MH	Low	VL	NS
ESI Ranks	5	4	3	2	1	0

NB: ESI = Environmental Sensitivity Index; VH = Very High; H = High; MH = Moderately High; VL = Very Low; L = Low; NS = Not Sensitive. Source: Modified after Onosemuode et al. (2019).

The sensitivity ranking and classification of Onosemuode et al. (2019) could not conveniently account for the various portions of the LULC in the buffered zones that were affected by oil spill. Rather, the results from such ranking and classification were done on a generalized form (Essien & John, 2011). Hence the researcher has to deploy an SRM which could account for the LULC in all the buffer class. This was to allow for comprehensive accountability for oil spill events (Onosemuode et al., 2019) (See **Table 3**).

Table 3. Determination of the minimum and maximum ESI class.

ESI CLASSES	BUFFER ZONES				TOTAL ESI CLASS
↓	100	200	300	400	
Combination of ESI class from Table 2	1	1	1	1	4
Combination of ESI class from Table 2	4	4	4	4	16
Combination of ESI class from Table 2	1	4	4	1	10
Combination of ESI class from Table 2	3	4	5	4	18
Combination of ESI class from Table 2	5	5	5	5	20

Taking the range of 0 to 20 ESI class, a further classification was carried out to arrive at the ESI class in **Table 4**. Class below 1 is classified as Not Sensitive to oil spill in the study area buffered zone, class of between 1 - 4 the Severity index is classified as Very Low in the buffered zone of the study area, class of 5 - 8 is classified as Low, class of 9 - 12 is considered as Moderately High while 13 - 16 is considered as High and 17 - 20 is Very High severity if impacted by oil spill.

Table 4. Characterization of severity ranking matrix.

Class	ESI Rank
Less than or equal to 0.9	NS
1 - 4	VL
5 - 8	L
9 - 12	MH
13 - 16	H
17 - 20	VH

NB: ESI = Environmental Sensitivity Index; VH = Very High; H = High; MH = Moderately High; VL = Very Low; L = Low; NS = Not Sensitive.

In the determination of land-use/cover the results are always in most cases calculated in areas and percentages. As a result, a further reclassification of the ESI was done in percentages to enable the evaluation of the severity of the oil spill in each buffer zone as shown in Table 5. The impact of 1% - 20% of land-use land cover in the buffered zone shows Very Low severity, 21% - 40% impact of land-use land-cover indicates Low Severity, 41% - 60% impact of land-use land-cover shows a Moderately High Severity in the event of oil spill and 61% - 80% impact shows High severity to oil spill while 81% - 100% indicate Very High severity on the land-use land-cover should oil spill occur. The researchers were able to use the SRM to enable classification of the overall sensitivity of the various LULC of the area.

Table 5. LULC classification of SRM using percentage.

ESI Rank	NS	VL	L	MH	H	VH
Classification Percentage (%)	≤0.9	1 - 20	21 - 40	41 - 60	61 - 80	81 - 100

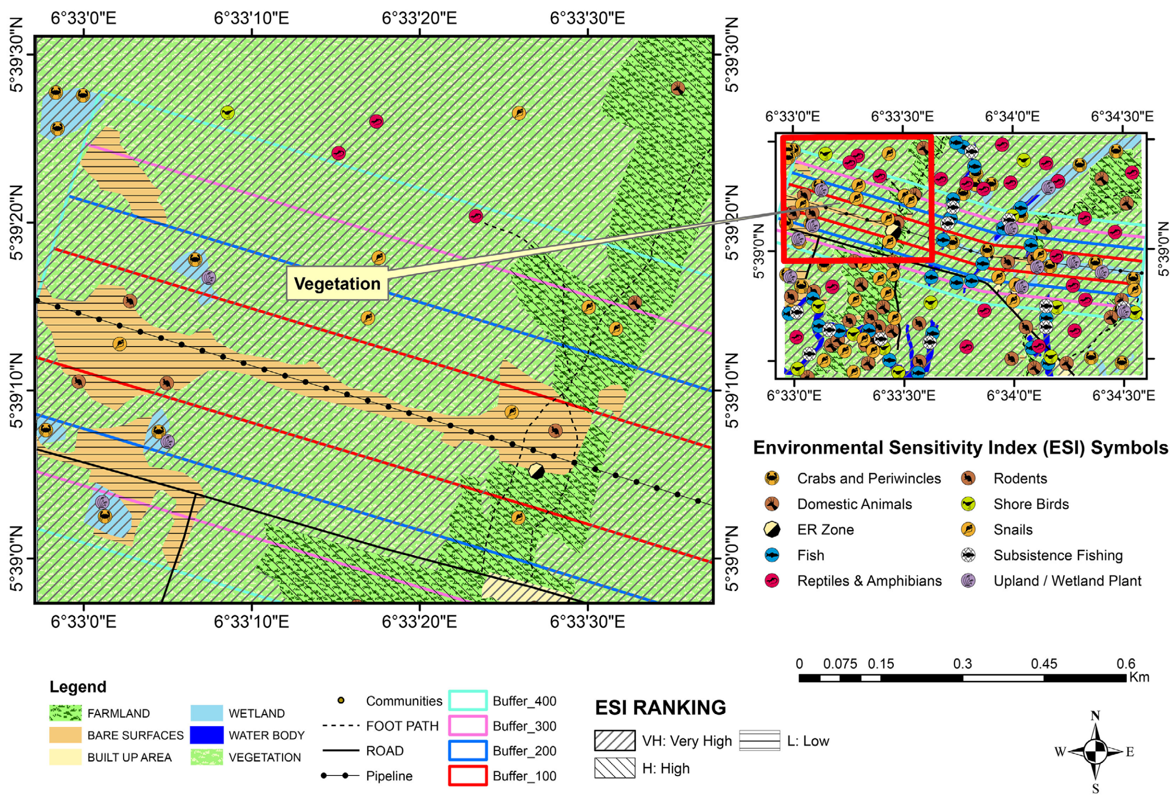
NB: ESI = Environmental Sensitivity Index; VH = Very High; H = High; MH = Moderately High; VL = Very Low; L = Low; NS = Not Sensitive.

3. Results and Discussion

Results of all the classification developed from the processed imagery (figure and percentage coding) using the predetermined buffer standards of 100 - 400 meters respectively are presented. A Risk Analysis map (RAM) of the location, that covered 3 km of the pipeline that traverse the Asemoku area (Figure 2), provided a summary of vulnerable assets in the event of spills in the buffered zones. Table 4 and Table 5 revealed classification of the LULC of the study area.

The vegetation was the LC resource that recorded the largest area of land in the buffer zone. This includes grassland, shrubs, and rain forest. It also is characterized by species like rodent, rabbits, squirrel and grass-cutter, snakes etc. This resource therefore presents the locals with opportunity to hunt and provide meat for their families and sell games for sustenance (Eyetan & Ozabor, 2021). Natural vegetation occupies a total land area of 38.641 hectares at 100 meters

(71.99%), 90.704 hectares at 200 meters (73.75%), 135.979 hectares at 300 meters (73.96%), and 180.213 hectares at 400 meters (73.76%) (Table 6 and Figure 3(a) and Figure 3(b)). The SRI of the vegetation was classed as High (H) having an ESI number of 4 (Table 4 and Table 5). It is therefore going to be very devastating for the locals and the vegetal resources in the event of an oil-spill (Weli & Famous, 2018). This finding agrees with that of Beyer et al. (2016).



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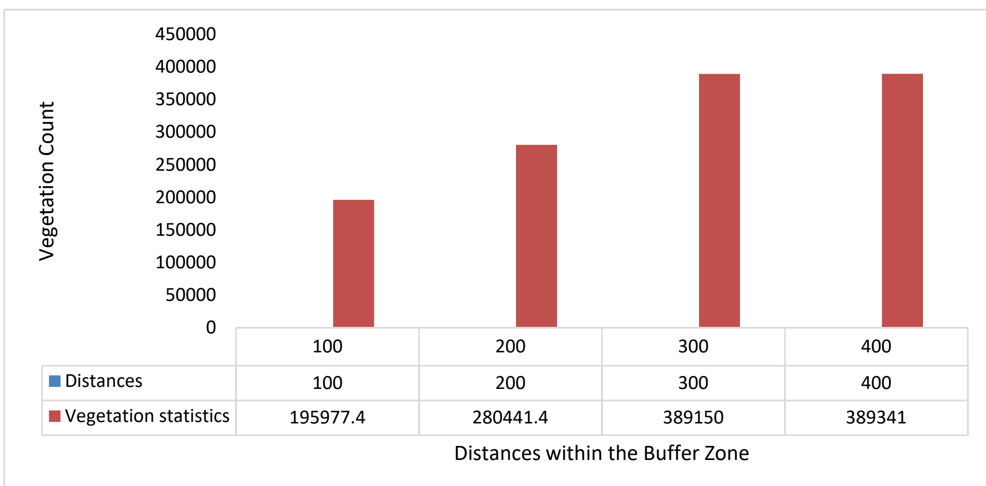


(b)

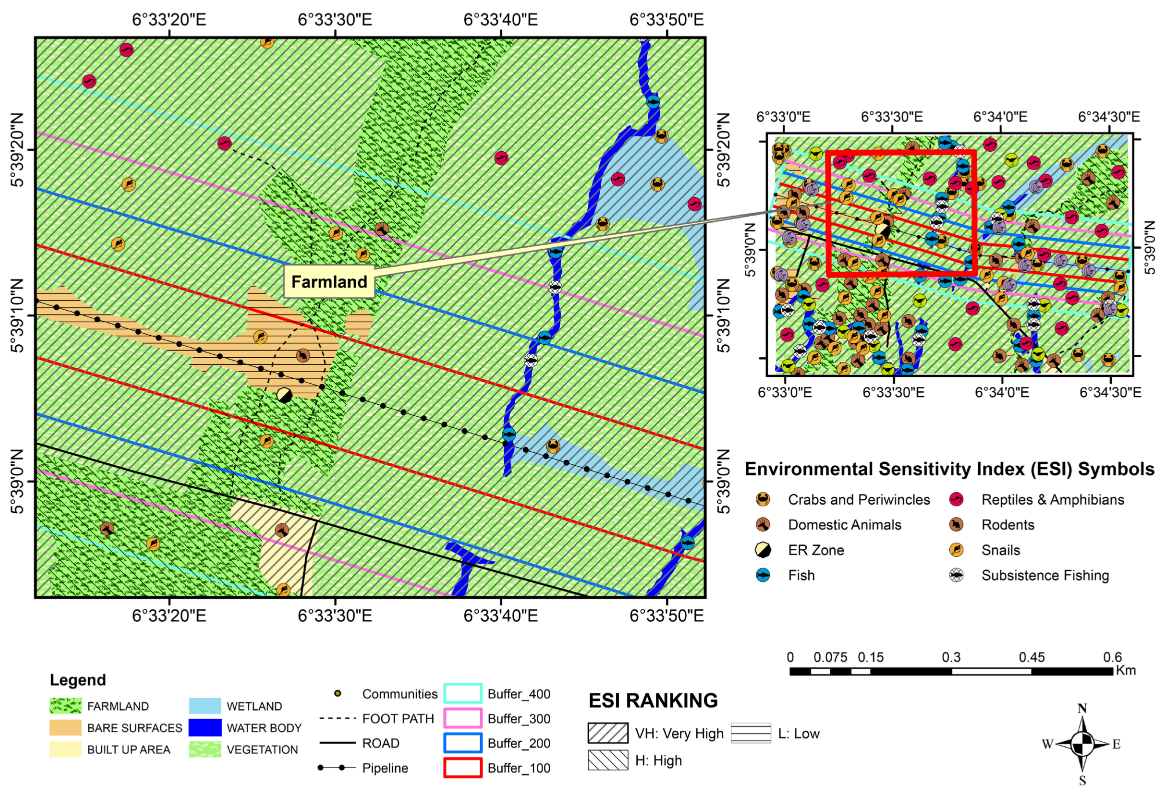
Figure 3. (a) Geospatial analysis showing vegetation at risk in 400 m buffer; (b) Selection statistics of vegetation at risk within 400 m buffer zone.

Table 6. LULC severity ranking matrix.

Risk factors	BUFFER ZONES																TOTAL ESI CLASS	Total Severity
	100 M				200 M				300 M				400 M					
	AREA	%	Severity	ESI CLASS	AREA	%	Severity	ESI CLASS	AREA	%	Severity	ESI CLASS	AREA	%	Severity	ESI CLASS		
Vegetation	38.641	71	H	4	90.704	73.752	H	4	135.97	73.96	H	4	180.213	73.766	H	4	16	H
Farm land	2.469	4.6	VL	1	6.494	5.282	VL	1	13.770	7.490	VL	1	23.205	9.499	VL	1	4	VL
Water body	0.491	0.916	VL	1	1.395	1.069	VL	1	2.613	1.422	VL	1	4.210	1.723	VL	1	4	VL
Wet land	9.396	17.506	VL	1	11.969	9.732	VL	1	13.974	7.601	VL	1	16.637	6.810	VL	1	4	VL
Built up	0.00	0.00	NS	0	0.186	0.15	NS	0	2.163	1.76	VL	1	3.909	1.600	VL	1	2	VL
Bare Surface	2.677	4.987	VL	1	12.312	10.15	VL	1	15.348	8.378	VL	1	16.130	6.602	VL	1	4	VL
Total			21	21				25				25				24		

The farmlands are areas in which the locals cultivate crops for sustenance and sales (Whittlesey, 1936). Crops found in the area of study includes but not limited to plantain, cassava, yam, vegetables, potatoes. These farmlands are cultivated by using crop rotation and shifting cultivation (Nwagbara et al., 2017). The farmland area occupies a total land area of 2.469 hectares at 100 meters (4.60%), 6.494 hectares at 200 meters (5.28%), 13.770 hectares at 300 meters (7.490%), and 23.205 hectares at 400 meters (9.499%) (**Table 6** and **Figure 4(a)** & **Figure 4(b)**). The farmland has Very Low (VL) SIR of 1 (**Table 4** and **Table 5**). Thus the farmlands are at a low risk in the event of a spill accident.

The water body comprised of rivers, streams, ponds cum creeks (Ushurhe et al., 2024). This environmental resource also serves as source of domestic water for the locals. The resource also serves as home for aquatic animals and vegetation such as hyacinths. The water body occupied a land area of 0.491 hectares at



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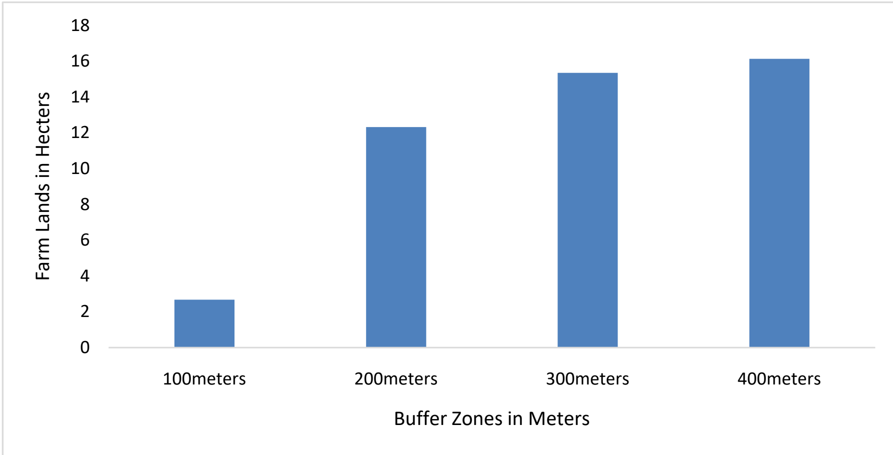
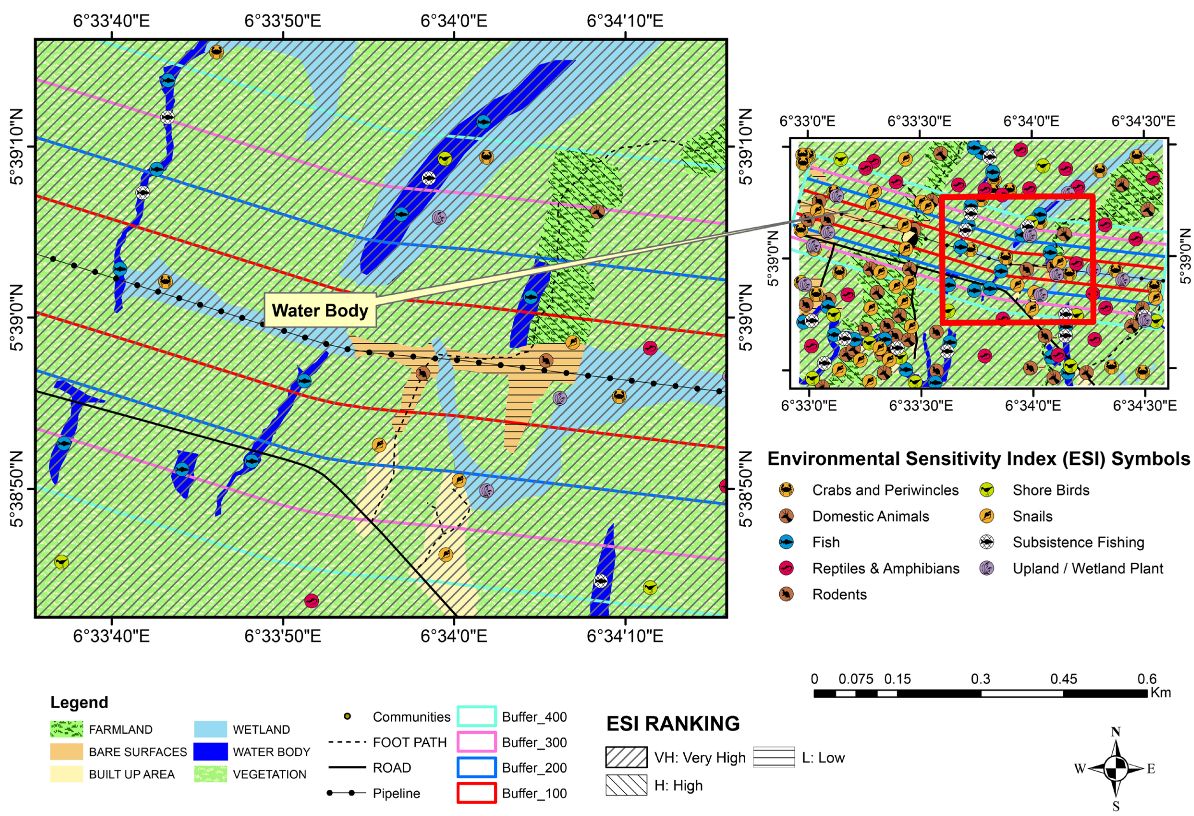


(b)

Figure 4. (a) Geospatial analysis showing farm land at risk in 400 m buffer; (b) Selection statistics of farm land within 400 m buffer zone.

100 meters (0.91%), 1.395 hectares at 200meters (1.07%), and 2.613 hectares at 300meters (1.42%) and 4.210 hectares at 400 meters (1.72%) (Table 6, Figure 5(a) and Figure 5(b)). Water body was classes very low (VL) SI and ESI ranking of 1 (Table 4 and Table 5) implying that water body belonged to the low risk environmental resources class. This finding agrees with that of Ushurhe et al. (2024).



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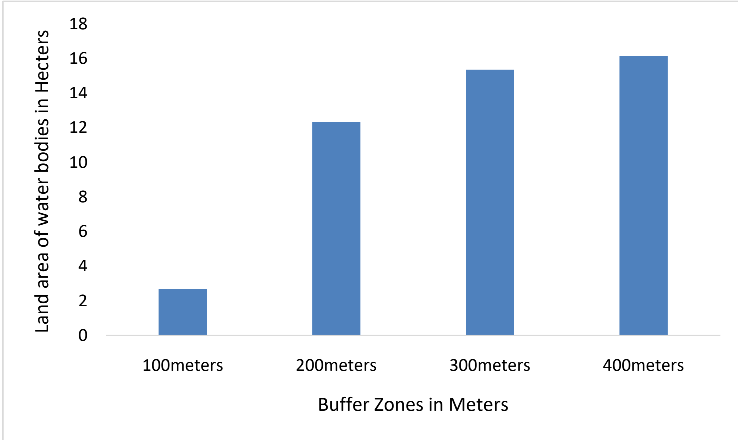
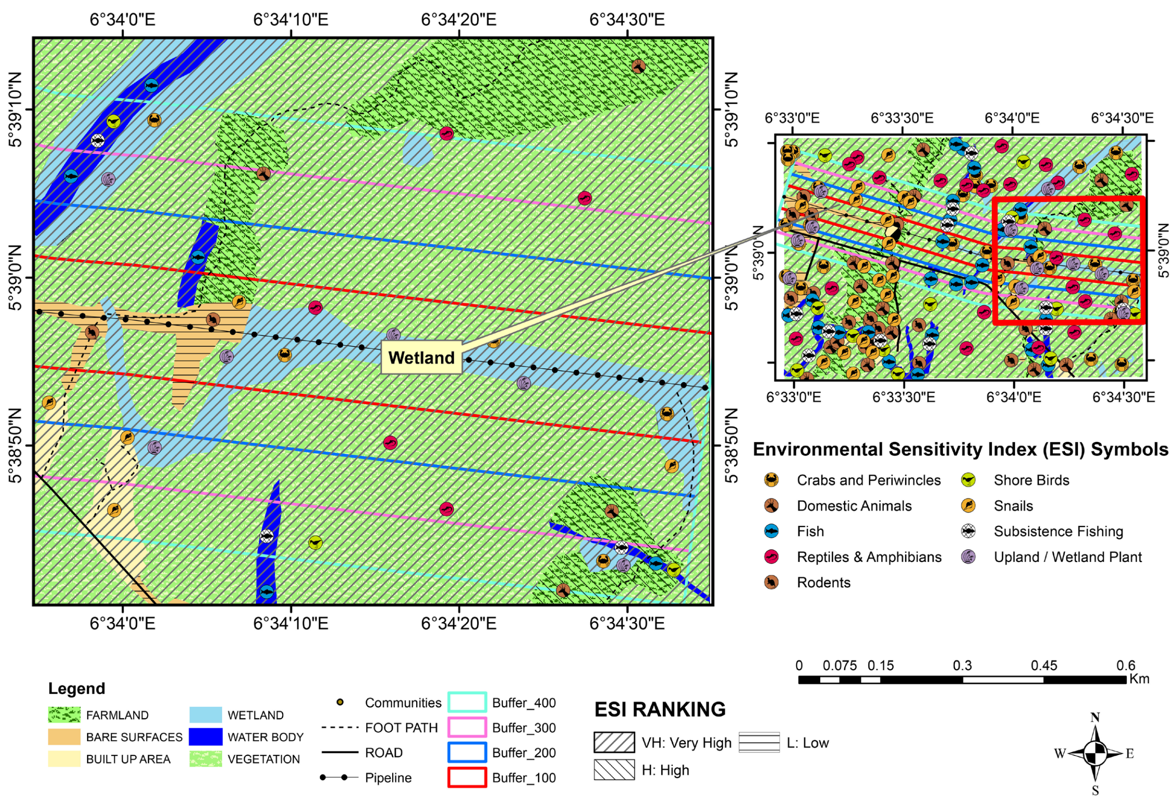


(b)

Figure 5. (a) Geospatial analysis showing water-body in 400 m buffer; (b) Selection Statistics of water-body within 400 m buffer zone.

The wetland areas comprise of ponds, marshes, forested freshwater, wet grassland and swamps (Brinson & Malvárez, 2002). The wetlands occupied a total land area of 9.396 hectares at 100 meters (17.51%), 11.969 hectares at 200 meters (9.73%), 13.974 hectares at 300 meters (7.601%), and 16.637 hectares at 400 meters (6.81%) in the buffer zones (**Table 6** and **Figure 6(a)** and **Figure 6(b)**). The Wet Land has "Very Low" (VL) SI and ESI ranking of 1 (**Table 4** and **Table 5**) indicating that the wet land herein is at low risk of oil-spills.



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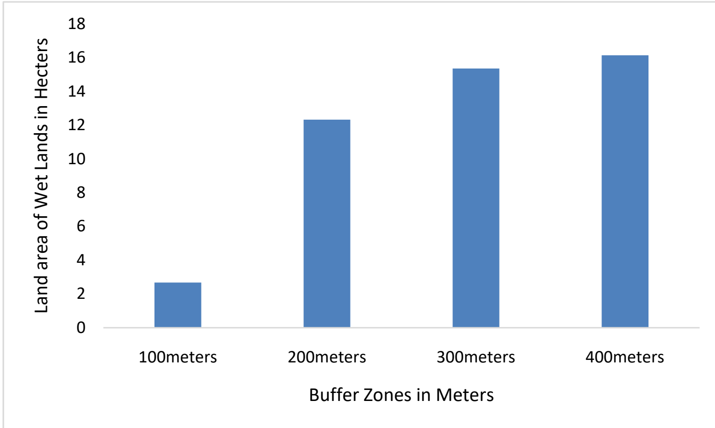
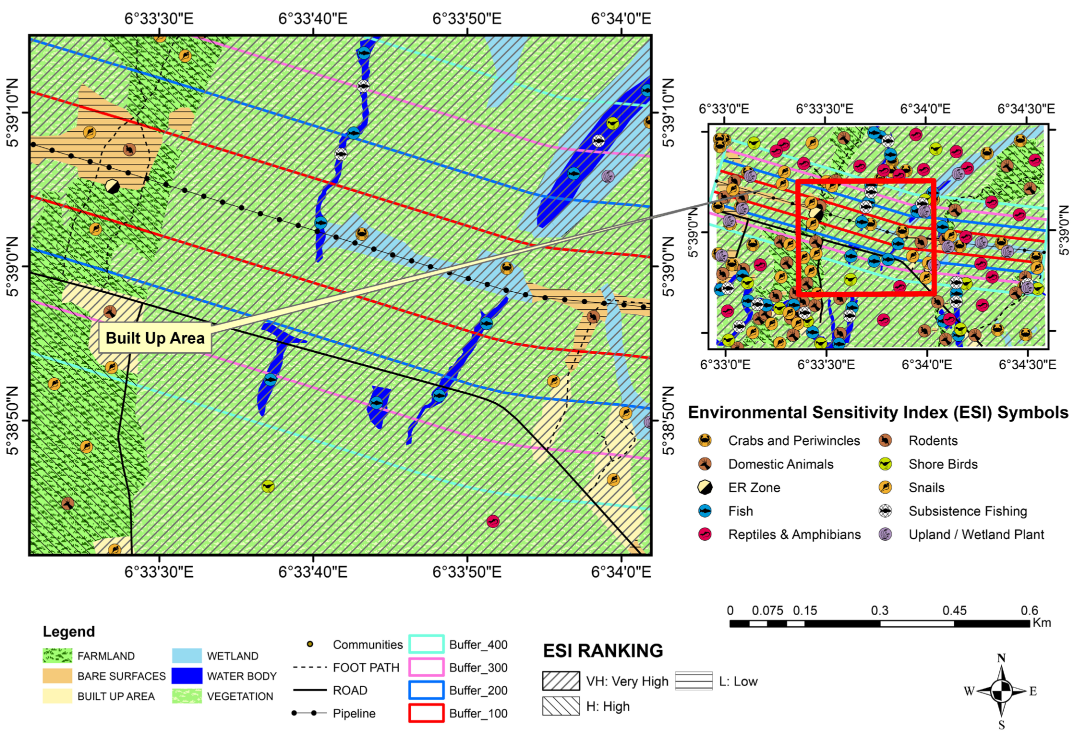


(b)

Figure 6. (a) Geospatial analysis showing wet land in 400 m buffer; (b) Selection statistics of wet land within 400 m buffer zone.

The built-up areas in the buffer zone is characterised with farm-houses, residential-camps, and processing sheds. This area comprises of diverse floras like orange, mango trees, coconut and palm trees, cocoyam, maize water leaf, bitter leaf, scent leaf plants and shrubs (Ushurhe et al., 2024). The faunas consist mainly of domestic animals such as dog, goat, fowls, cats, etc. The built up area occupies a total land-area of 0.186 hectares at 100 meters (0.15%), 2.163 hectares at 200 meters (1.760%), and 3.909 hectares at 300 meters (1.600%) (Table 6 and Figure 7(a) and Figure 7(b)). The Built up area has Very Low (VL) SI and also ESI ranking of 1 (Table 4 and Table 5).



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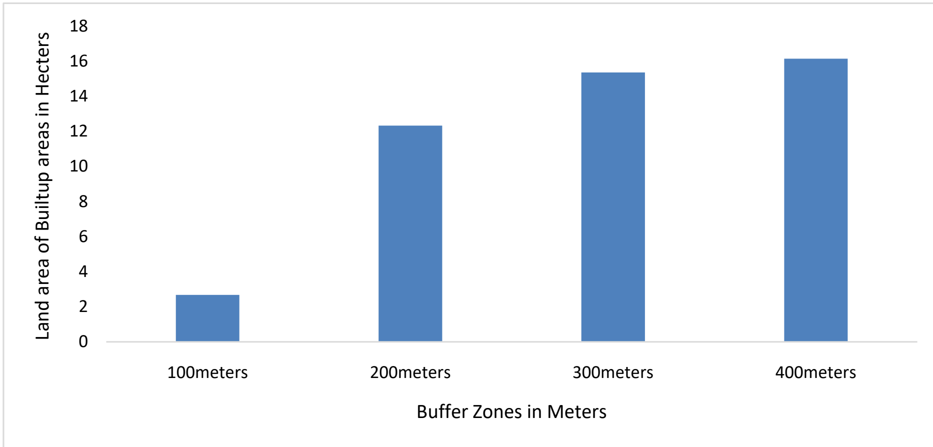
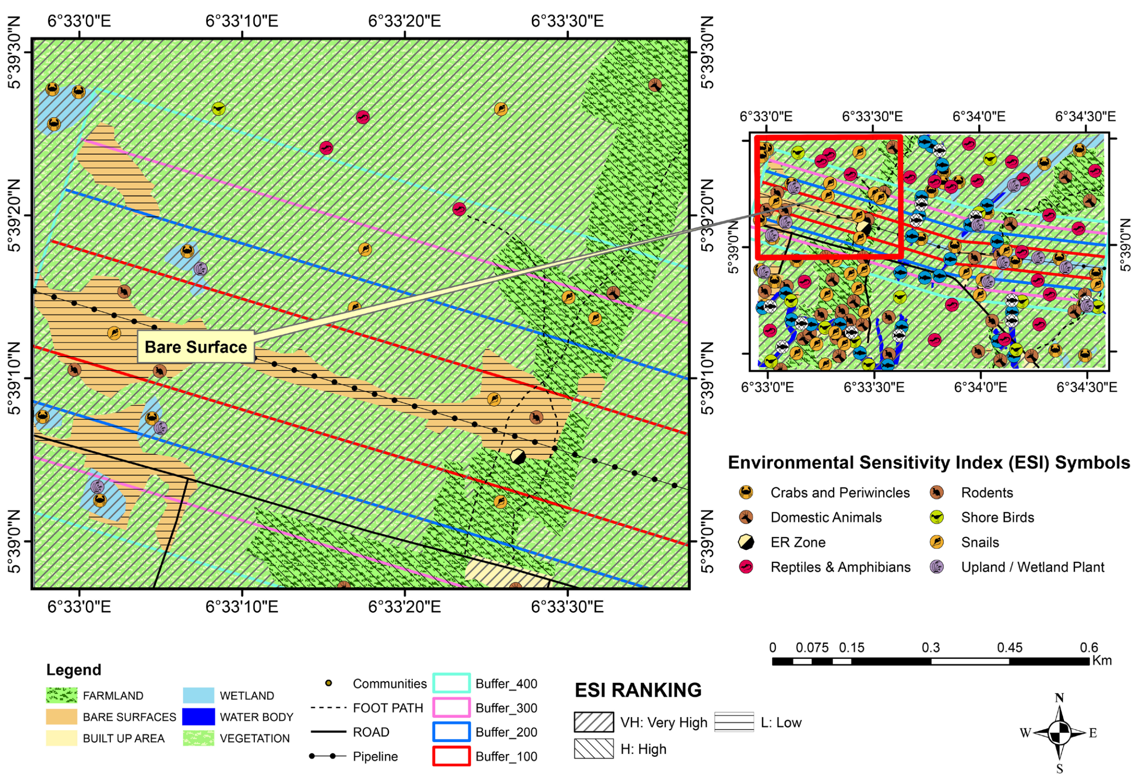


(b)

Figure 7. (a) Geospatial analysis showing built up area in 400 m buffer; (b) Selection statistics of built up area within 400 m buffer zone.

The bare surfaces are exposed surfaces which outcomes of anthropogenic actions (Otutu, 2011). It hardly supports plants growth due to nutrients unavailability (Otutu, 2011). The bare surfaces occupied a total land area of 2.677 hectares at 100 meters (4.98%), 12.317 hectares at 200 meters (10.01%), 15.348 hectares at 300 meters (8.34%), and 16.130 hectares at 400 meters (6.60%) (Table 6 and Figure 8(a) and Figure 8(b)). The bare surface has very low (VL) SI and ESI ranking of 1 (Table 4 and Table 5).



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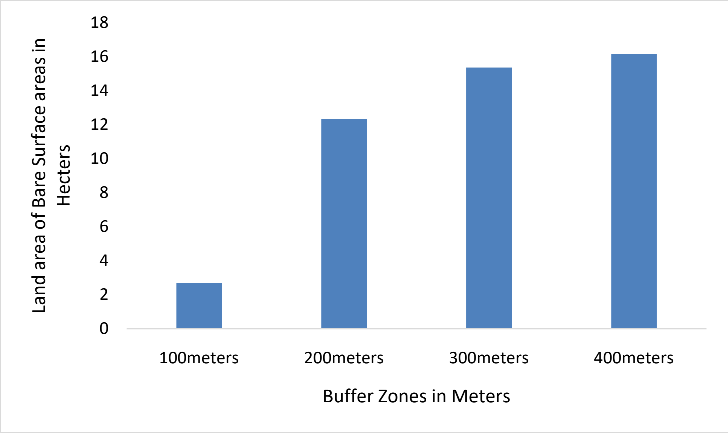

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Figure 8. (a) Geospatial analysis showing bare surface in 400 m buffer; (b) Selection statistics of bare surface within 400 m buffer zone.

As a result of the ESI and RA determined by this study, the establishment of an Emergency Response Zone (ERZ) was proposed. This ERZ should be strategically positioned location which should be easily accessible to all stakeholders. The ERZ are usually located in the environment where the risk of impact is higher and in places where resources (humans and equipment) can easily be deployed in the shortest of time after a pill-incident (Wekpe et al., 2024). In this study, the ERZ was proposed to be situated within the Asemoku community at around 50 m buffer zone (Figure 9). This proposal results from its proximity to the pipeline and other features that can be affected in the event of a pipeline-spill.

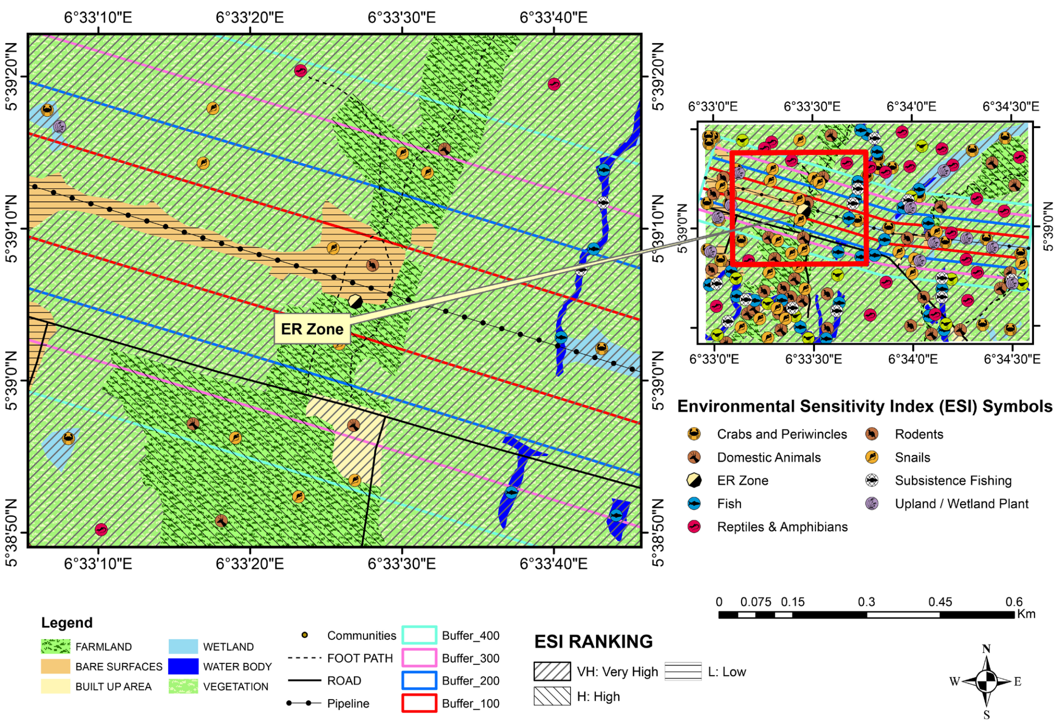

Figure 9. The proposed Emergency Response Zone (ERZ) along the pipeline.

4. Conclusion

This study assessed the risk inherent of crude oil spill on the different LULC in the Asemoku area. The study found that vegetal cover was most susceptible to crude-spill impacts and was the most sensitive LULC in the created buffer zones. Although other LULC will be affected in the event of a spill, the vegetation belt will be the most affected in the area. Environmental sensitivity Index (ESI) and Risk Analysis (RA) performed herein, explicates early warning and response for potential spill event. The study showed the extent of potential adverse effects in-case of a spill occurrence. It is hoped that this informs policy development and planning. This research mapped out LULC as quantitative factors which give clearer understanding of ecosystem and their sensitivity to spill by developing ESI maps of the study area. Sensitivity mapping (SM) and Risk analysis developed herein can deploy for support of strategic oil spill contingency plans. By mapping the area, the sensitive resources have been identified and the most sensitive LULC determined. It is hoped that policy makers pay attention to these resources while planning a clean-up response in the event of a crude spill. Furthermore, the study has been able to establish ERZ for the area, however, there is need to as a matter of urgency provide palliatives for survival for the locals on the short term, while servicing the pipe lines, creating a smart warning spill detection signal and pipeline overhaul be applied for the long term oil spill management contingency.

Conflicts of Interest

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

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