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Geographic Information System and Remote Sensing Assisted Analysis of Right-of-Way Encroachment along Petroleum Pipeline Facility

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Abstract
This research work utilized geographic information system (GIS) and remote sensing technologies to analysis the level of encroachment activities along petroleum pipeline right-of-way. The study area is in Eziorsu Community of Oguta Local Government Area of Imo State, Nigeria. The geospatial analysis was between a three timeline decades of 2002, 2012 and 2022. Remotely sensed data of Landsat ETM+ 2002, 2012 and 2022 of the area were acquired and processed using ArcGIS 10.5 software. Groundtruthing was carried out with a hand-held GPS device and digitized with the aids of high resolution imagery. Three classes of land use/land cover, namely built-up, vegetation and waterbody were identified. The extent of encroachment was determined by overlaying the pipeline right-of-way layer on the classified land use map of the study area for each of the decades with respect to different standard right-of-way of 15m, 30m and 60m buffers. The results show that the area encroached upon by built-up was 16.83(70.3%) , 19.8 (82.71%) and 20.7173 (86.05%) hectares for 2002, 2012 and 2022 respectively for 15m PROW, the waterbody was almost constant while the area encroached upon by vegetation was 6.93 (28.9%), 3.96 (16.5%) and 2.4352(10.12%) hectares for 2002, 2012 and 2022 respectively. It is clear that the encroachments on the petroleum pipeline right-of-way by built-up based on buffered zone of 15m pipeline right-of-way had increased while encroachments by vegetation which comprised of majorly farmland, wetland, exposed surface and other scrubs had decreased. Public education of risks associated with encroachment on the pipeline right-of-way is highly recommended.

Keywords: ARCGIS, Built-Up, Geospatial Analysis, Land Use/Land Cover, Satellite Images, Vegetation, Waterbody

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1.0. Introduction

Oil Pipeline transportation has become a veritable means whereby companies and government transport oil and gas over a long distance. Primarily, pipeline transportation is a long distance movement of oil and gas from one location usually source to another, terminal or depot through a system of pipes. The need for transportation of fluids through pipelines can be emphasized thus: for safety of human and products because of reduction or total absence of accident which characterize other means of transportation modes such as tankers, badges and cargoes; cheaper cost of transportation; and as a fixed transportation system which does not require human personnel like drivers to operate. Pipeline transportation is the safest mode of transporting fluids (liquid and gases). Pipelines are the most economical mode of petroleum transportation due to its very low operating and maintenance costs [1]. Handling and operational costs are minimized with the use.

Encroachment is the unauthorized use of a licensed or permitted right-of-way by an unauthorized person [2]. This might include building structures, roads or some other form of intrusion upon a contracted easement except the private right of way [2]. Encroachment by host communities on pipeline right-of-way (PROW) constitutes a major problem for the oil and gas sector of the economy [3].

Usually, a pipeline right-of-way is established about 15m from each side of a pipeline, excepting special conditions like swamps and coastal areas [4]. Encroachment is the unauthorized use of a licensed or permitted right of way by an unauthorized person [2]. This might include building structures, roads or some other form of intrusion upon a contracted easement except the private right of way [2]. Encroachment by host communities on pipeline right-of-way (PROW) constitutes a major problem for the oil and gas sector of the economy [5].

Due to the importance of pipelines to the Nigeria's economy, a route was created for these pipes to pass. Just as lands were mapped and properly demarcated for roads and railway lines, lands and even water bodies were demarcated and mapped out for pipelines. These lands were duly acquired from the locals who are the customary owners of the land through Pipeline Easement Agreement. However, these landowners after the Pipeline Easement Agreement encroach on the Pipeline Right of Way without taking into cognizance the environmental and human risk impact of this practice. This study thus is to determine and ascertain whether there is an encroachment on the Pipeline Right of Way in the oil producing community of Eziorsu, Oguta Local Government Area (LGA) of Imo State.

Nigeria has a total pipeline grid of just above 5001 km. This consists of 4315 km of multiproduct pipelines and 666 km of crude oil pipelines [6]. This system of oil pipelines transports crude oil to the refineries in Port-Harcourt, Warri, and Kaduna, covering a total distance of 719 km [7]. These pipelines are of great economic importance to Nigeria. 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) [8]. Thus, any disruption in the production and supply chain of oil and gas in the country has devastating impacts on the already fragile economy [9].

Of concern to the oil and gas industry and the general public are disturbances to the network by accidental spills, encroachment from human activities, and land form changes due to fires, floods and other natural events. Pipeline right-of-way as stipulated by Department of Petroleum Resources (DPR) regulations and Shell Petroleum Development Company (SPDC) guidelines today are being encroached upon by people and used for many human activities

[5]. This practice negates the safety of pipelines, and violates the Pipeline Easement Agreement. The locals while carrying out there human activities such as farming, buildings, pathways etc, encroach on the Pipeline Right of Way. This ugly trend poses imminent danger to oil and gas facilities, environment, human and the Nigerian economy. Encroachment can lead to man-made disaster such as oil spill, vandalisms, artisanal refining and fire/explosion. All this have left an indelible mark on the petroleum sector, causing environmental pollution and revenue losses to both the government and international oil companies [10]. Studies have also shown that the quantity of oil spilled in the Nigerian environment in five decades was at least 9-13million barrels, equivalent to (50) Exxon Valdez oil spills of 1989 (260,000 barrels) [11]. Consequently, these disasters have affected the environment, arable lands, water resources and livelihood structures of the immediate oil producing communities of Nigeria [12]. The impact further degenerates to increase in poverty, crisis and unrest within the crude oil producing environment [13]. Reports indicate that there have been over 16,083 cases of "pipeline tampering" and vandalism within the last 10 years, amounting to a loss of 174.57 billion (or approximately $484 million) in 2006–2016. Further reports indicate that, between 2016 and 2017, a total of 992 cases of pipeline vandalism were recorded across pipelines and depot lines, amounting to a loss of N167 billion (approximately $464 million). What is left behind after acts of vandalism has also created environmental concern, with both water bodies and farmlands of the ambient environment becoming victims of the activities [10]. Act of vandalism led to the death of over 250 people in Jesse Town in Delta State in 1999 when a vandalized pipeline exploded in flames. In addition, in the period described above, over 477 acts of pipeline vandalism were recorded [10]. In 2022, over 100 persons were burned beyond recognition in Egbema, Imo State at an artisanal refining site. Despite the dangers inherent and associated in these awful practices, and its consequent environmental impacts, the local dwellers do not observe the Pipeline Right of Way Easement. This is worrisome, and a serious issue of concern to experts, government and oil companies owing to its negative consequences culminating in fire explosion, contamination of the ecosystem, monumental destruction of economic trees and cash crops, damage to oil facilities, injury and even death to man.

Pipelines usually crisscross wilderness. This wilderness makes access to pipelines difficult. Again, due to the terrain of the Niger Delta - the creeks, swamps, seas, and waters where these pipelines pass through, make repair, maintenance and surveillance uneasy to perform. Some pipelines rights-of-ways have been characterized by encroachments – farming activities, settlements, weeds. This has encouraged pipeline vandalisms, artisanal refineries, and leaks from natural tendencies. These have culminated in high cost of repairs, maintenance and surveillance.

Aim of the study is to assess the level of encroachment activities along Petroleum Pipeline Right-of-Way. While the objectives of the study are:

i. To examine the existing pipeline infrastructures in the study area.
ii. To identify the extent of encroachment on Pipeline Right of Way (PROW) of the study area.
iii. To examine the trend/pattern of encroachment on the PROW.

2.0. Materials and Methods

2.1. *Materials*

2.1.1 *Area of Study*

Eziorsu Community, Oguta Local Government Area, Imo State, Niger Delta

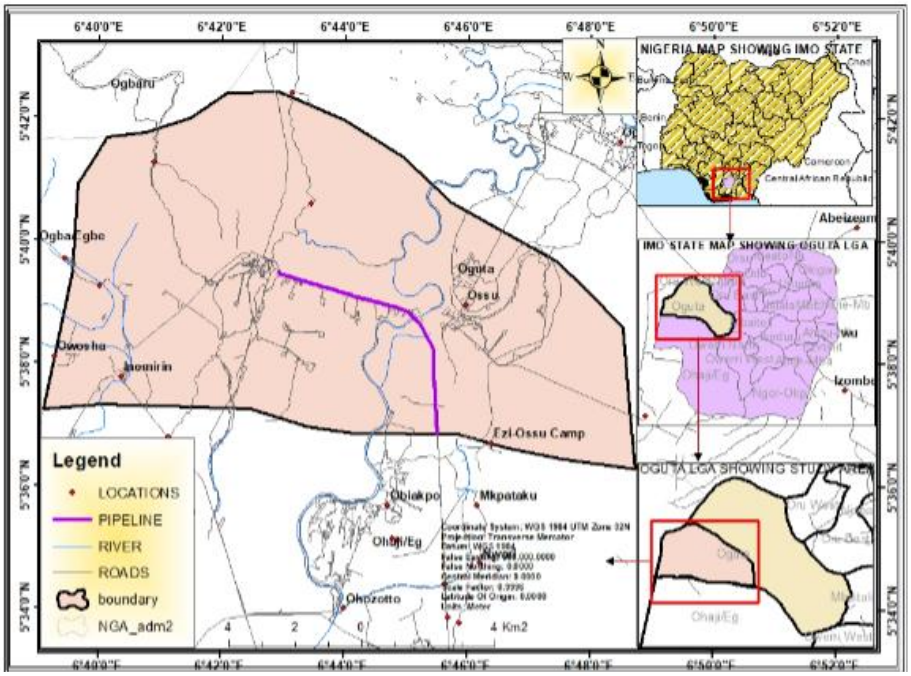


Figure 2.1 Map of Eziorsu

2.1.2. *Location*

Eziorsu is an autonomous community on the south bank of Oguta Lake in Oguta Local Government Area (LGA) of Imo State, Niger Delta, Nigeria [13]. It lies on the longitude between $6^0$40'0"E – $6^0$90'0"E, and latitude between $5^0$39'0"N - $4^0$20'0"N. It spans over 131.307km^2 making it the largest community in Oguta LGA in terms of land mass. In the south, it shares boundary with Opuoma Autonomous Community in Ohaji/Egbema LGA, and Obiakpu in Ohaji/Egbema in the south-east. The east is bordered by Orsu-Obodo and Izombe both in Oguta LGA. The northern part of Eziorsu is bordered is by K-Beach (otherwise known as Kalabari Beach)/Oguta Lake, while the western part is bordered by Ogwu in Anambra State (North West), and Anieze/River Niger in Rivers State (South-west).

2.1.3. *Population*

The population of Eziorsu according to the 1991 Population Census is put at 14,560 [15]. Using 2.9% growth rate (1991-2005) obtained from the Nigerian Population Commission; the population projection was 22,356 in 2005 using the equation:

$P = (1+ R/100)^N$…….2

The population projection of the community rose to 37,006 in 2022 using population growth of 3.2% (2006-2022).

2.2 *Methods*

They include: Planning stage, Data acquisition, Digitization/Data conversion and coordinate plotting, GIS database design and creation, GIS analysis and results. The methods implored in this research work are Remote Sensing and Geographic Information System (GIS) for pipeline map data collection, and analysis.

2.2.1 *Reconnaissance Survey*

A reconnaissance survey was carried out. This was to acquaint with the study area and help in preliminary field data collection. Some of the preliminary field data include pictures of warning signposts, broken pipeline markers as well as the path taken by these markers. The settlements through which the pipeline traverses were identified.

2.2.2 *Dataset*

Shape files for pipelines and roads from SPDC and imageries from remote sensing were obtained. Excel spreadsheet was used to enter the coordinates of the pipeline markers captured with hand held GPS receiver. The data were processed, converted and plotted as polylines in ArcGIS environment. Pipeline facilities operated by SPDC on behalf of the federal Government and managed by Pipelines and Products Marketing Company (PPMC) which is a subsidiary of NNPC [16] were identified. The study area was divided into 3 zones using buffers of 15m, 30m, and 60m, respectively for a three timeline decades between 2002, 2012 and 2022. The encroaching patterns/activities were determined, and areas/facilities severely encroached upon in the study area were determined by the buffering operation.

Table 2.1 The characteristics of the three datasets.

S/N	DATA SENSOR	YEAR	SOURCE	RESOLUTION
1.	LANDSAT 5 TM	2002	USGS (earth explorer)	60m
2.	LANDSAT 7 OLI-TIRS	2012	USGS (earth explorer)	30m
3.	LANDSAT 8 OLI-TIRS	2022	USGS (earth explorer)	30m

2.2.3. *GIS Operations*

According to (17) in ArcGIS, a geo-database is created in order to better manage information for decision making. With the whole data carefully added in ArcMap 10.5, it was easy to create polygons of individual building and a buffer region (30m x1km and less in some cases) using the ROW limit as a reference. These newly created polygons of buildings and the buffers were stored in a well-organized personal geo-database.

2.2.4 *Data Processing*

The coordinates of the pipeline markers from the Global Positioning System (GPS) was transferred into Microsoft Excel worksheet and stored for easy transfer into ArcGIS environment. Landsat imagery of the study area for 2002, 20012 and 2022 were used for the analysis.

2.2.4.1 *Image Enhancement: Pan Shaping:*** The image enhancement techniques are used as a pre-processing step. This is used to improve the spatial resolution of an image in order to extract meaningful information. ArcGIS 10.5 was used to achieve this.

2.2.4.2. *Classification:* Many applications, such as disaster response, law enforcement, and environmental monitoring, rely on satellite imagery. Remote sensing, image analysis, and pattern recognition all depend on image classification. Therefore, Landsat imagery was used to perform supervised classification and three classes of land use/land cover were identified, namely, built-up, vegetation and water body.

2.2.5. *Data Analysis*

The processed data obtained were analyzed in order to achieve the set objectives of the study explained as follows:

2.2.5.1. *Objective 1*: To determine the rate of encroachment on ROW. An overlay operation in ArcGIS software was carried out to achieve this objective. The buffer zone layer created on the ROW was overlaid on the Landsat imageries for each of the years. Specifically, the built-up of 2002, 2012 and 2022 were overlaid separately on the buffers of pipeline for further analysis and map making. (The individual buildings that fall within the buffer zone were those that have encroached on the pipeline right of way). The rate of encroachment was obtained by calculating how much of the right of way was encroached upon by the activities.

2.2.5.2. *Percentage Rate of Change*

Percentage rate of change allows change over the years to be calculated. The area occupied by each buffer was used for the calculation. The simple formula for percentage rate of change that was also employed by this study is as in [17].

Percentage of encroachment = $E/\Sigma A \times 100/1$ …1

Where: E = Area encroached
A = Total Area

2.2.5.3. *Objective 2:* To examine the activity/pattern of encroachment on the ROW. The geo-referenced SPOT imageries of the study area were digitized on screen and showed the pattern of encroachment within a buffer region in a particular decade. This was subsequently repeated for the other years covering the study period. The ROW layer was then overlaid (polygon-on-polygon overlay) on the digitized satellite imageries of the study area for each of the three decades to carry out further analysis.

3.0. Results and Discussion

3.1.*Results*

3.1.1 *Identification of Pipeline Right-of- way*

The pipeline markers were used to trace the ROW. The GPS was used to select visible and accessible waypoints on the pipeline markers that were used to determine the pipeline's path. The gathered GPS coordinates were imported into the ArcGIS 10.5 environment after being saved as a.csv file in Microsoft Excel. A line feature class was utilized to connect the points after the coordinates were imported, superimposed on satellite imagery and stored as a point feature. A vector (linear) feature illustrating the pipelines' course is the output. The red line in figure 4.1 delineates the Right-Of-Way from PT_1 to PT_20 which covered length of 7.92km. The settlements through which the pipeline traverses, and the land uses that encroached on the ROW were discussed individually. The coordinates of the pipeline markers shows in table 1 below were obtained using a GPS (Garmin 62) and plotted using ArcGIS 10.5 to show the route taken by the pipeline.



Figure 3.1 Satellite imagery of the Area showing the pipeline right of way.

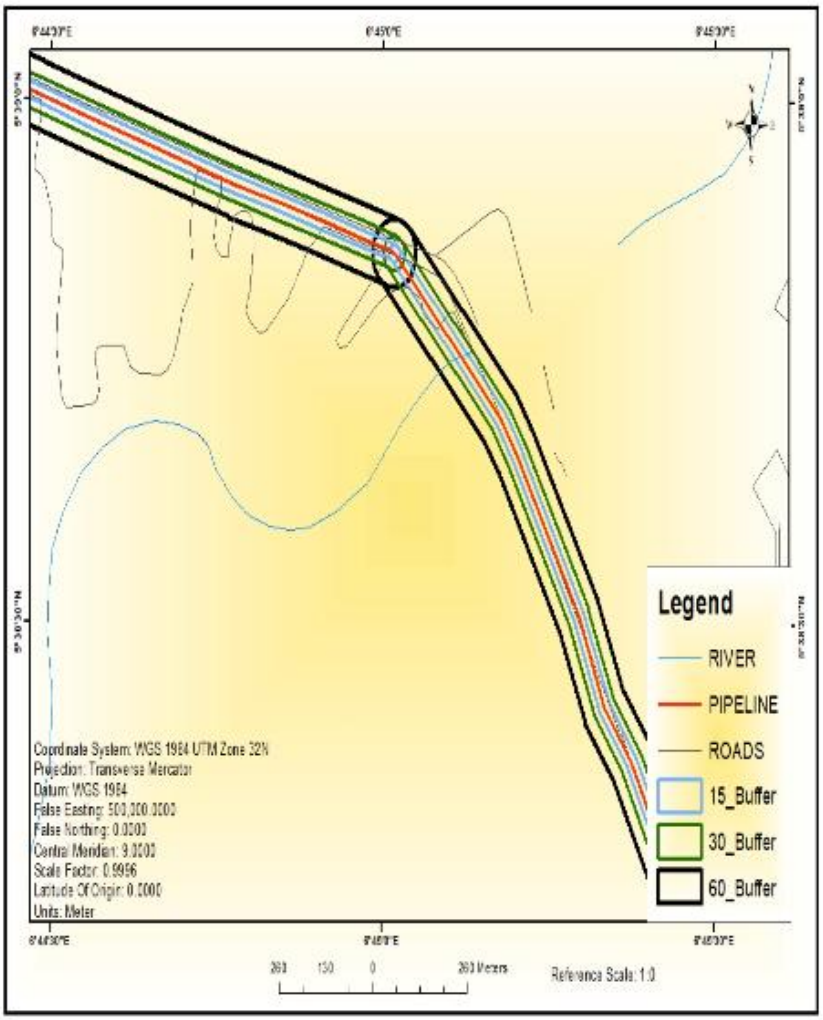


Figure 3.2 15m, 30m and 60m buffered zone

Table 3.1 Summary of Encroachments on pipeline ROW using 15m buffer for 2002, 2012 and 2022.

FOR 15 METERS

	2002		2012		2022	
LANDUSE/LANDCOVER	AREA	PERC	AREA	PERC	AREA	PERC
WATERBODY	**0.**18	**0.**75188	**0.18**	**0.**75188	**0.**9225	**3.831776**
BUILT-***UP***	**16.83**	**70.**30075	**19.8**	**82.**7068	**20.7173**	**86.05**
VEGETATION	**6.93**	**28.94737**	**3.96**	**16.**5414	**2.4352**	10**.12**
TOTAL	**23.94**	100	23**.94**	100	**24.075**	100

Table 3.2 Summary of Encroachments on pipeline ROW using 30m buffer for 2002, 2012 and 2022.

FOR 30METERS

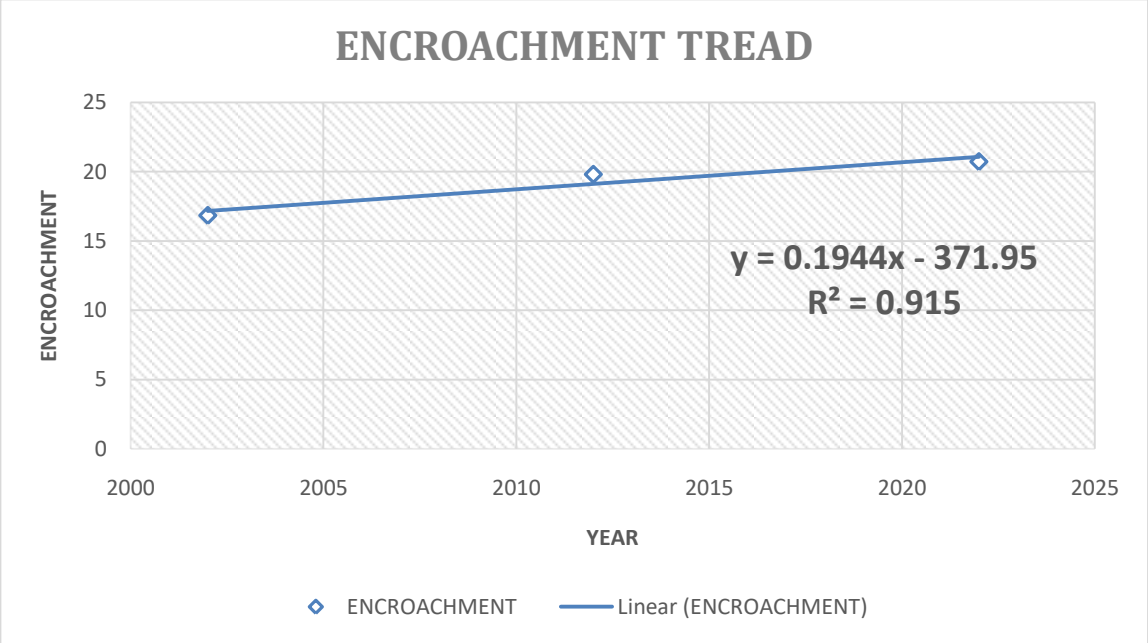
	2002		2012		2022	
LANDUSE/*LAND* COVER	**AREA**	**PERC**	**AREA**	**PERC**	**AREA**	**PERC**
WATERBODY	**0.54**	**1.129944**	**0.54**	**1.129944**	**0.5603**	**1.13**
BUILT-*UP*	**37.5975**	**70.0565**	**33.48**	**82.29755**	**43.4062**	**87.53**
VEGETATION	**8.82**	**28.81356**	**13.77**	**16.57251**	**5.6235**	**11.34**
TOTAL	**46.9575**	**100**	**47.79**	**100**	**49.59**	**100**

Table 3.3 Summary of Encroachments on pipeline ROW using 60m buffer for 2002, 2012 and 2022.

FOR 60 METERS

	2002		2012		2022	
LANDUSE/LANDCOVER	**AREA**	**PERC**	**AREA**	**PERC**	**AREA**	**PERC**
WATERBODY	**1.08**	**1.1505**	**1.1**	**1.1674**	**1.09**	**1.1142**
BUILT-UP	**62.73**	**66.8265**	**69.73**	**74**	**78.5825**	**80.3256**
VEGETATION	**30.06**	**32.023**	**23.4**	**24.8329**	**18.1575**	**18.56026**
TOTAL	**93.87**	**100**	**94.23**	**100**	**97.83**	**100**

3.1.2. *To Examine The Trend Of Encroachment On The Prow.*



Graph 1: Encroachment trend

3.2. *Discussion of Results*

There are visible encroachments along this pipeline ROW at different point which has proved using satellite imagery. From the analysis, it has shown that, there is an increase in built-up and decrease in vegetation. It also showed that some areas that are free from encroachment in 2002 but are encroached in 2012 and 2022 due to urbanization.

It was also noticed that more built-up keep encroaching on the pipeline right of way as the year goes by. This research work shows in its results that encroachment has practically increased throughout the times within the space of three (3) years. Precisely, encroachment has moved from 16.83(70.3%) to 19.8 (82.71%) and finally to 20.7173 **(**86**.**05**%)** hectares between 2002 and 2012 and 2022 using 15m buffered. Also, for 30m buffered, there is an increase in built-up, between 2002 and 2012, encroachment has risen from 30.5975ha to 33.48ha and again moved to 43.4062 in 2022 respectively.

4. Conclusions and Recommendations

4.1. *Conclusion*

This study mapped encroachment in the study area using GIS and remote sensing techniques. The study has shown that a geospatial technology can be used to support land and infrastructural management decisions. From the findings of the study, it was observed that the major factor responsible for these encroachments was uncontrolled urban growth as well as the absence of clear demarcating structures to inhibit people from encroaching on the pipeline ROW. More residential buildings and farming are springing up in areas very close to the pipeline ROW; hence, more protective measures need to be put in place to checkmate further encroachments by these upcoming structures.

4.2. *Recommendation*

i. The pipeline company, government and NGOs should regularly educate and sensitize the public about the level of vulnerability and risks associated with encroachment on the PROW.
ii. Aerial surveillance of the pipeline using remote sensing and GIS technologies should be deployed for effective development control operations in the study area.
iii. Regular removal of structures on the PROW, and clearing of bushes should be carried out for public safety. However, this requires finding adequate resettlement for the affected persons.
iv. The PROW should have markers and setback embankments to inhibit encroachments. This should be carried out by the pipeline company. In addition, there should be warnings signs and inscriptions on the PROW to wad people off.
v. Proper and regular monitoring of the pipelines in the area to curtail encroachment, sabotage, vandalism and theft.

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