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Original Research Paper

GIS Based Oil Spill Risk Assessment Model for the Niger Delta's Vegetation

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ABSTRACT

Frequent oil spills in the Niger Delta have severely influenced the environment in oil production and transportation areas. Vegetation degradation is one of the remarkable results of oil spills in the region. Hence, GIS was used to build an Oil Spill Risk Assessment Model for Vegetation (OSRAMV) in the southern part of the Rivers state, mainly in the Bonny district to define areas under high levels of oil spill hazard and vegetation areas under high oil spill risk. Oil Spill Hazard Model (OSHM) was examined to ensure its accuracy by recorded oil spill impacted areas; 71.6% of impacted areas pixels were in severe hazard areas. Whereas none of impacted areas were located in very low, or low oil spill hazard areas. The final OSRAMV showed that 66.5% of the examined oil spill sites were located in high risk areas.

INTRODUCTION

During emergency response to oil spills, accurate information and clear communication are required to reduce the risk of oil spill disasters in order to protect the environment and reduce economic losses. Recently, Geographic Information System (GIS) has gained popularity in the field of oil spill researches due to its efficient storage, retrieval, analysis and visualization interface of spatial data, combining with other tabular data (Ivanov & Zatyagalova 2008, Nwankwoala & Nwaogu 2009, Fustes et al. 2014).

GIS is allowing the integration of information from previous oil spill incidents and many different other sources to be presented through one interactive interface (APASA and The Ecology Lab Pty, 2003; Aukett 2012). It is viable and quite suitable for detecting, manipulating, analysing, assessing predicting and managing oil spillage (Dahdouh-Guebas 2002, Nwankwoala & Nwaogu 2009). It is helpful in oil spill monitoring, sensitivity mapping, planning and response (APASA & the Ecology Lab Pty 2003, Ivanov & Zatyagalova 2008).

Degradation of vegetation is affecting the whole ecological system; it is leading to many environmental problems and influence the sustainability of goods and services. Generally, forests are declining worldwide as a result of severe agricultural and demographic pressure (Wokocha et al. 2013). However, petroleum industry activities including exploration, refining, transportation, and distribution are largely responsible for vegetation degradation in oil production and transportation areas in Nigeria generally and the Niger Delta especially (Nwankwoala & Nwaogu 2009). With more than 1,000 oil production wells, and 47,000km of oil and gas pipelines (Ngobiri et al. 2007), the Niger Delta is facing some serious environmental problems. It is reported to be one of the worst oil-impacted locations in the world due to regular oil spills (Nwankwoala & Nwaogu 2009).

Generally, there are various reasons leading to spill incidents: a natural disaster such as landslide and earthquake, operational failure, such as poor maintenance and human errors, and vandalism which aims to oil theft or sabotage (Anifowose et al. 2012). In the case of Nigeria, oil pipeline vandalism by local inhabitants is the main and most serious reason for oil spills. In addition, ageing of the pipelines, oil blow outs from flow stations, and other operational reasons are responsible for the rest of the oil spill incidents (Nwilo & Badejo 2005).

Nigerian pollution control efforts are slow and limited. First Environmental Impact Assessment (EIA) in Nigeria has been done after more than 30 years of oil production in 1992 (Anifowose et al. 2014). Besides, there was a general ignorance about environmental contamination for a long time. This is owing to that petroleum industry in the country is still being run by foreign and multinationals companies, who seem to care very little about the Nigerian environment protection. In addition, cleaning polluted areas cost is too high for the government to spend (Ogri 2001).

As long as petroleum exists, it will be discharged (accidentally or incidentally) in the environment. As a hazard, oil spill puts the people and environment in danger. Hence, it is better to be prepared for a spill than to be caught unaware by it (Udoh 2010). Risk assessment is one of the main processes to prepare for oil spills. It has emerged as a result of worldwide interest in different aspects of hazards (Udoh & Ekanem 2011). Environmental risk assessment of pollutants, deals with the effects of hazardous substances that are present in the environment (Lahr & Kooistra 2010). Standards Australia (1995) defined risk as “the chance of something happening that will have an impact upon objectives measured in terms of consequences and likelihood”.

Traditionally, results of environmental risk assessment are provided in a non-spatial way. However, this has been changing rapidly over the past decade. The development of Geographic Information Systems (GIS) has greatly improved spatial representation and spatial analysis of all kinds of information and data. As a consequence of that development, environmental risk mapping of pollutants is rapidly developed (Lahr & Kooistra 2010).

Recently, oil spill risk assessment model studies have significantly increased. Many researches were conducted in different areas around the world for this aim such as, the Itaqui-Bacanga port complex, state of Maranhão, Brazil (de Andrade et al. 2010), La Maddalena, Sardinia, Italy (Olita et al. 2012), Mazandaran province, Iran (Vafai et al. 2013), Crete (Alves et al. 2014), Bohai Sea, China (Liu et al. 2014), southern Adriatic and Northern Ionian (SANI) Seas (Liubartseva et al. 2015).

In Nigeria, many researchers were interested in oil spill risk assessment studies such as: Miller & Onwuteaka (1999) in the East Central area of coastal Nigeria; Nwankwoala & Nwaogu (2009) in the Etche Local Government Area, Rivers state; Udoh (2010) in the Coastal Areas of South Eastern Nigeria; Oydepo & Adeofun (2011) in Atlas Cove, Lagos; Udoh & Ekanem (2011) in Akwa Ibom State.

This study aims to build a GIS based oil spill risk assessment model for vegetation in the Niger Delta based on oil spill incidents recorded by the SHELL company in the Rivers state, Nigeria. These reports were used to create a comprehensive spatial database for oil spill in the Rivers State. Normalized Digital Vegetation Index (NDVI) and Multi Endmember Spectral Mixture Analysis (MESMA) techniques were used to detect vegetation changes inside the oil spill impacted areas. Data from oil spills, besides the results of vegetation degradation for these two techniques, were used to create an oil spill risk assessment model for vegetation in a sample area inside the Niger Delta.

STUDY AREA

The Niger Delta is the world’s third largest mangrove wetland and the biggest river delta in Africa (Kuenzer et al. 2014). It is under a tropical climate, and receives precipitation average of 2400 to 4200mm per year, mainly during the rainy season between April and November, with high temperature and humidity levels (Ibeanu 2000, Egberongbe et al. 2006, Kuenzer et al. 2014). Flora and fauna in the delta are very diverse. However, the main vegetation type in the Niger Delta is mangrove forests, which occupy an area between 5000 and 8600 km^2 (Kuenzer et al. 2014). Mangrove forests are tropical or subtropical intertidal forests and occur mainly between the Tropics of Cancer and Capricorn. Mangroves provide protection to coastline against erosion, act as breeding, spawning, hatching and nursing grounds for many marine species of both lagoon and off-shore origin (Dahdouh-Guebas, 2002). In addition, different vegetation types are widely represented including large freshwater swamp plants and Napa Palms (Kuruk 2004, Fabiyi 2011).

MATERIALS AND METHODS

Data acquisition: 250 oil spill reports in the Rivers State during the period from January 2011 to June 2013, have been collected from SHELL Oil Company’s website (SHELL 2014), to build a comprehensive geodatabase for oil spills in the Rivers state during this period. Two Landsat7 images and one Landsat8 image have been downloaded from the United States Geological Survey (USGS) website (USGS 2014) to be used in this study. The Landsat8 image has been spectrally re-sized as Landsat7 bands to support the two Landsat7 images to produce the vegetation and environment layers for OSRAMV. Whereas, two STRM 1 Arc-Second Global DEM images were used in this study to produce a topographical map. The two SRTM DEMs are represented in Table 1. In addition, 71 high resolution images

Table 1: Inventory of the satellite images used for this study.

Sensor Type	Scene Id.	Scene location	Date acquired
Landsat7	LE71880572013355SG100	188/057	21/12/2013
	LE71880572014006SG100	188/057	06/01/2014
Landsat8	LC81880572014014LGN00	188/057	14/01/2014
SRTM	SRTM1N04E006V3	N04/E006	11/02/2000
	SRTM1N04E007V3	N04/E007	11/02/2000

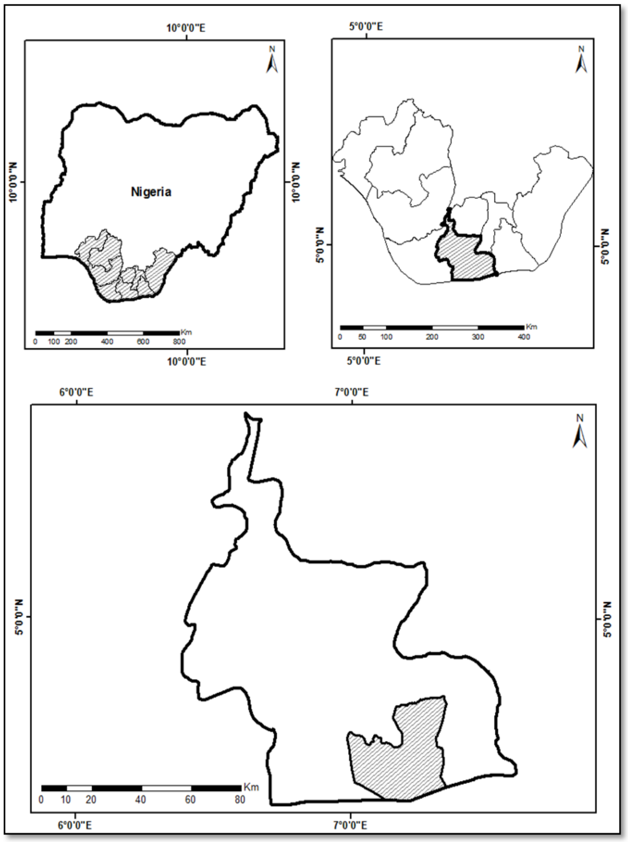

Fig. 1: Study area; (a) The Niger Delta States in Nigeria, (b) Rivers State location among the Niger Delta states, (c) Risk analysis model applied area.

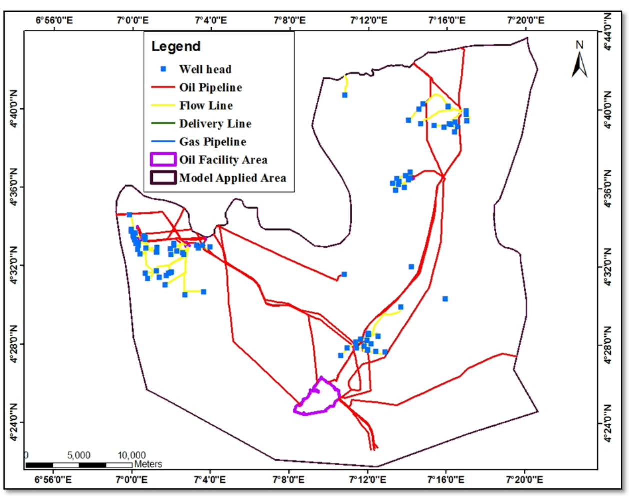

Fig. 2: Interpreted oil facilities inside OSRAMV sample area.

have been downloaded from Google Earth. These high resolution images were used to digitize different oil facilities for the study area.

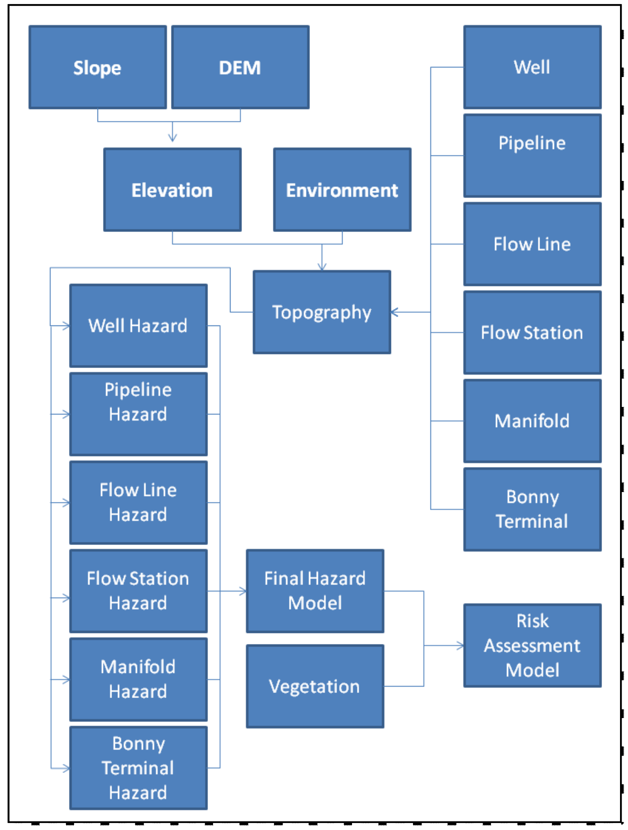

Fig. 3: OSRAMV process.

Data preparation: Landsat7 and Landsat8 data, which were used in this research are L1T data, these data were radiometrically, geometrically and Terrain corrected (NASA 2013, USGS 2013b, EESA 2014). So, Fast Line-of-sight Atmospheric Analysis of Hypercubes (FLAASH) was used to atmospherically correct all Landsat satellite images.

Two feature class layers were created to contain oil spill reports data for Rivers State during the study period; the first layer is a point feature class representing oil spill sites, and the second layer is a polygon feature class representing oil spills impacted areas. Then, well heads, pipelines, flow lines, flow stations and manifold layers were created to represent petroleum facilities inside the study area. These layers were geometrically digitized using Google Earth high resolution images with the assistance of oil spill sites data, which was increased for this purpose by using more oil spills reports from SHELL company till the end of August 2014 (SHELL 2014).

Different oil facilities were interpreted using Google Earth high resolution images by defining similar features of previously recognized petroleum facilities in oil spill sites. In addition, pipelines routes were interpreted by following possible and logical connections between different oil

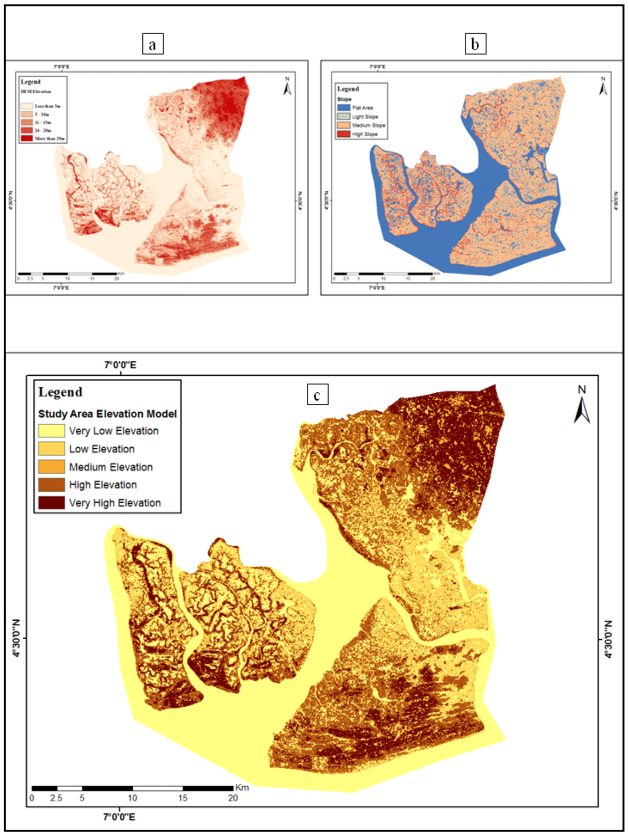

Fig. 4: Elevation Model; (a) DEM elevation categories, (b) Applied area slope, (c) Final elevation model result.

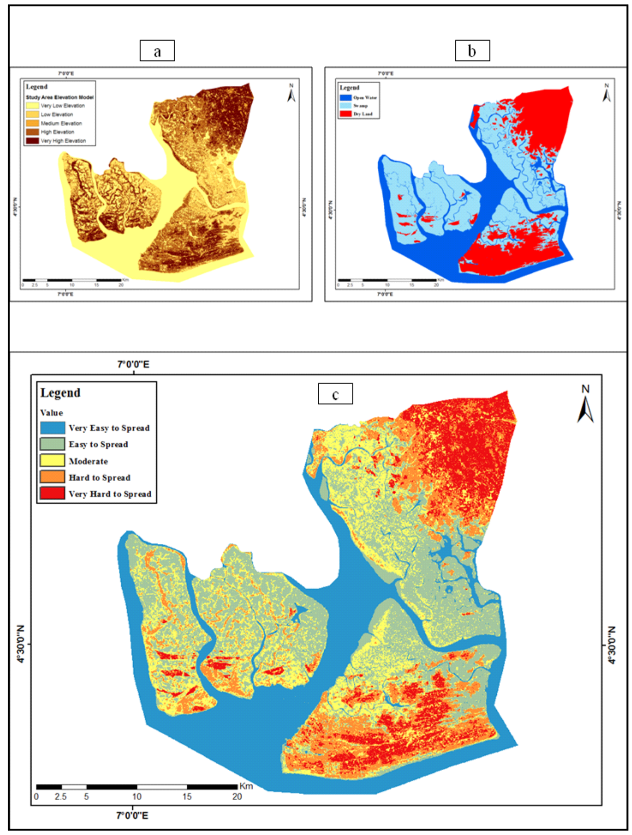

Fig. 5: Topographic Model; (a) Elevation Model, (b) Environment Model, (c) Final Topographic Model Result.

facilities. Fig. 2 represents the final oil facilities map for the OSRAMV sample area.

Check bad values process was applied for the two STRM DEM raster, and then fill tool was applied to fill gaps in these two DEMs which might affect the accuracy of analysis, and finally mosaic tool was applied to combine the two DEMs in single raster to be ready for analysis.

Oil spill risk assessment model for vegetation (OSRAMV) process: Risk assessment is a sum of two factors, hazard, and vulnerability. Hazard refers to the probability of occurrence of a potentially damaging phenomenon. Whereas, vulnerability is the degree of loss resulting from the occurrence of the phenomenon (Miller & Onwuuteaka 1999, Udoh 2010, Udoh & Ekanem 2011). Steps of OSRAMV are represented as follows (Fig. 3).

***Step one: Create the elevation model*:** Elevation model has been created using the two STRM 1 arc-second DEMs to extract elevation values and create a slope map. DEM values were classified in five different categories; less than 5m, 5-10m, 11-15m, 15-20m and more than 20m. Whereas, four classifications of slope were categorized inside the study area; flat plane, light slope, medium slope and high slope. The final elevation model was created by multiplying slope layer with DEM classified layer. Then, Quantile method was used to classify the final elevation model to five different classes: very low elevation, low elevation, medium elevation, high elevation, and very high elevation.

***Step two: Create the topographic model*:** Viper tools add-on was used in the ENVI4.8 environment to create a model for applied area environment. Two spectral libraries were combined in a MESMA process analysis to extract the final result; first one was a combination of vegetation, bare soil, and building spectra to represent dry lands, and the other spectral library was representing different water spectra. Two Landsat7 images and one Landsat8 image were used to produce applied area environment model. MESMA process was applied directly on the two Landsat7 images. Whereas, resize data tool in the ENVI software environment was used to resize Landsat8 image spectrally to fit the spectral libraries which was produced for Landsat7 spectral bands. Then, mosaic was applied to the results of Landsat7 and Landsat8 three images to cover gaps caused by SLC-OFF in landsat7 data and clouds cover in each image.

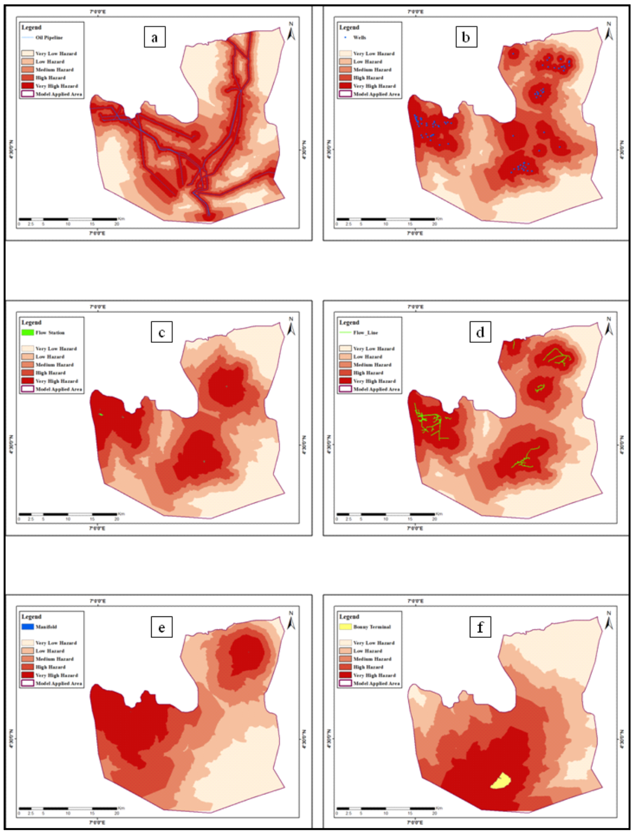

Fig. 6: Study area oil facilities hazard maps; (a) Pipeline hazard map, (b) Well hazard map, (c) Flow station hazard map, (d) Flow line hazard map, (e) Manifold hazard map, (f) Bonny terminal hazard map.

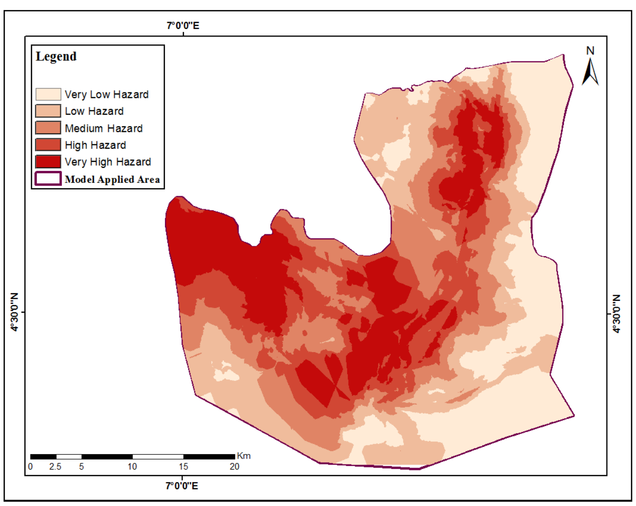

Fig. 7: Oil facilities hazard model.

The topographic model was created by multiplying applied area environmental model and the elevation model which were created previously. Then, Quantile method was used to classify the result of five classes according to the ability of spilled oil to spread; very easy to spread, easy to spread, moderate, hard to spread, very hard to spread (Fig. 5).

***Step three: Create the hazard model*:** The topographic model was used as a 'Cost Raster' to create hazard maps for each type of oil facilities individually, using cost distance tool in ARGIS. This tool calculates the least accumulative cost distance for each cell to the nearest source depending on a cost surface. So, topographic model is classified from lowest to highest to represent environments from easy to difficult environment for spilled oil spread (Fig. 6).

The final hazard model was calculated according to three different parameters; vegetation degradation result for both NDVI and MESMA techniques (Mohamadi 2015), spilled oil amount for spills during study period, and percentage of spill points from different facilities in the Rivers state (534 spill points from 1st of January 2011 to 31st of August 2014).

Average of the three parameters; NDVI and MESMA analysis results, spilled oil amount, and spill points were calculated (Table 2). The final hazard result was ranked from highest to lowest as: Pipeline (5), Manifold (4), Well (3), Flow line (2), Flow Station (1).

In addition, the study area has a big terminal for exporting Nigerian crude oil named Bonny terminal. Since, no spill incident has been recorded from this terminal during the study period (This could be due to safety procedures for a 24hours working day terminal with a high number of employees and workers), Bonny terminal has been given the lowest rank (1).

The final hazard map was calculated as follows:

$$HM = (FS) + (FL*2) + (WH*3) + (MF*4) + (PL*5) + (BT)$$

Where, HM is the hazard model result, FS is the flow station hazard model, WH is the well head hazard model, MF is the manifold hazard model, PL is the pipeline hazard model, FL is the flow line and delivery line hazard map, and BT is the Bonny terminal hazard map. The final hazard model is as represented in Fig. 7.

***Step four: Create the final risk assessment model*:** A vegetation quantity percentage model was created by applying MESMA analysis on study area's images to analyse vegetation percentage inside each pixel. Two spectral libraries were used for this purpose; one for vegetation spectra and the other is for non-vegetation spectra which contains bare soil and building spectra.

Mosaic with maximum value was applied for MESMA results from different images to calculate highest vegetation value inside each pixel to avoid no-data pixels values caused by Landsat7 SLC-OFF and clouds cover in these images.

Table 2: Final hazard model parameters.

Parameter	Classification	Well Head	Pipeline	Flow Station	Flow Line & Delivery Line	Manifold
Vegetation	NDVI	50%	56.6%	0%	45.1%	33.3%
Degradation Result	MESMA	66.5%	75%	100%	56.7%	100%
Percentage from total incidents		2.7%	75%	1%	19.2%	2.1%
Spilled oil volume (More than 25 B)		40%	53.6%	0%	5.4%	66.7%
Total percentage		39.8%	65.1%	25.3%	31.6%	50.5%
Calculation rank		3	5	1	2	4

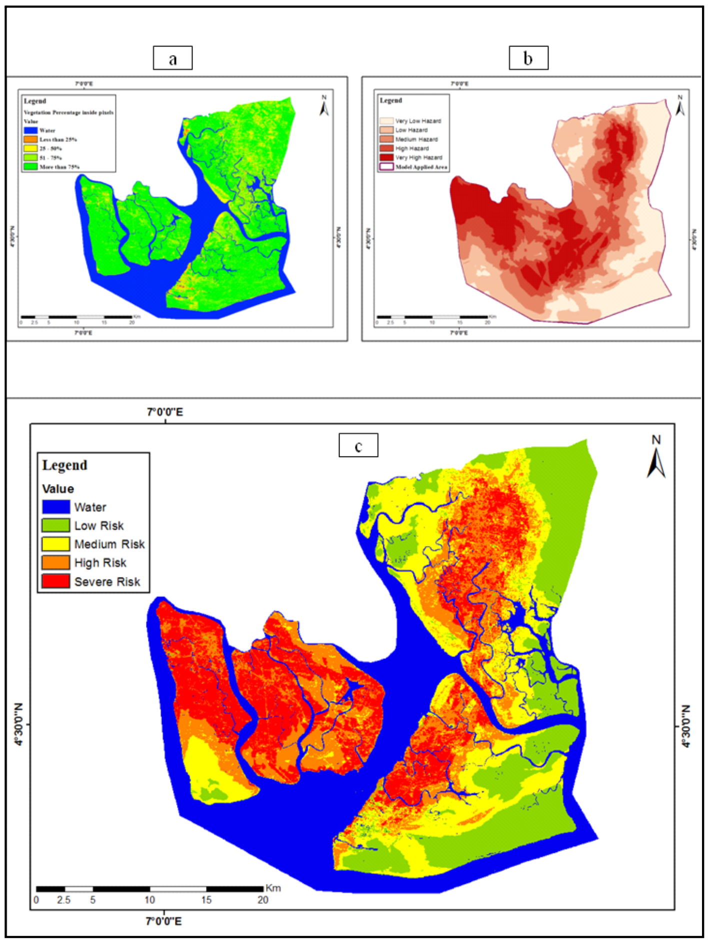

Fig. 8: Oil Spill Risk Assessment Model of Vegetation final result; (a) Vegetation percentage inside each pixel, (b) OFHM, (C) OSRAMV final result

Final Oil Spill Risk Assessment Model on Vegetation (OSRAMV) was created by multiplying Oil Facilities Hazard Model (OFHM) and Vegetation quantity model. The final result is as represented in Fig. 8.

RESULTS

Oil facilities hazard model accuracy was examined to ensure the final OSRAMV result. Seventy seven impacted areas of oil spills between 1st of January 2011 and 30th of June 2013 inside the study area were checked by counting impacted areas number of pixels inside each hazard category. Results revealed that no impacted areas are located inside very low and low hazard areas. Whereas, 71.6% of impacted areas coverage was in severe hazard areas. 25.3% of impacted areas extent was in high hazard areas, and only 3.1% were located in medium hazard areas.

Severity of oil spills on the Niger Delta's vegetation was obviously represented in this OSRAMV, 200 oil spill sites between 1st of January 2011 and 31th of August 2014 were examined on the final result of this model. Results revealed that 66.5% of oil spill points were located in high risk areas, and 16% were located in severe risk. Another 16% were located in a medium risk, and only 1.5% of oil spill points were located in low risk areas.

CONCLUSION

Geographic Information System (GIS) becomes very popular in the field of oil spill studies. It has the capabilities of analysing spatial patterns using a wide variety of input data files, and efficient in risk and hazard modelling. Whereas, risk assessment is one of the main processes to prepare for oil spills, it has emerged as a result of worldwide interest in different aspects of hazards.

Petroleum industry activities in Nigeria are responsible for environmental degradation in the oil production areas of the country. Hence, this study was conducted to build a GIS based oil spill risk assessment model for vegetation in the Niger Delta. The OSRAMV process was started by creating an elevation map for the study area, and combine it with environment map to build a topographic model. This topographic model was used to create hazard maps for each oil facility type inside the study area. Then, all hazard maps were combined in one oil spill hazard model (OSHM) for the area of study. Finally, the OSHM was combined with a vegetation quantity map to create the final OSRAMV.

Oil facilities hazard model accuracy was examined to ensure the final OSRAMV result by using known oil spill impacted area location. Results revealed that no impacted areas are located inside very low and low hazard areas. Whereas, 71.6% of impacted areas extent was in severe hazard areas, 25.3% of impacted areas extent was in high hazard areas, and only 3.1% were located in medium hazard areas. Final result for SHELL's oil spill sites revealed that 66.5% of oil spill points were located in high risk areas, and 16% in severe risk. Another 16% were located in medium risk, and only 1.5% of oil spill points were located in low risk areas.

This study represents the severity of oil spills in the Niger Delta's vegetation, and how much the Nigerian environment is in danger. This model can be applied in different wetland areas around the world generally, and in different other areas of the Niger Delta especially.

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