International Journal of
Science and Engineering Investigations vol. 5, issue 53, June 2016
ISSN: 2251-8843

Geo-Intelligence Mapping and Monitoring of Potential Oil-Spill Disaster Hotspots in Niger Delta

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Abstract- The Niger Delta region remains the epicenter of crude oil exploration, exploitation and pollution hotspot. Presently, oil pipeline spans over 300 kilometers networking over 280 flow station. Imperatively, communities hosting crude oil production will continue to be a potential conflict zone as long as oil exploitation persists in the region, especially, in the absence of critical oil mining cadaster, geo-intelligence monitoring, and management of oil facility hotspots. Sustainability therefore is a critical challenge in the region, not just for food security, shelter and quality of life of the present but for the needs of the region. The hallmark of spatial-based research solution to development and societal problems anchors on geospatial data that is time and location critical. This paper demonstrates geo-intelligence applications as spatial Decision Support System (SDSS) for the management of oil-community hotspots sampled from the region. A buffer analysis carried in ArcGIS 9.3 environment captured 184 hotspot communities across two sampled states of Rivers and Bayelsa State .These communities were identified within a 1km buffer zone of oil facilities. Hence, Earth Observation and Satellite (EOS), geo-informatics applications and web-mapping technology will provide an effective geo-intelligence real-time and location-critical monitoring and management of oil-community hotspots in the region.

Keywords- *Geointellligence, Mapping, Monitoring, Hotspots, Oil Spill Disaster*

I. Introduction

Disasters, whether natural or human induced are location-based emergency event beyond the management capability of local resources. All phases of the emergency event (disaster) management requires appropriate data that are logically gathered, organized and deployed to determine possible mitigation measures that could be administered proactively, or reactively. Most of these data requirement are spatial in nature and can be displayed in maps [8]. In order to manage disasters proactively potential hotspots should be identified, described and evaluated prior to the event. It is also necessary to provide access to such vital geospatial data so that all stakeholders can effectively participate in prevention or recovery of a disaster event.

Access to geospatial data required for disaster events such as oil spillage is lopsided due to the cost and technicalities involved in providing and managing such database .Hence, only the oil exploitation companies in Niger Delta region currently maintains environmental information systems required for oil spill management .Whereas government agencies, host communities and non–governmental bodies lacks geospatial database. In order to manage disasters proactively, potential hotspots should be identified, described and evaluated prior to the event.

Nigeria may not be on a global list of disaster hotspots as experienced in such locations as Bangladesh, the pacific, India, and Japan. However, anthropogenic disasters such as oil spill; floods and erosion on a high scale are prevalent in Nigeria, especially, the Niger Delta Region. In developing an effective management strategy to tackle these environmental problems, a systematic approach that will enhance proactive efforts through prediction monitoring, early warning, risk assessment, and recovery is most vital [7].

This paper, therefore, advocates for the effective integration of geospatial technology to oil spill disaster management. It focused on the identification and mapping of potential oil spill disaster hotspot communities in the Niger Region to enhance a proactive monitoring and management of oil spillage.

II. Geo-informatics and Oil Spill Disaster Management

Geo-informatics is a new technological paradigm of mapping science. It is a geospatial–based multi-disciplinary approach and technological development of mapping and map products. Balogun [2] in his description of the world of maps noted'' that maps are visual representation of a geographical space .Maps provide graphical image and mental picture in addition to verbal description .The world of maps consist of several maps produced at various scale, subjects quality and mode of production" .the transformational trends in the quality of modern maps underscore geo-informatics technology applications.

Hence, geo-informatics is a multi-disciplinary science that synergies technological inputs and principles of Digital

Cartography, Remote sensing. Photogrammetry, Surveying, Global positioning system (GPS), Geographic Information System (GIS) and automated data capture system using high resolution geo-referenced spatial data. Geo-informatics is a combination of computerized cartography system (that stores map data) and a database management system (DBMS) that stores attribute data. It is a computer-based system that is used to encode, store, process and manipulate geographic data [5].

All phases of emergency events (disaster management) requires appropriate data that are logically gathered, organized and displayed to determine possible mitigation measures that could be administered proactively or reactively.

Most of these data requirements are spatial in nature which can be displayed on the map [8].Disaster management is highly complex and requires the right information, provided at the right time with simplicity and clarity to enhance effective mitigation measures. Geospatial data is essential to various stages of oil spill disaster management because it is a spatio-temporal event.

In order to manage oil spill disaster proactively, potential hotspots need to be identified, described and evaluated prior to such event .Effective monitoring and early warning system are also essential while response and risk assessment are followed. Studies in the field of disaster management, oil pollution, and geo-information are among attractive issues that have the attention of many researchers .Building ease to decision-making and implementation of proactive environmental management is critical to our information-based century .if the system is simply described, linkages between potential spill locations, ecological sensitivity and different clean-up methods could be established [15].

Conventionally, emergency management programme are planned, implemented and modified based on the volume of business or reaction to emergency as they occur. Geo-informatics technology allows emergency management needs to be identified prior to an incident. Hence, conscious application of geo-informatics technology can take much of the panic, cost, time and surprises out of emergency hazards and conflicts [8]. Fig.1 is a flow chart of geo-informatics-based application for disaster management.

Response capabilities depend on the variability of data from agencies. The capability to access and process information quickly and deploy resources during disaster events is mission critical .Hence information about the location of an incident or disaster is vital to response strategies.

With geo-informatics technology effective planning for emergency response, mitigation priorities, historical events analysis and prediction of future events can be executed [18].

III. Oil Spill Disaster and the Niger Delta Region

The Niger Delta is a potential disaster region due to the extensive exploration of crude oil. Ineffective reactive measures to environmental problems, especially those accelerated by the oil and gas projects have denied the region sustainable development.

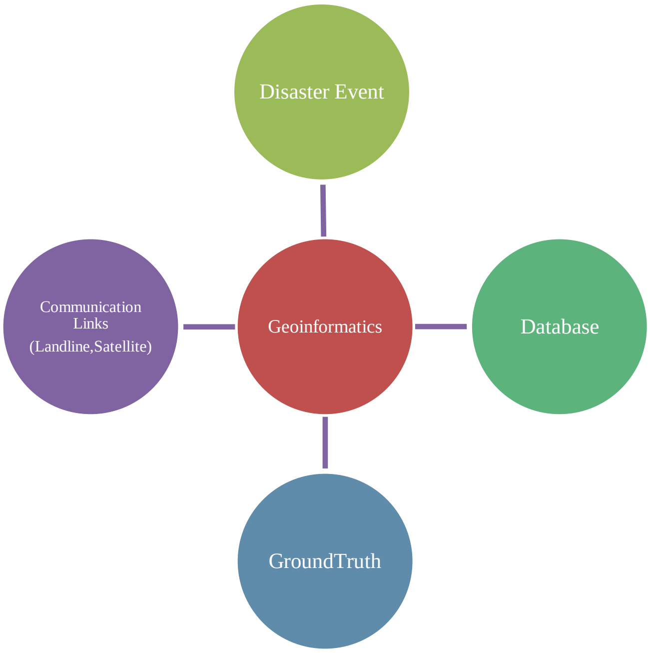

Figure 1. Schematic Model of geo-informatics Application for Disaster Management

Both oil and non-oil activities impact negatively on the biophysical environment. Losses of biodiversity, aquatic, terrestrial and groundwater pollution, as well as loss of lives and properties, are some of the environmental consequences of socioeconomic activity in the region [3].

Crude oil impacts negatively in the event of an accidental discharge as a result of the blowout, bunkering, pipeline rupture and other mysterious causes. It is on record that oil spill disaster has led to a serious environmental damage in the region[13].Conventional mitigation measures for oil spill disaster management are well known to environmental managers in the region . Whereas a multidisciplinary approach involving geo-informatics technology application is lacking. Illegal fuel siphoning as a result of the thriving black market for fuel products has increased the number of oil pipeline explosions in recent years. In July 2000, a pipeline explosion outside the city of Warri caused the death of 250 people. An explosion in Lagos in December 2000 killed at least 60 people [13]. The NNPC reported 800 cases of pipeline canalization from January through October 2000. In January 2001, Nigeria lost about $4 billion in oil revenues in 2000 due to the activities of vandals on our oil installations. The government estimates that as much as 300,000 bbl/d of Nigerian crude is illegally bunkered (freighted) out of the country. Nwilo and Badejo [13] laments that for petroleum industries; oil spill is a big threat. A huge sum of money is spent just for oil clean up. There is a natural human tendency to consider the conservative or reactive approach towards the management of environmental crises such as a catastrophic oil spill, considering the fact that oil volume is commonly reported in barrels, rather than metric units [9].

TABLE I. FREQUENCY AND MAGNITUDE OF OIL SPILLS IN NIGERIA (NIGER DELTA REGION) 1991-2000

Year	Number of Spills	Quality of spilled oil	Total (%)
1991	201	106,827.98	16.7
1992	367	51,131.91	7.97
1993	428	9,757.22	1.52
1994	515	30,282.87	4.7
1995	417	63,677.114	9.93
1996	621	65,005.122	10.14
1997	688	60,288.99	9.4
1998	728	96,449.699	15.0
1999	818	79,608.154	12.4
2000	998	17,608.154	2.7
Total	5781	640,987.209	100

Source: NNPC Petroleum Resources, 2001, Adeyemo, A.M. (2008)

Oil spillage is categorized into four groups: minor, medium, major and disaster. The minor spill takes place when the oil discharge is less than 25 barrels in inland waters or less than 250 barrels on land, offshore or coastal waters that do not pose a threat to the public health or welfare. In the case of the medium, the spill must be 250 barrels or less in the inland water or 250 to 2,500 barrels on land, offshore and coastal water while for the major spill and the discharge to the inland waters is in excess of 250 barrels on land, offshore or coastal waters [3, 13]. The disaster refers to any uncontrolled well blowout, pipeline rupture or storage tank failure which poses an imminent threat to the public health or welfare. Fig. 2 Shows photographs of some spill sites in Niger Delta.

Figure 2. Some Oil Spill Disaster Sites in Niger Delta Region

Network of crude oil pipelines and tankers are major sources of thousands of barrels of oil already spilt in our Niger delta environment. This is consequent to lack of maintenance of these pipelines and storage tanks. Some of these facilities are hardly replaced even after decades in active usage [3, 13].

IV. GEOGRAPHICAL DESCRIPTION OF THE NIGER DELTA REGION

The Niger Delta region is approximately geo-referenced to Latitudes 4° and 6°N and Longitudes 5° and 9° E, situated in the southern part of Nigeria where the river Niger produces a delta as it discharges its water into the Atlantic` ocean .It occupies a landmass of about 112,110km^2 representing 12 % of Nigeria's total surface area with over 31 million inhabitants. The Niger delta is the world's third largest wetlands characterized by biodiversity and oil reserve [10, 16, 12, 1].

The region comprises of nine states of Nigeria (see figure 3 Niger Delta Map and Table 1).

The Niger Delta Environmental Survey (NDES) Report (1990) identified four cartographic definitions of the Niger Delta as follows:

1) The Natural (Geographical) Niger Delta comprising of the areas bifurcated by the River Niger distributaries.
2) The political Niger Delta Comprising of the states administered as Niger Delta Region.
3) The oil mineral producing area commission (OMPADEC) Covering the Oil producing communities.
4) The operational definition for the purpose of Niger Delta Environmental Surveys (NDES).

For the purpose of this research the region implies all the geographical area concerned with oil exploration and exploitation which comprises the nine states as shown on the map (figure 3).

However, two sates namely Bayelsa and Rivers State were sampled for the purpose of analysis in this paper. The Niger Delta region is rich and divers in its ecological features. Five distinct ecological zones ranging from barrier islands forest to montane habitats can be identified [6, 12].

The Niger delta region lies mainly from the hot equatorial forest in the southern lowlands to the humid tropical in the northern highlands and the cool montane type in the obudu plateau area. The wet season last from March to February while dry season last November to February, whereas, the annual rainfall ranges from 21500 mm at the upland location, the dry months are not completely free from torrential rainfall [4]. The area is characterized by high relative humidity with an average of 90% for Brass and Nember and a fairly constant temperature of maximum 30 c most of the year [14]. The tropical maritime and tropical continent air masses strongly influence the region. Temperature averages on the monthly variation of 28c to 33c and 21 c to 23 c respectively. February, March and early April are the warmest months in most part of Niger Delta region [12].

The region is the dominated by low-lying plains of the sedimentary environment of the modern Niger Delta .The land surface is generally less than 120 m above sea level and slopes gently in the north-south direction to the sea. The land surface is also shaped by the meeting of the freshwater and tidal drainage systems of the region [12]. The hydrological system is made up of large and medium sized natural channels as well as rills, rivulets, and small perennial streams. The large rivers such as Nun, Forcados, Orashi have wide channels. The rivers system can be classified into the fresh water a (black) and tidal (brackish water) river system [9].

The Niger delta soil is characterized by recent (HOLOCEN) alluvium and beach deposit s [4]. The soils can be broadly classified into three physiographic units to comprises: the sandy Beaches: the ridges along the coast, the tidal and mangrove swamps with a distinct root-mat in the upper 50 cm to 100 cm depth [4]

According to Teme, the soil comprises of Entisoils, inceptisols, and ultisols with varying textures of silly clay alluvium to coarse sands of beach ridges. The swamp contains mostly interbeded silt and clay .The mud's which are flooded diurnally dominates the inter tidal area while the sandy areas include the levee crest, levee slopes saline sands beach ridges and areas of sombeiro-warri Deltaic plains [4]

A. The Study Location

The study area is Niger Delta region from where selected sample locations were showcased for analysis. This includes parts of Bayelsa and Rivers state for hotspot communities (figure 3).

The study area is networked with pipelines which cut across the selected sampled communities/location.

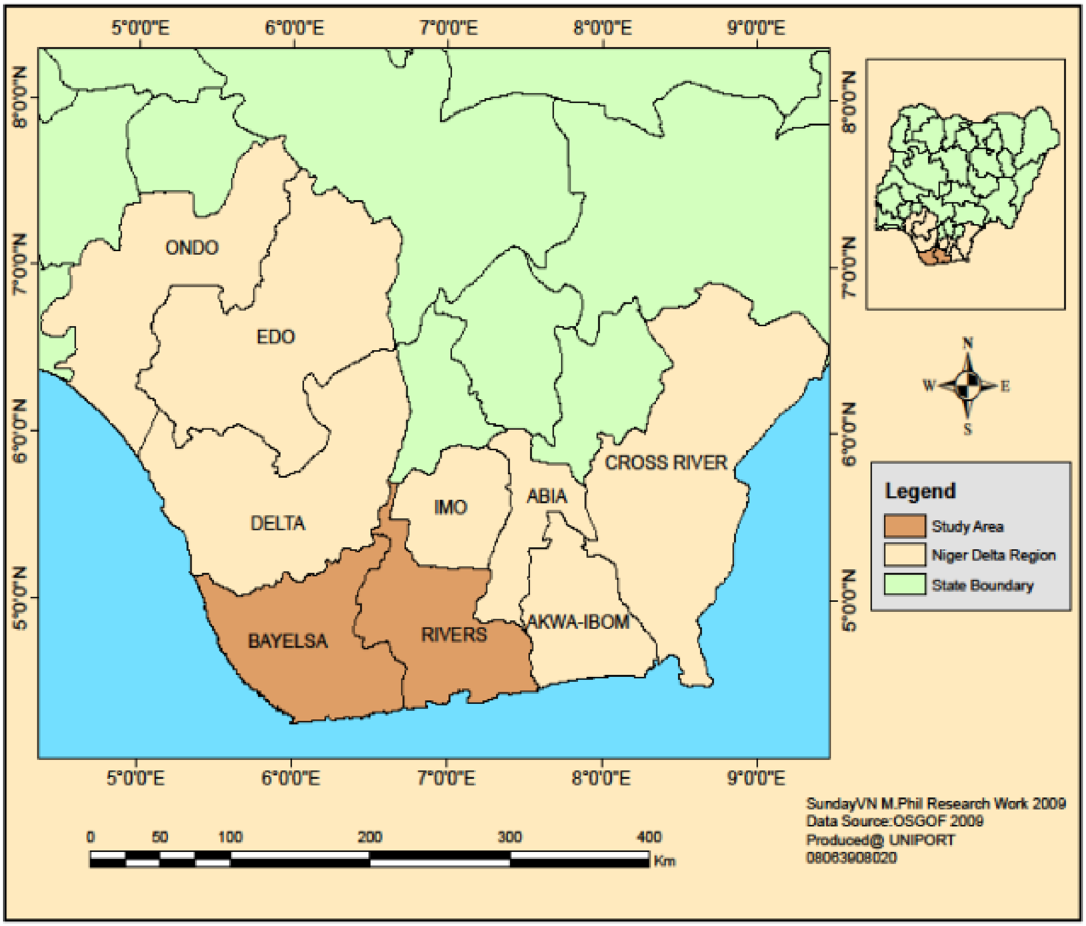

Figure 3. Niger Delta Showing Study Area

V. MATERIAL AND METHODS

This section deals with the procedures and methods used in collection, analysis and presentation of data as well as the equipment used. It is divided into data collection, instrumentation and data analysis.

A. Data Collection

The following data sets, sources and methods were adopted for the data collection. Figure 4 is a schematic diagram of data collected.

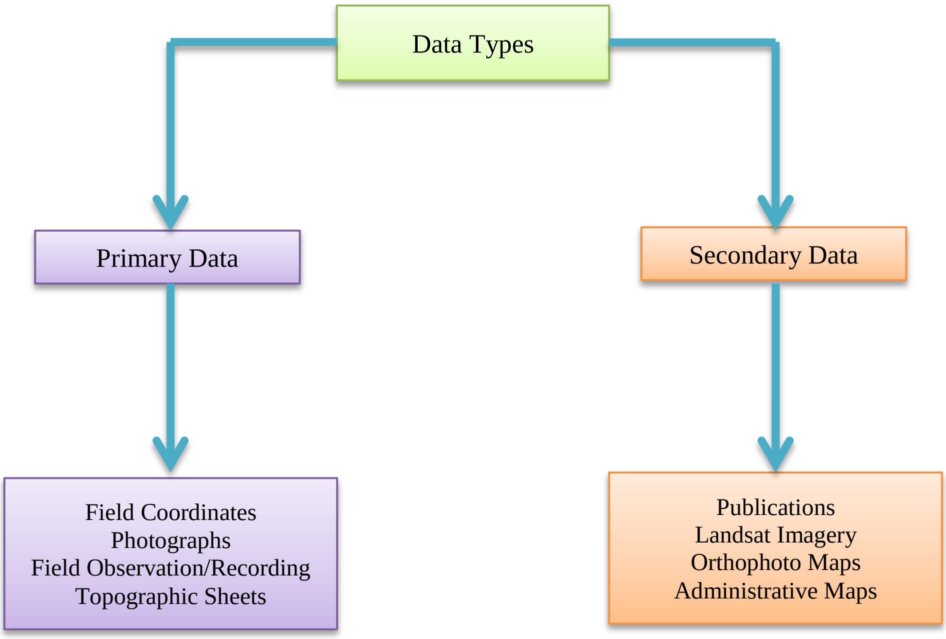

Figure 4. Schematic Diagram of Data Collection

1) Administrative Map

Administrative map sheet of Rivers state and part of Bayelsa state on a scale of 1:200,000 (December 2007, edition) from SPDC, Eastern Division was used. This was used as a base map which provided vital data such as the real geographical locations of pipelines, roads, place names and rivers. it also served as a base map for onscreen digitization of the pipeline and other oil facilities. Administrative base map used is attached to appendix.

2) Topographic Maps

Port Harcourt NE sheet n 338 of 1963;Degema NE sheet 328 and Degema SE sheet 328, (all on scale of 1:50,000, Federal Survey, Lagos, 1963 edition). These topographic maps served as important data sources for the study, especially, with data analysis on selected sampled locations dealing with land use classification.

3) Satellite Imagery

Landsat Landuse landcover (LULC) satellite imagery of Niger Delta was extracted from NNDC GIS database for overlay analysis of ecological units of sampled study locations namely; Ibaa, Rumuekpe and Rukpokwu.

4) Spill site Photographs

This was taken for visual appreciation of spill impact on the environment. Sampled spill sites in the study area were covered with snapshots.

B. Instrumentation

The following instrument/equipment were employed to facilitate the study:

- Global Positioning Systems(GPS)
- Digital Camera
- ArcGIS 9.2 GIS Software
- Scanner, Printer and laptop

C. Data Analysis

Data analysis carried out were mainly GIS/Remote Sensing techniques used to generate spatial data and land use classification of the study area in the form of the pipeline network, oil host communities and environmental sensitivity mapping of the area. ArcGIS 9.2 versions were used as the major GIS software packages for the application process.

The following procedural techniques and sequence were carried out:

1) GIS/Digital Cartographic Technique

a) Scanning

Base maps, administrative maps, and satellite imageries were scanned and saved as jpeg files for onward importation into GIS environment.

b) Geo-referencing

Maps obtained through scanners into GIS environment were geo-referenced to facilitate digitization. This operation enables the paper maps to be converted to true ground coordinates for further geographic analysis. This was carried out by locating three to four coordinates points on the map and keying the coordinate figures already collected, using the cursor and Arc view or ArcGIS tool for geo-referencing. This gives the map graticules in longitudes and latitudes as well as nothing and easting grids.

c) On-screen Digitizing

Accurate geo-referencing will enhance digitization process of maps. Pipeline network, roads, and rivers were digitized as lines, land use classification, GA boundaries, and settlements were digitized as polygons and points. The ArcView tools such as the editing menu, the view menu, the theme or add field menu enabled the on-screen digitization. It also helps the conversion of the created themes to shape files. It also allows topological building, clearing, and georectification.

Attribute table were created during onscreen digitization. These includes attributes of point data; communities and villages, identification numbers, names, line data; roads, path, rivers and pipeline identification numbers, Polygon; landuse/land cover types, LGA boundary, settlement classes, identification numbers.

d) Buffering Operations

In Udoh and Uluocha [16], the buffer zone is defined as an area of specified width that is drawn around a specific map element. Buffer zones are built to determine the proximity of the area, communities, and features which have contact with the pipeline network. A three-kilometer buffer zona of one kilometer each was created around the pipeline network to delineate settlements of communities and villages considered as hotspot communities based on their proximity to the pipeline right-of-way network. Subsequently, buffer zones were also created for each sampled spill site locations to determine land use classification proximity, water body, and infrastructures that could be affected by the spill.

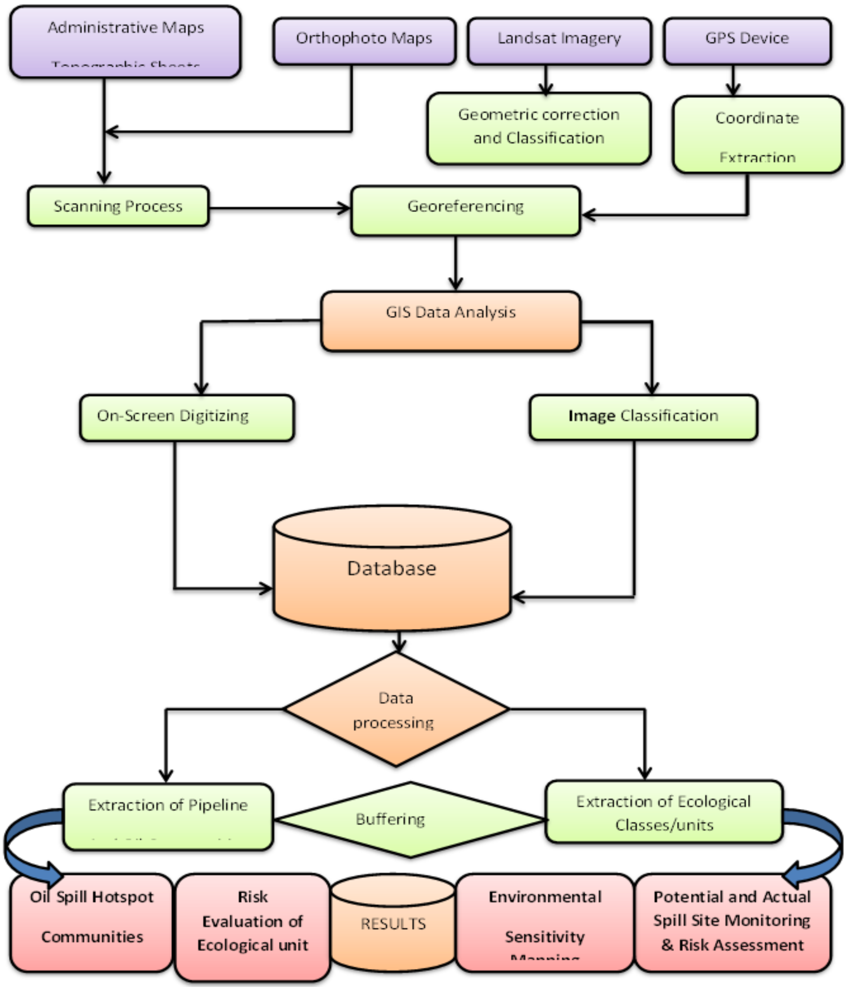

Figure 5. Schematic Diagram of General Data Analysis

Hence, the research attempted an integration of accessible applications of geo-informatics technology for data acquisition and analysis. The applicable tools were Remote Sensing (Satellite imagery analysis and classification, Global positioning System (GPS) for field geo-referencing, Geographical Information System (GIS) for digitization and manipulation, Cartographic techniques for geo-visualization.

VI. RESULTS

Communities were identified and classified as hotspots for oil spill disaster in the region, using GIS spatial analyst tool. A selection for ring buffer of 1km around oil pipeline was carried out, to identify communities that fall within 1km proximity to the pipeline. This operation was carried out for Bayelsa and Rivers state respectively with an emergence of about 184 communities being delineated within a 1km proximity to the pipeline. Since, these communities are located within a radius of Ikm to vulnerable oil spill pipeline; they stand the risk of actual and potential oil spill and as such were identified and mapped as oil spill hotspot communities (Figure 6).

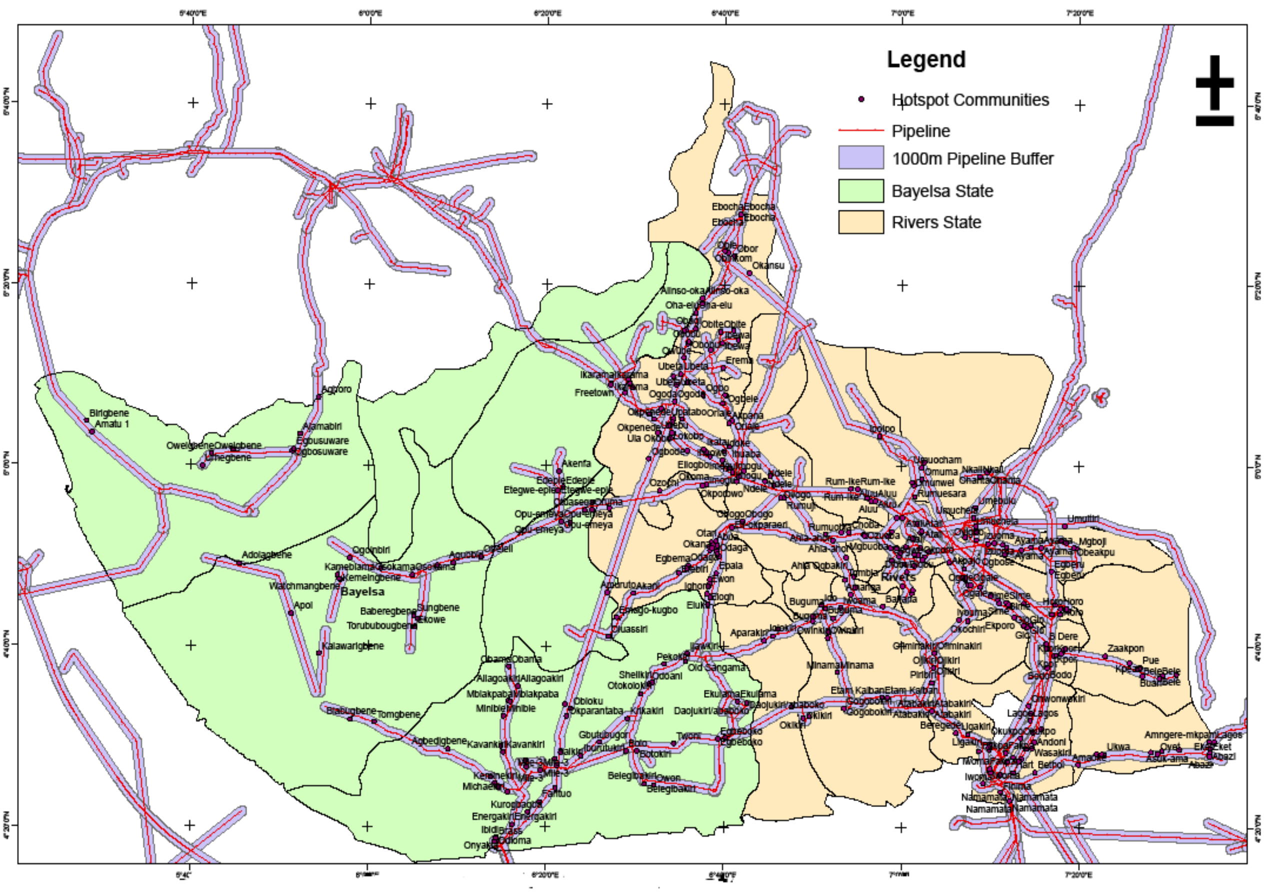

Figure 6. Identified Hotspot Communities by 1000m Oil Pipeline Buffer in Bayelsa and Rivers State

VII. CONCLUSION

Imperatively, the following underscore the importance and findings of this research as summarily outlined:

- Geoinformatics tools can be effectively used for environmental management of oil spill disaster.
- Geoinformatics tools provide an effective interplay of decision-making system essential for a proactive management of environmental crises such as oil spill
- Oil spill locations or communities with a high risk of the potential spill event were identified as hotspot oil spill communities using GIS buffering analytical tool, totaling about 184 communities from sampled study area.

This study has also demonstrated that recent advancement in geo-informatics technology provides a powerful tool for effective mapping, monitoring, and management of oil spill disaster. This implies that response to spill event will be proactively tackled, with minimal time and cost-effectiveness, considering information required for such emergency response. Location specific attribute problems relating to such spill response management will be checked easily, while effective preventive strategies and or clean–up measures implemented, without strenuous field cost and planning. Consequently, an integrated and synergistic approach involving geo-informatics technology applications towards oil spill response in Niger Delta Region is advocated.

VIII. ACKNOWLEDGEMENT

The work is an extract from the lead author's thesis and as such wish to acknowledge the enormous support and supervision given by Dr. C. L. Eze, Dr. O. Ngerebara and Professor S. C. Teme from the Institute of Geosciences and Space Technology, Rivers State University of Science and Technology, Port Harcourt, Nigeria as well as Niger Delta Development Commission for access to data collection.

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