MAPPING OIL SPILL HUMAN HEALTH RISK IN RIVERS STATE, NIGER DELTA, NIGERIA.

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ABSTRACT

Oil pipelines play a significant role in crude oil transportation and bring danger close to communities along their paths. Pipeline accidents happen every now and then due to factors ranging from operational cause to third party damage. In the Niger Delta pipeline system, interdiction is common; therefore, every length and breadth of land covered by a pipeline is vulnerable to oil pollution, which can pose a threat to land use. Weak enforcement of rights of way led to encroachment by farmers and human dwellings, thereby bringing people in close proximity to pipelines. Considering the impact exposure can have on human health, a method was developed for identifying vulnerable communities within a designated potential pipeline impact radius, and generic assessment criteria developed for assessing land use exposure.

The GIS based model combines four weighted criteria layers, i.e. land cover, population, river and pipeline buffers in a multi-criteria decision making with analytical hierarchy process to develop an automated mapping tool designed to perform three distinct operations: firstly, to delineate pipeline hazard areas; secondly, establish potential pipeline impact radius; and thirdly, identify vulnerable communities in high consequence areas. The model was tested for sensitivity and found to be sensitive to river criterion; transferability on the other hand is limited to similar criteria variables.

To understand spatial distribution of oil spills, 443 oil spill incidents were examined and found to tend towards cluster distribution. Meanwhile, the main causes of spills include production error (34.8%) and interdiction (31.6%); interdiction alone discharged about 61.4% of crude oil. This brings to light the significance of oil pipeline spills and the tendency to increase the risk of exposure. The generic assessment criteria were developed for three land uses using CLEA v 1.06 for aromatic (EC5-EC44) and aliphatic (EC5-EC44) fractions. The use of the model and screening criteria are embedded in a framework designed to stimulate public participation in pipeline management and pipeline hazard mitigation, which policy makers and regulators in the oil industry can find useful in pipeline hazard management and exposure mitigation.

ACKNOWLEDGEMENT

The past five years has been the most difficult and trying period of my life. This programme was expected to take 36 months, but it eventually took me about 66 months to accomplish. During this period, I had to overcome challenges placed before me and in the process; my courage was exhausted, my pride shattered, my determination stretched thin, and my motivation completely depleted. At the end, it was the fear of failure that saw me through.

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DEDICATION

To

Shaun and Shannon

For the strength they gave

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LIST OF ABBREVIATIONS

API	American Petroleum Institute
ASME	American Society of Mechanical Engineers
BTEX	Benzene, Toluene, Ethylbenzene, Xylene
CAST	Community and Shell Together
CLEA	Contaminated Land Exposure Assessment
EC	Equivalent Carbon
DF	Design Factor
DPR	Department for Petroleum Resources
EGASPIN	Environmental Guidelines and Standards for the Petroleum Industriy in Nigeria
FCT	Federal Capital Territory
FCT	Federal Capital Territory
FTO	Freedom to Operate
GAC	Generic Assessment Criteria
GIS	Geographic Information System
HCA	High Consequence Area
HCSR	High Consequence Settlements Register
HCV	Health Criteria Value
HRA	Horizontal Revenue Allocation
JV	Joint Venture
JIT	Joint Investigation Team
MCDA-AHP	Multi-Criteria Decision Analysis– Analytical Hierarchy Process
MEND	Movement for the Emancipation of the Niger Delta
MOC	Multinational Oil Company
MOSOP	Movement for the Survival of Ogoni People
NAPIMS	National Petroleum Investment Management Service
NDPVF	Niger Delta People's Volunteer Force
NESREA	National Environmental Standard and Regulation Enforcement Agency
NNPC	Nigerian National Petroleum Corporation
NOSCP	National Oil Spill Contingency Plan
NOSDRA	National Oil Spill Detection and Response Agency
NPC	National Population Commission
NRMAFC	National Revenue Mobilisation, Allocation, and Fiscal Commission

NYCOP	National Youth Council of Ogoni People
OEL	Oil Exploration Licence
OML	Oil Mining Lease
OPL	Oil Prospecting Licence
PAHs	Polycyclic Aromatic Hydrocarbons
PIB	Petroleum Industry Bill
PPIR	Pipeline Potential Impact Radius
PPMC	Pipeline Product Marketing Company
PTDF	Petroleum Technology Development Fund
ROW	Right of way
SOM	Soil Organic Matter
SPDC	Shell Petroleum Development Company
SST	Soil Screening Target
TPD	Third Party Damage
TPH	Total Petroleum Hydrocarbon
UNEP	United Nation Environment Program
UTM	Universal Transvers Mercator
VRS	Vertical Revenue Sharing

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CHAPTER 1

INTRODUCTION

1.0 Introduction

Pipelines are undoubtedly the most convenient and economic means of transporting crude oil across difficult terrain and over long distances from production facilities to distribution outlets (Alencar and de Almeida, 2010; Dey, 2010; Batzias et al., 2011; Lins and de Almeida, 2012). Pipelines are not only important in oil and gas transportation; they change the economic and political landscape of energy transmission in the world (Kandiyoti, 2012). However, as pipelines convey crude oil across different political and hostile boundaries, the risk of third party damage increases. Despite this, the number of pipeline constructions is increasing, just as third party damage is becoming significant in hostile and conflict areas of the world (Montevecchi et al., 2011; Achebe et al., 2012; Anifowose et al., 2012; Kandiyoti, 2012; Marcoulaki et al., 2012). Pipelines criss-crossing the Niger Delta have not only become conflict pipelines, they bring danger close to homesteads and farms (Ugochukwu and Ertel, 2008; Phil-Eze and Okoro, 2009; Sojinu et al., 2010; Williams and Benson, 2010). Hence, the same pipelines that supposedly transport wealth are causing environmental devastation.

1.1 Statement of the Problem

Following the discovery of crude oil in Nigeria in 1956 (Benedict, 2011), several Multinational Oil Companies (MOCs) proliferated in the Niger Delta region to prospect and produce oil on joint venture contracts with the Federal Government of Nigeria. Today, there are multinational and indigenous oil companies operating in the country, and collectively they contribute not less than 90-95% of export and over 90% of foreign earnings to government revenue (Benedict, 2011; Ogwu, 2011; NNPC, 2013). Considering large crude oil and gas reserves, the government plans to increase production from the current 2.5 million barrels per day to 4.5 million barrels per day by 2020 (NNPC, 2013). However, the misconceptions on the government's involvement with MOCs, intentions of the MOCs, and the government's complacent attitude in performing its regulatory obligations, which allows MOCs to operate without recourse to international "good oilfield practice" (Steiner, 2010) has pitched host communities against the MOCs and the government.

Oil-producing communities are agitating for more benefits from oil since parts of the country that do not produce oil seem to be receiving more than them, while they bear the externalities of oil production (Ogwu, 2011). The notion of other regions benefiting more from oil production while the Niger Delta people bear the cost of production is an ethical question that causes dissatisfaction in the distribution of cost and benefits of environmental consequences (Pulido, 1996; Byrne et al., 2002). Therefore, the present quest to increase production without addressing the animosity between host communities, government, and MOCs may further aggravate existing problems of oil interdiction in oil-producing communities (Onuoha, 2008; Achudume, 2009). During last decade, oil interdiction, oil theft, bunkering and artisanal refining have become popular not only as a form of protest against the government's neglect and MOCs' conduct, but also as a process of claiming what the people feel is rightly theirs (Duffield, 2010; Martyn, 2011; Will, 2012; John, 2013). However, this attitude has caused significant damage to the environment with serious repercussion for land use and implication on human health.

The series of protests and agitations against oil pollution and its impact in the Niger Delta prompted the Federal Government of Nigeria to commission the United Nations Environment Programme (UNEP) in 2009 to assess polluted sites in Ogoniland (UNEP, 2011; Shell Nigeria, 2013). The report (UNDP, 2011) revealed the presence of petroleum hydrocarbons in the environment several times higher than most international standards, but is silent on land use exposure or assessment criteria, thereby relegating human health risk-assessment as an important variable in remediation. In view of the wide spread hydrocarbon contamination, it is important to prioritise clean-up efforts such that areas with established pollutant linkages are given first order priority to protect human health.

Most oil spills and pipeline accidents in the Niger Delta, according to the government and MOCs are caused by interdiction[1] (SPDC, 2007; Afrol News, 2008; Thisdayonline, 2009). Meanwhile, the public blame oil spills on the deteriorating condition of pipelines due to ageing and poor maintenance (Osuji, 2002; Osuji and Onojake, 2006), a position supported by Achebe et al. (2012), who aver that 73% of pipelines lack asset integrity (maintenance). This is strange because in developed countries, pipeline asset integrity complies with guidelines and standards. For instance, in the United States of America, pipeline asset integrity is enshrined in the Pipeline Safety and Regulatory Certainty Act of 2011 (US Department of Transport, 2011). The Act demands strict compliance with pipeline safety standards and impact procedures, through Pipeline Impact

[1] The term '*interdiction*' refers to deliberate sabotage, vandalism and bunkering (Church et al., 2004; Anifowose et al., 2012).

Radius (PIR) demarcation and High Consequence Areas' (HCAs) designation (Steiner, 2010; US Department of Transportation, 2011; Kramer, 2013). While the American Society of Mechanical Engineers (ASME), the American Institute of Petroleum (API), and their affiliates have adopted the approach as "good oilfield practice", according to Steiner (2010), MOCs in Nigeria do not exhibit such standards. The requirement by the Oil Pipeline Act of 1956 of the Federal Republic of Nigeria of 30-metre rights of way (ROW) for pipelines is not being enforced because homesteads and farms have already encroached on several ROWs (UNEP, 2011) which should have been cleared by the government and pipeline operators.

Meanwhile, since most sites of pipeline accidents eventually become contaminated with hydrocarbons, it is important to evaluate the proximity of human dwellings, sources of water, farms etc. to sources of hazards (pipeline). In a spatial context, locations of hazards, pathways, and receptors can be determined and mapped to evaluate the proximity to hazards in time and space. Even though the intensity of a hazard is not static over time and space, the influence of frequency, quantity, and weathering/degradation on potential risk can be analysed with a GIS for risk assessment (Gay and Korre, 2006; Gay et al., 2010).

The scale of deliberate and accidental oil spills in the Niger Delta is extensive and multifaceted across all levels of oil production, and the relationship between communities and MOCs is worsening. For instance, the involvement of host communities (people) in oil interdiction exacerbating oil pipeline spills, MOCs' noncompliance with international standards in their operations (Steiner, 2010; Amnesty International, 2013), and the government's complacence in regulating the oil industries all contribute to a failure in oil pollution management (Field Interview, 2010). Therefore, in order to generate achievable strategies for policy development and a sustainable system for land contamination management, a functional tripartite relationship, which gives oil-producing communities a stake in oil production and decision making, was developed as a means of eliminating human-induced oil spills and mitigating against unnecessary exposure. Consequently, this research has developed an alternative method for mapping pipeline impact areas and high consequence areas using GIS-based Multi-Criteria Decision Making (MCDM) and Analytical Hierarchy Procedure (AHP), and risk assessment criteria for assessing rural land use exposure for some total petroleum hydrocarbon (TPH) aliphatic and aromatic fractions using the CLEA model.

1.2 Aim of the Research

The aim of this research is to develop a method for mapping areas susceptible to oil pipeline impact for land-use risk assessment and pipeline hazard management.

1.2.1 Objectives

In order to achieve the aim, the following objectives were derived:

i) To describe the geography of Nigeria and highlight the multi-ethnic distribution, political structure, and climate characteristics of the country. (Chapter 2)

ii) To provide an overview on the issue of distributive justice and environmental movement in the Niger Delta, and public disharmony with the government and MOCs in the struggle for oil benefits in the Niger Delta. (Chapter 2)

iii) To examine crude oil production in Nigeria, the government's involvement with MOCs and environmental legislation for regulating oil pollution. (Chapter 3)

iv) To review risk assessment criteria for evaluating exposure to hazardous substances and a framework for assessing human health risk. (Chapter 4)

v) Examine the application of GIS functionalities and integration of Multi-Criteria Decision Making (MCDM) in spatial decision-making applications. (Chapter 5)

vi) Examine spatial distribution, frequency, cause, and quantity of oil spills in the Niger Delta and determine the proximity of settlements to pipeline networks, rivers, and previous oil spill sites. (Chapter 7)

vii) Map pipeline hazard area to identify communities susceptible to pipeline hazard for land use exposure and risk assessment. (Chapter 9)

viii) Provide a framework for stakeholder interaction and integration of oil communities in pipeline management and the decision-making process. (Chapter 10)

1.3 Structure of the Thesis

The thesis consists of 11 chapters comprising of an introduction, literature review, methodology, analysis, discussion, and lastly a conclusion. This section introduces the chapters, giving a brief explanation on what they contain.

Chapter 1 introduces the purpose and scope of the research, and the role of pipelines in oil and gas transportation. The statement of the problem highlights the government's involvement with MOCs in oil production, and agitation for distributive justice and clean environment by oil-producing communities. Despite hostilities and interdiction of oil pipelines by the people, the government plans to increase oil production from 2.5 million barrels per day to 4.5 million barrels by 2020. Meanwhile, the scale of deliberate interdiction by communities, and MOCs' lack of compliance with "good oilfield practice" and government compliancy to address oil pollution has implications on not only the environment but humans as well. Consequently, this research set out to develop a method for mapping a pipeline impact area and to develop a framework for public participation in pipeline management. To achieve this, eight objectives were developed (Subsection 1.2.1) for fulfilling the aim (Section 1.2).

Chapter 2 presents a description of the geography of Nigeria, and ethnic distribution, climate, and vegetation of the country (Section 2.1). Section 2.2 describes more explicitly oil and gas production in the country and the type of laws and licences in operation. Figure 2-10 illustrates the contributions of various oil production contracts to government revenue and foreign exchange, which is the cause of resource conflict and struggle for distribution justice and environmental movement. I reviewed the revenue sharing formula that gave oil-producing states 13%, which they consider inadequate compensation for externalities caused by oil production. I also reviewed the origin of environmental movement in the Niger Delta to show how the struggle for equality and a clean environment pushed people to help themselves through oil theft and vandalism. This is important to the research, i.e. understanding the root cause and the culpable stakeholder; so far, the people blame MOCs and the government for their woes, yet Shell showed its commitment through direct investment in developmental programmes; however, the government is yet to increase allocation to oil-producing states beyond 13%.

Chapter 3 reviews the cause of oil spills and pipeline accidents around the world and in Nigeria. The chapter discusses the role of third-party damage in pipeline accidents and identified inconsistency in oil spill data in Nigeria, a situation that has led to questioning the efficiency of regulatory agencies in the country. The utilisation of EGASPIN by NOSDRA was shown to conflict with the National Oil Spill Contingency Plan (NOSCP), which stipulates a three-tier approach to oil spill management based on proportional quantities, against the joint inspection of oil spills greater than 100kg (0.1 tonne) only. The results of TPH concentration reported by the UNDP (2011) were reviewed and a map showing sites where samples were collected was produced (Figure 3-7) to demonstrate the extent of oil pollution along pipelines in Ogonland. International conventions, to which Nigeria is signatory and from whence some environmental legislation and legal frameworks in the country emanated, were produced. Considering the implication of oil pollution to the environment and human health, the socio-economic and cultural impact of oil pollution was reviewed. The review of crude oil classification provided a background for explaining the behaviour of crude oil when released in the environment and the effect of weathering processes on the composition of oil properties.

Chapter 4 reviewed risk assessment procedures and exposure criteria developed in the United States of America and the United Kingdom, for evaluating human exposure to hazardous substances through inhalation, ingestion, and dermal contact. In addition, values recommended by the US Environment Protection Agency, Environment Agency and the Land Quality Management/Chartered Institute of Environmental Health (LQM/CIEH)

Generic Assessment Criteria (GAC) for assessing human exposure were reviewed to ascertain their applicability for land use assessment in the Niger Delta. TPH fractions and effect of weathering on petroleum hydrocarbon toxicity with background concentrations of benzene, toluene, ethylbenze, xylene, naphthalene and benzo(a)pyrene were also reviewed.

Chapter 5 reviews the GIS technique used in the research: firstly, the concept of GIS as a mapping tool, and then its applications in environmental risk mapping were reviewed. The integration of MCDM in spatial decision analysis and its previous application in the literature were reviewed to support MCDM integration in GIS to solve spatial problems. The procedure for delineating PIR and the use of high-consequence areas in pipeline accident mitigation, and integrity management in the pipeline industry were reviewed for adaptation in this study.

Chapter 6 describes the methodological approach adopted in the study, detailing the type of data collection, analysis, site inspection, questionnaires, and oral interviews conducted for the research. In Section 6.0, a detailed description of the study area and events leading to the selection of the area is discussed. In addition, the statistical instrument used to analyse the oil spill data and questionnaire responses is explained; also, the difficulties and constraints during data collection is discussed.

Chapter 7 covers data gathering and pre-processing. Most of the datasets collected for this work were secondary data; as such, a lot of transformation and preparation was done in order to make them suitable for purpose. Due to a paucity of data, certain relevant information was derived by simulation to generate community polygon shapefiles and TPH concentration/toxicity reduction due to weathering (Section 7.0). The spatial distribution of spill locations indicates cluster, while quantity, frequency, and cause of spills revealed that the rate of interdiction exacerbates oil pollution in the area (Section 7.1). A proximity analysis of communities to pipelines and rivers revealed that the majority of settlements are located close to rivers and pipelines (Section 7.2).

Chapter 8 GAC was developed for three rural land uses with CLEA version 1.06. Three land uses were conceptualised and exposure parameters assigned from the literature and questionnaire responses regarding frequency and duration of activities. At the end, generic risk screening criteria were developed for land use exposure to TPH fractions.

Chapter 9 presents the pipeline hazard modelling using the MCDM-AHP technique. The GIS base automated model is a tool for mapping land use hazard zones using proximity to pipelines; the tool delineates areas susceptible to pipeline impact represented with a buffer called the potential pipeline impact radius (PPIR). Communities found within the PPIR area are treated as susceptible communities with more likelihood of impact from pipeline hazard. The reliability and robustness of the model were tested with sensitivity analysis while its transferability was demonstrated.

Chapter 10 brings together results of the research with which a framework for integrating communities in decision-making was developed. It is hoped that their involvement in decision-making, and participation as stakeholders in the oil industry would encourage them to protect oil facilities, and eliminate oil interdiction and hostilities in the region. Most importantly, this chapter integrates the results of the research in the broader context of environmental risk assessment for human health risk management.

Chapter 11 concludes that a method for mapping a pipeline impact area has been developed (Chapter 9), and generic assessment criteria for three rural land uses developed (Chapter 8) to form the basis for future land-use exposure assessment, since none exists in the country. In addition, the stakeholder integration framework provides a chance to develop mutually beneficial and transparent relations between community, government, and MOCs.

CHAPTER 2

THE GEOGRAPHY OF NIGERIA AND THE NIGER DELTA, AND THE ENVIRONMENTAL MOVEMENT

2.0 Introduction

This chapter describes the geography of Nigeria, the Niger Delta, the climate, and the diverse ethnic groups in the country. The chapter provides an overview of the environmental movement and distributive justice as a contributing factor influencing civil disobedience and human-induced interdiction of oil installations, especially pipelines in the Niger Delta region. Understanding the root cause of societal behaviour is critical to unravelling the underlying political and economic issues surrounding public agitation for resource benefits and control in the Niger Delta. This must be resolved in order to bring down the rate of human-induced oil spills and pollution.

2.1 Nigeria and the Niger Delta

Nigeria is located on latitude 10^0N and longitude 08^0E occupying approximately 910,768 square kilometres (km^2) of land and 13,000 km^2 of water (Onuoha, 2008). It is bounded to the south by the Atlantic Ocean, to the east by Cameroon and Chad, to the north by Niger Republic and to the west by Benin Republic. Nigeria gained independence on 1st October 1960; the country currently has 36 states, and a Federal Capital Territory (FCT) located in Abuja. The states are grouped into geopolitical zones, i.e. NorthWest, NorthCentral, NorthEast, SouthWest, SouthSouth and SouthEast (Figure 2-1).

The Niger Delta on the other hand is located on latitude $4^0 10'$ to $6^0 20'$ north and longitude $2^0 35'$ east of the equator protruding towards the Gulf of Guinea on the Atlantic coast of West Africa (Hooper et al., 2002; Imoobe and Iroro, 2009). It stretches from the coasts of Ondo, Delta, Bayelsa, Rivers, Akwa Ibom to Cross Rivers' states (Imoobe and Iroro, 2009). The region covers about 70,000 km^2 of wetland, which is among the world's top ten wetlands and deltaic ecosystems (Hooper et al., 2002; Phil-Eze and Okoro, 2009; Achebe et al., 2012). Located in the SouthSouth geopolitical zone, it is comprised of Abia, AkwaIbom, Bayelsa, Cross River, Delta, Edo, Imo, Ondo and Rivers' states (Phil-Eze and Okoro, 2009).

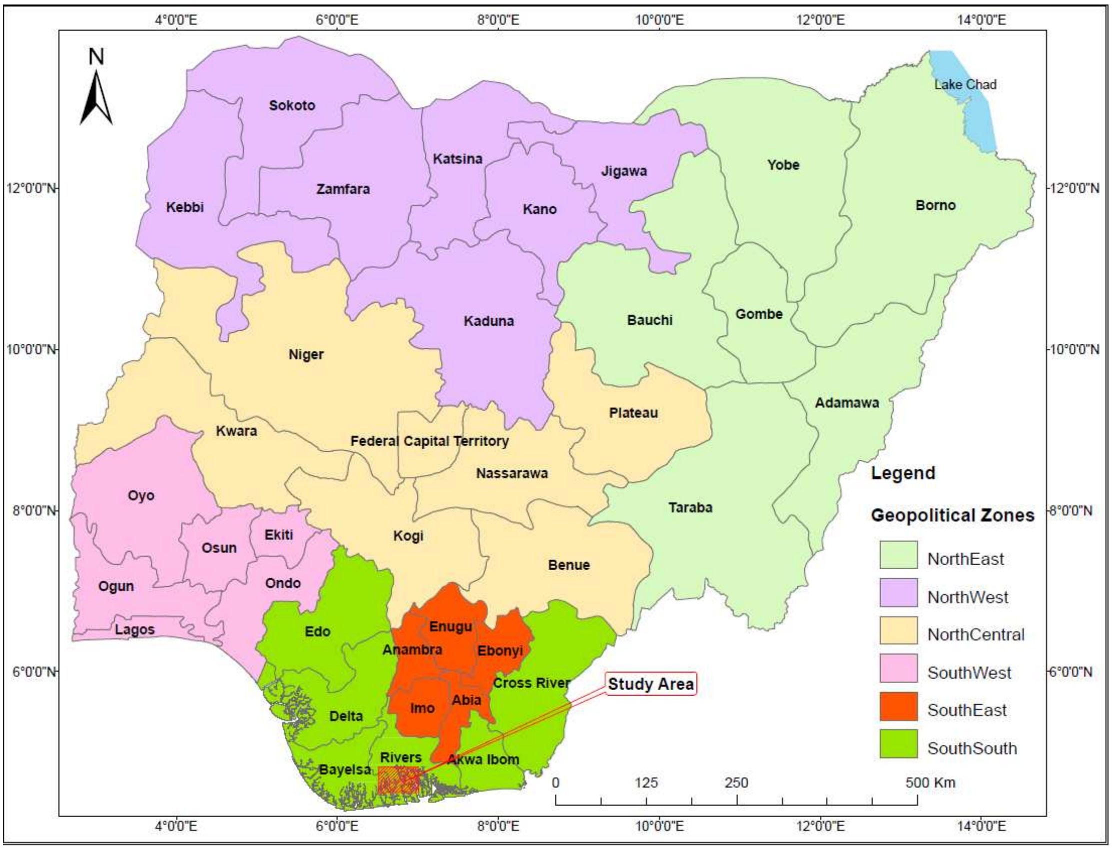

Figure 2-1: The six geopolitical zones in Nigeria (by Author 2013; Map datasets from University of Lagos).

The Niger Delta has an extensive hydrology system connecting rivers, creeks, and estuaries flowing towards the Atlantic Ocean (Akpokodje, 1987; Abam, 2001).

2.1.1 Population and Ethnic Diversity

The population of Nigeria is around 140,437,790 comprising of 71,315,488 males and 69,122,302 females (NPC, 2012), and more than 250 ethnic groups (Figure 2-2).

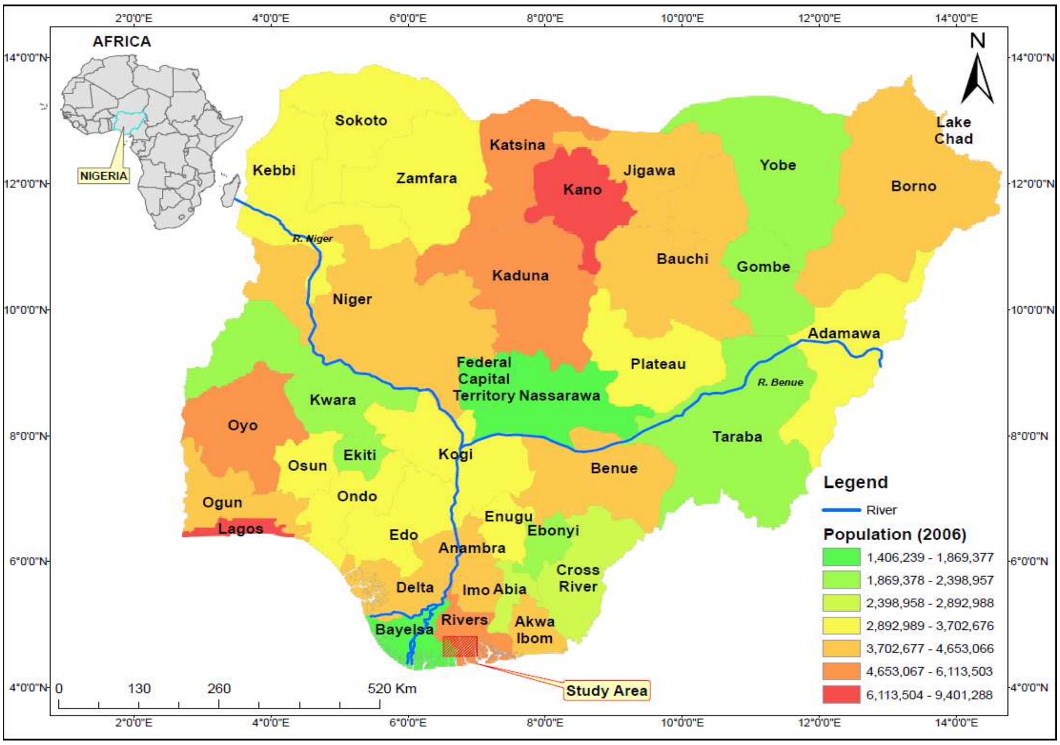

Figure 2-2: States and population distribution (by Author; Source of population data National Bureau of Statistics; Map datasets from University of Lagos).

The most dominant ethnic groups are the Hausa-Fulani, Kanuri and Tiv in the North, the Yoruba in the SouthWest, Ijaw in the SouthSouth and Igbo and Ibibio in the SouthEast (Figure 2-3). The dominant tribes in the Niger Delta are Ijaws, Ibobios, Efiks and Edo, distributed across more than 3,000 autonomous communities with the population estimated at around 31 million. The majority of the population is heavily concentrated in the two major cities of Port Harcourt and Warri due to high rural-urban migration (Abam, 2001). The rural communities are scattered settlements, each mostly inhabited by a few hundred people whose traditional occupations are subsistent farming, fishing, hunting and trading.

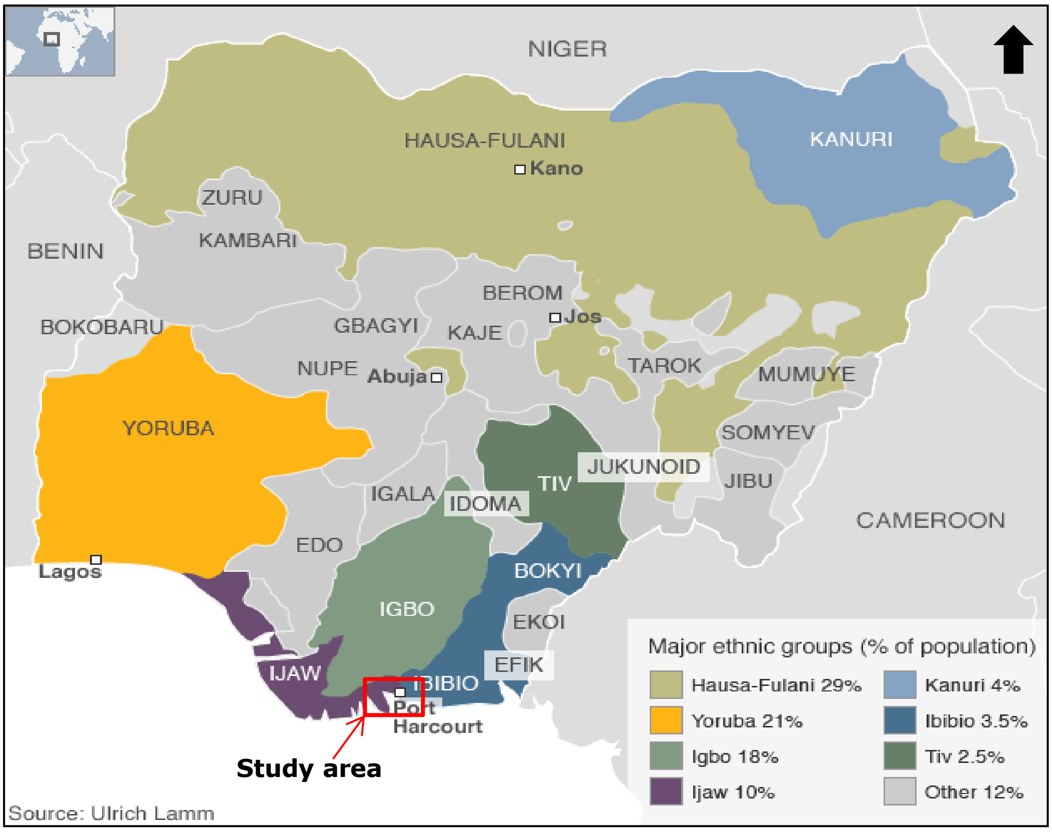

Figure 2-3: The spatial distribution of tribes in Nigeria (BBC, 2012).

2.1.2 Climate and Vegetation

Nigeria has two distinct seasons i.e. dry and rainy (wet) seasons; the lengths of each season vary from south to north. The south has an equatorial climate, the north is arid, and the central area has a tropical climate. The southern and northern parts of the country have respective average annual maximum temperatures of about 32^0C and 41^0C in the rainy season, and average minimum temperatures of 13^0C and 21^0C in the dry season (Ministry of Environment, 2003; Nigerian Meteorological Agency, 2010). Figure 2-4 shows spatial variation in temperature across the country.

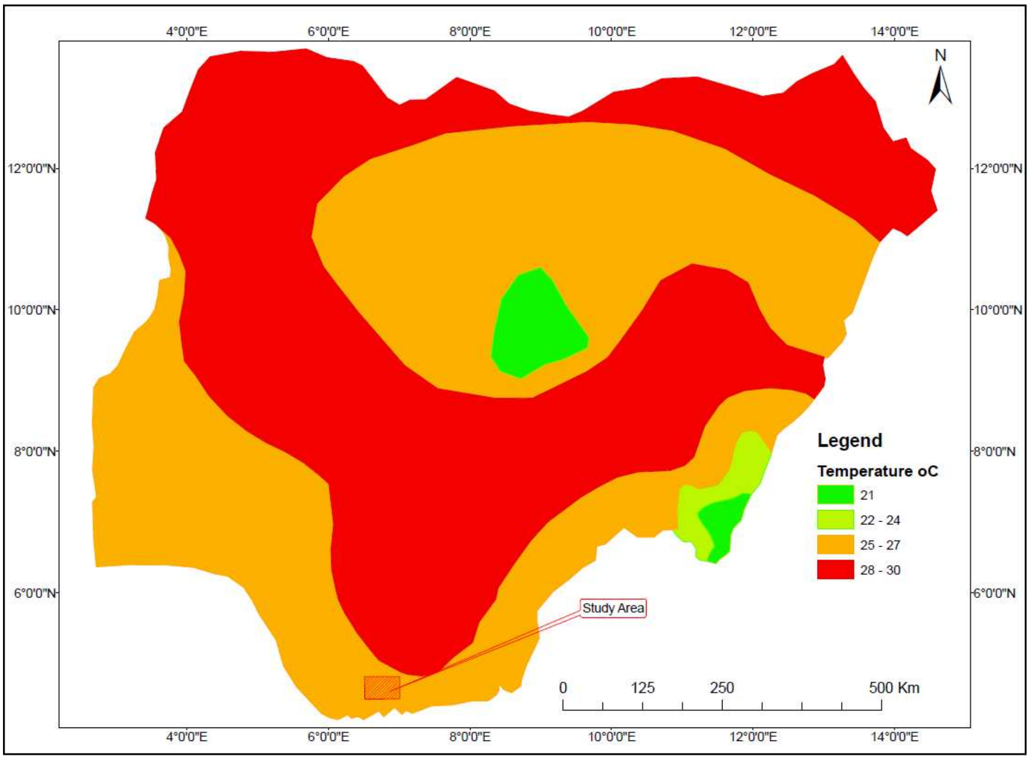

Figure 2-4: Mean annual temperature in Nigeria (digitised by Author 2013; Source Ministry of Environment, 2003; Map datasets from University of Lagos).

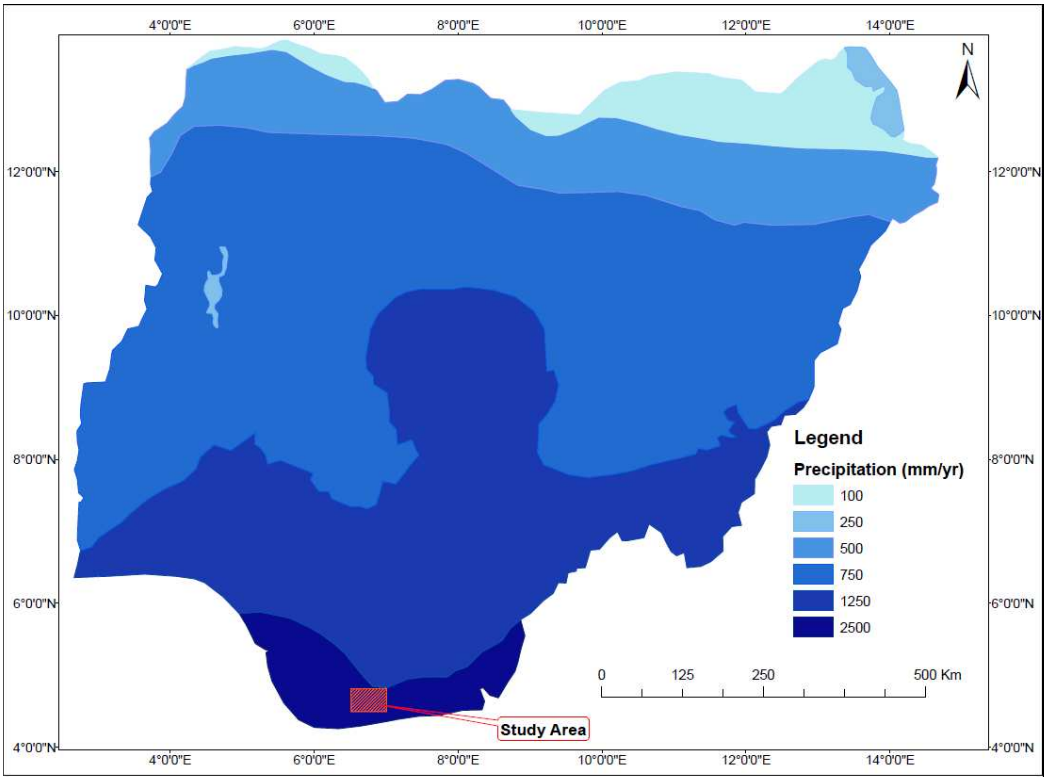

Figure 2-5: Annual rainfall distribution in Nigeria (digitised by Author 2013; Source Ministry of Environment, 2003; Map datasets from University of Lagos).

The Niger Delta area lies within the wet equatorial climate; high cloud cover and fewer sunshine hours cause damp weather conditions throughout most parts of the year. Though the temperature is moderated by cloud cover and the damp atmospheric conditions, the mean daily temperature is about 28^0C in the coolest month of August and 34^0C or higher in the hottest months of February and March. The annual rainfall is about 2,500mm (Figure 2-5) from April to December, with a break in January through March (NDES, 1999 cited in Osuji et al., 2006; Omo-Irabor et al., 2011). The rainy season generally lasts for about nine months in the south, and less than four months in the north (Nigerian Meteorological Agency, 2010).

The major vegetation in the study area of Nigeria (see Figure 2-6), comprises of mangrove and freshwater swamp.

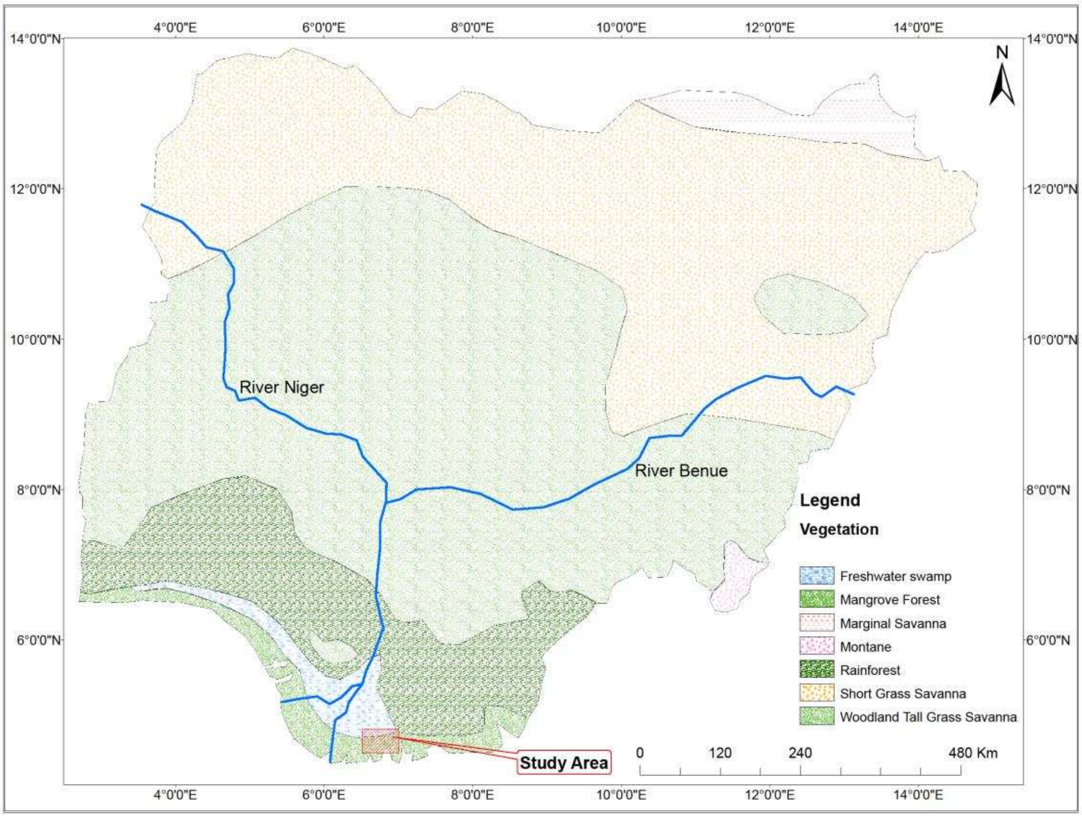

Figure 2-6: Vegetation map of Nigeria (digitised by Author, 2013; Map from University of Lagos).

The mangrove forest extends from Lagos to Sapele (Delta state) connecting with the freshwater swamp some few kilometres inland, which in turn gives way to the rainforest inland (Ministry of Environment, 2003; Omo-Irabor et al., 2011; Onojeghuo and Blackburn, 2011).

The land cover of inhabited areas in the Niger Delta consists of arable farmlands, tree crop plantations, and patches of natural vegetation. Generally mangrove forest, freshwater swamp and rainforest are dominated by tree species like *Elaeis guineensis* (Osuji and Opiah, 2007; Phil-Eze and Okoro, 2009). Ownership of land, swamps, ponds etc. is by heredity and rent or loan to strangers; the land is usually used for subsistence cultivation of arable crops like cassava (*manihot esculanta*), yam (*dioscorea sp*), maize (*zea mays*) etc.

2.1.3 Geology and Geomorphology of the Niger Delta

The Niger Delta landform was created from accumulated marine and deltaic sediment over 50 million years ago in the upper Cretaceous period (UNEP, 2011). The sediments deposited by fluvial processes centuries ago led to the formation of a relatively flat alluvium basin like natural levees and ox-bow lakes (Abam, 1999). The deltaic plain is flat lying at about 40m above sea level towards the interior, and less than 8m above sea level on approaching the coast (Akpokodje, 1987). A high rainfall regime, shallow aquifer, and flat topography cause perennial inundation when rivers overflow their banks (Akpokodje, 1987; Ministry of Environment, 2003; Osuji et al., 2006). The UNEP (2011) recently reported that there is only one aquifer serving both shallow and deep boreholes; the shallowest water table is about 0.7m below ground level while the deepest is around 14m below ground level (UNEP, 2011).

The soils were formed from a deposition of alluvium materials during the late Pleistocene to early Holocene time (Osuji et al., 2006; Ugochukwu and Ertel, 2008).

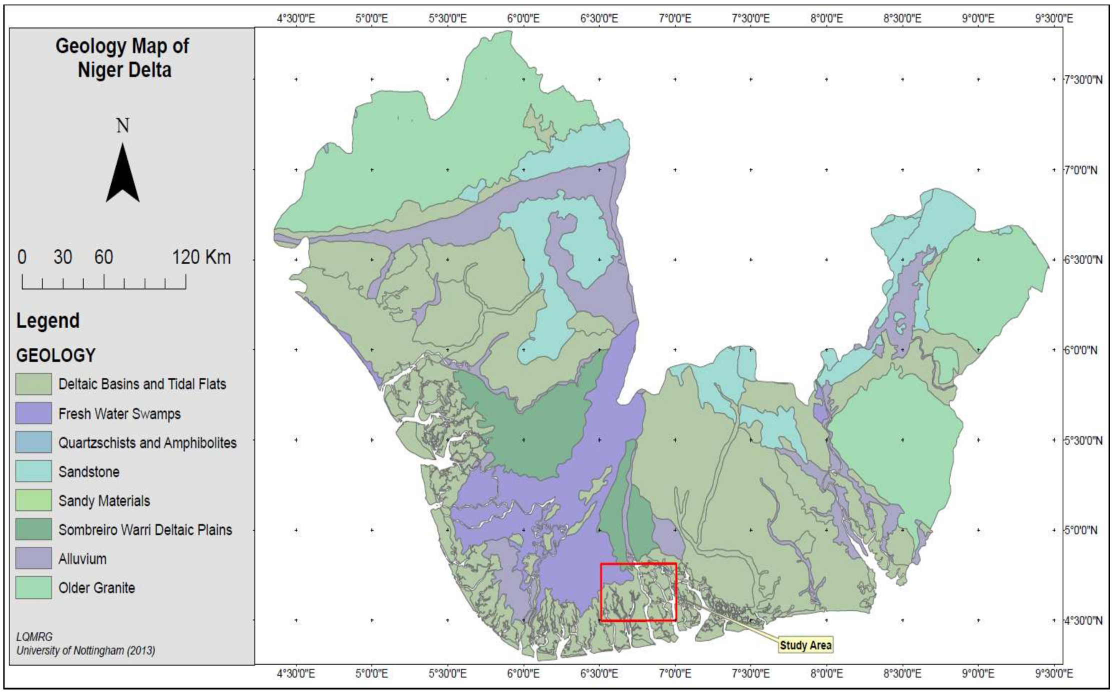

Figure 2-7: Geology of the Niger Delta (Source: University of Lagos).

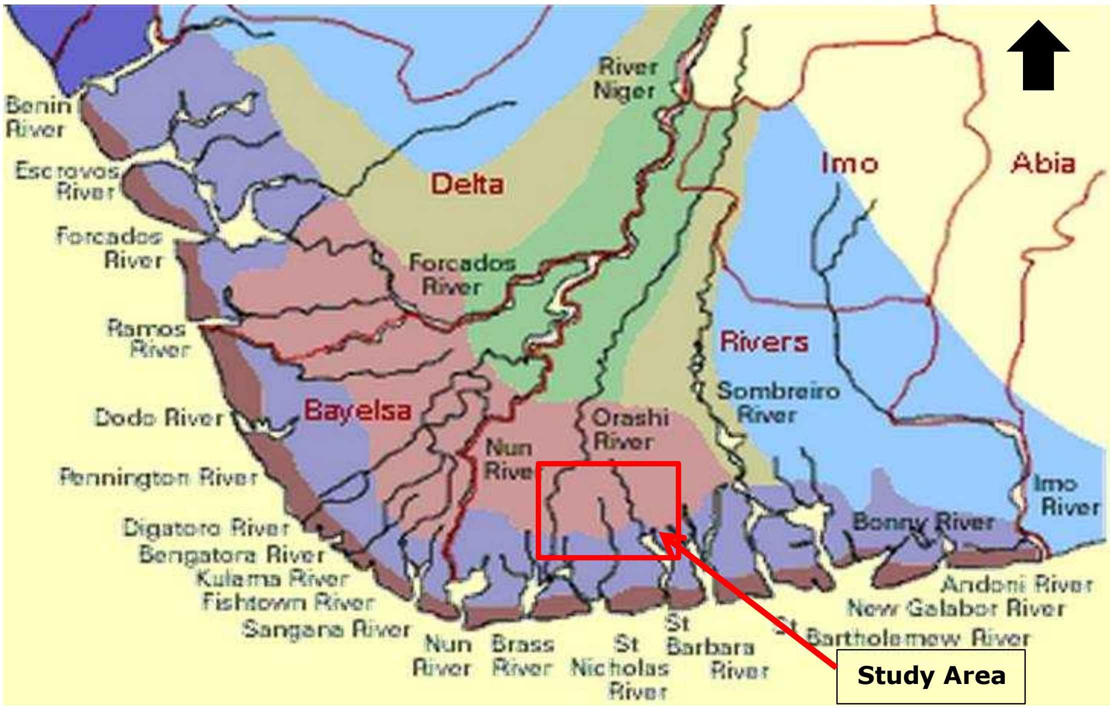

Figure 2-8: Niger Delta river drainage and tributaries (Waado, no date).

The type of soils encountered inland from the Atlantic Ocean are i) coastal beach ridge and sand; ii) dark organic peat clay; iii) light grey fine sand to silt clay; iv) brownish sandy clay; and reddish-brown sandy clay loam (Akpokodje, 1987). However, clay and loamy soils separate the topsoil from the aquifer, but the clay is no longer continuous as previously thought according to the UNEP report (Osuji et al., 2006; UNEP, 2011).

As pointed out elsewhere in this chapter, several rivers, estuaries and creeks (Abam, 2001) dissect the region, for instance the River Benue drains into the River Niger at Lokoja en-route to the Atlantic Ocean through the Niger Delta plains. The River Niger diverges into two tributaries known as the River Nun and the River Forcados, then splits into other distributaries 50–100km from the coast, giving way to a braided river and creek network, seen in Figure 2-8 (Akpokodje, 1987; Abam, 1999, 2001).

2.1.4 Niger Delta: Ecosystem

This is the physical and biological component of the environment co-habiting through natural interaction (Park, 2008). The aboitic components represents non-living things like rock, soil etc.; the biotic components are living things like plants and animals (Koshland and Connelly, 2001; Cadenasso and Pickett, 2002; William and Benson, 2010). The common ecosystems in the region are:

i) *Forest habitats*: made up of rich mangroves, lowland and swamp forest;
ii) *Marine ecosystem*: consists of the oceans, salt marsh, estuaries and lagoons, mangroves and coral reefs, the deep sea and the sea floor;
iii) *Hydrology*: made up of the rivers, creeks, estuaries, lakes, ponds and streams.

The forest harbours a rich diversity of wildlife mammals, reptiles, birds, insects and many more. The water on the other hand holds a variety of aquatic lives like shellfish, crustaceans, crocodiles, hippopotamus etc. (NDES, 1997). The people consider ecosystem resources very valuable to not just their livelihood but also their cultural wellbeing. For instance, they depend on forest resources for firewood, timber, herbs and for religious shrines (Adekola et al., 2012). Palm trees are used to produce palm wine (local gin) and palm oil (vegetable oil) and for household income generation (Omofonmwan and Osa-Edoh, 2008).

The value of the Niger Delta ecosystem services to the people and the nation cannot be overemphasised. It is common knowledge that the biodiversity and natural resources utilised directly or indirectly from ecosystem services support human well-being and help define socio-economic potentials of many human societies (Brown et al., 2011; Haines-Young, 2011). The local people have depended on the ecosystem services for livelihood since time immemorial, and the huge deposit of hydrocarbon reserves distinguishes the area as a major oil-producing region in the world.

2.2 Oil and Gas Production in Nigeria

The history of petroleum development in Nigeria reveals that oil production began with a modest daily output of between 5,100 and 6,000 barrels; after discovery in Oloibiri in 1956 by Shell, Nigeria began to export in 1958 (Egberongbe et al., 2006; Benedict, 2011; Onwe, 2012). The daily output increased to 12,000 barrels per day by the end of 1959 and 900,000 barrels per day from the late 1960s to the early 1970s. By the late 1970s to 1980s Nigeria reached a production level of over 2 million barrels per day, and 2004 saw significant improvement as production reached a record level of 2.5 million barrels per day. In fact, the government has developed strategies to increase daily production from 2.5 to 4.5 million barrels per day in the near future (Egberongbe et al., 2006; Benedict, 2011; NAPIMS, 2012; Onwe, 2012; NNPC, 2013).

Following the discovery of oil, exploration rights in onshore and offshore dichotomy were extended in 1960 to companies like Chevron, Exxon, Gulf, Mobil, Royal Dutch/Shell, and Texaco to prospect and produce oil in the Niger Delta area (Onwe, 2012). The proliferation of these companies began to manifest in the number of oil wells being drilled; Ifeadi et al. (1987) cited in Benedict (2011) claimed that, between 1960 and 1985, a total of 3,525 oil wells were drilled. As a result, there are more than 5,284 oil wells existing in both offshore and onshore dichotomy (Achebe et al., 2011, NAPIMS, 2012).

Also there are about 606 oil fields (355 onshore and 251 offshore) and more than 527 flow-stations, plus six export terminals located at Forcados and Bonny (operated by Shell); Escravos and Pennington (operated by Chevron); Qua'Iboe (operated by ExxonMobil) and Brass (operated by Agip). An extensive network of multiproduct pipelines link these facilities to ports and Nigerian National Petroleum Corporation (NNPC) depots in the Warri, Port Harcourt, Mosimi, Kaduna and Gombe regions (Nnubia, 2008; Ugochukwu and Ertel, 2008; Edino et al., 2010; Sojinu et al., 2010; Achebe et al., 2012; Anifowose et al., 2012). Figure 2-9 shows energy network of oil facilities in Nigeria, pipelines used to convey crude and refined products across the country and spatial location of oil wells in the Niger Delta. The country's downstream regions are grouped into five regions, as seen in Figure 2-9. Each region is made up of several states (Figure 2-1); the Port Harcourt region consists of Adamawa, Taraba, Benue, Enugu, Cross River, Ebonyi, Imo, Akwa Ibom, Anambra, Bayelsa and Rivers states. The Rivers' state is where the study area is located. According to Anifowose et al, (2012) the south has three NNPC regions due to the high-density network of oil installations, against two in the north which has few pipelines and oil installations.

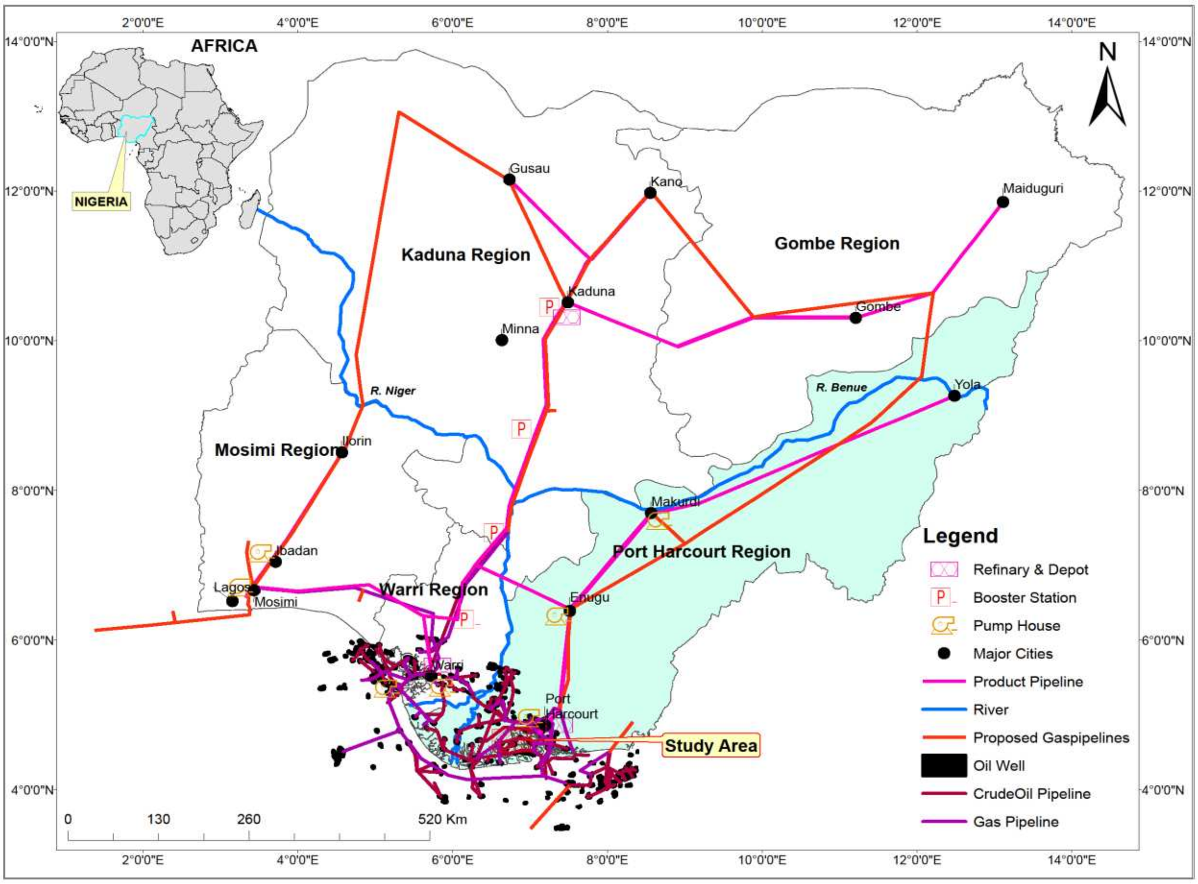

Figure 2-9: Petroleum energy map of Nigeria showing primary pipelines and oil wells in the offshore and onshore dichotomies (Source: *The Petroleum Economist*, 2005; Anifowose et al., 2012).

2.2.1 Types of Licences and Contracts in Nigeria

Chapter IV Section 44 No.3 of the Constitution of the Federal Republic of Nigeria provides that:

> *"… the entire property in and control of all minerals, mineral oils and natural gas in, under or upon any land in Nigeria or in, under or upon the territorial waters and the Exclusive Economic Zone of Nigeria*

shall vest in the Government of the Federation and shall be managed in such manner as may be prescribed by the National Assembly."

Consequently, the Petroleum Act 1969 provides the following type of licences (Table 2-1) for upstream operation on behalf of the government through the Minister of Petroleum.

Table 2-1: Oil licences in the Nigerian upstream (Petroleum Act , 1969).

Licences	
Oil Exploration Licence (OEL)	This licence is no longer in use but was for preliminary exploration only and valid for only a year but renewable annually
Oil Prospecting Licence (OPL)	This is for the prospecting and exploration survey for five years. Beneficiaries can dispose-of a small quantity of oil discovered during prospecting, but if discovered in a commercial quantity the field is handed over to the NNPC
Oil Mining Lease (OML)	This allows full production once oil is found in commercial quantity. The licence gives exclusive rights to beneficiaries to prospect, explore, produce, and market oil for 20 years

Following provisions in the above law, the NNPC engage MOCs in exploration and production contracts (Table 2-2) on behalf of the federal government (Hamid, 2012; Olaniwun, 2013). The NNPC is an entity established under the NNPC Act: Cap N123 LFN[2] to represent the government in the petroleum industry. NNPC implements the government's policy in the oil and gas sector in addition to its regulatory responsibilities. The NNPC Act vested the following powers in the NNPC (Olaniwun, 2013):

i) *exploring for or acquiring, possessing and disposing of petroleum;*

[2] LFN: Laws of the Federal Republic of Nigeria

ii) refining, treating, processing and engaging in handling of petroleum for the manufacture and production of petroleum products and their derivatives;

iii) purchasing and marketing petroleum products and by-products;

iv) providing and operating pipelines, tankers or other facilities for the conveyance of crude oil, natural gas and their products and derivatives, water and any other liquids or other commodities related to the NNPC's operations;

v) doing anything required to give effect to agreements entered into by the government with a view to securing participation by the government or the NNPC in activities connected with petroleum; and engaging in activities that would enhance the petroleum industry in the overall interest of Nigeria.

Table 2-2: Upstream contracts entered into with the NNPC.

Type of Contracts Operated by the Nigerian Government	
Participatory Joint Venture (PJV)	The NNPC has majority holding in this contract; each participating company contributes an amount proportional to their share in running the E & P Company, and to "cash call"
Production Sharing Contracts (PSC)	The NNPC has sole ownership of the Oil Prospecting Licence (OPL) and the Oil Mining Lease (OML). However, a contractor has exclusive rights of exploration and production activities for 20 years while taking total responsibility for development and operational costs.
Risk Service Contracts (RSC)	The NNPC has the ownership of Oil Prospecting Licence (OPL), but the contractor bankrolls development of the field. The contract is for 2-3 years, renewable for two years at the discretion of the NNPC. Here the contractor is reimbursed from sale of crude oil acquired from the field. If oil is not found in sufficient quantity the contractor bears the loss

2.2.2 Oil Resource and Production

The production of petroleum is the mainstay of Nigeria's economy, i.e. from 1981–2012 crude oil contributed an average of 76% to government revenue (Appendix H) and about 95% to foreign exchange (Ogwu, 2011; Onwe, 2012; Shell Nigeria, 2013c). The share of government revenue comes from joint contracts (Subsection 2.2.1) with MOCs (Onwe, 2012).

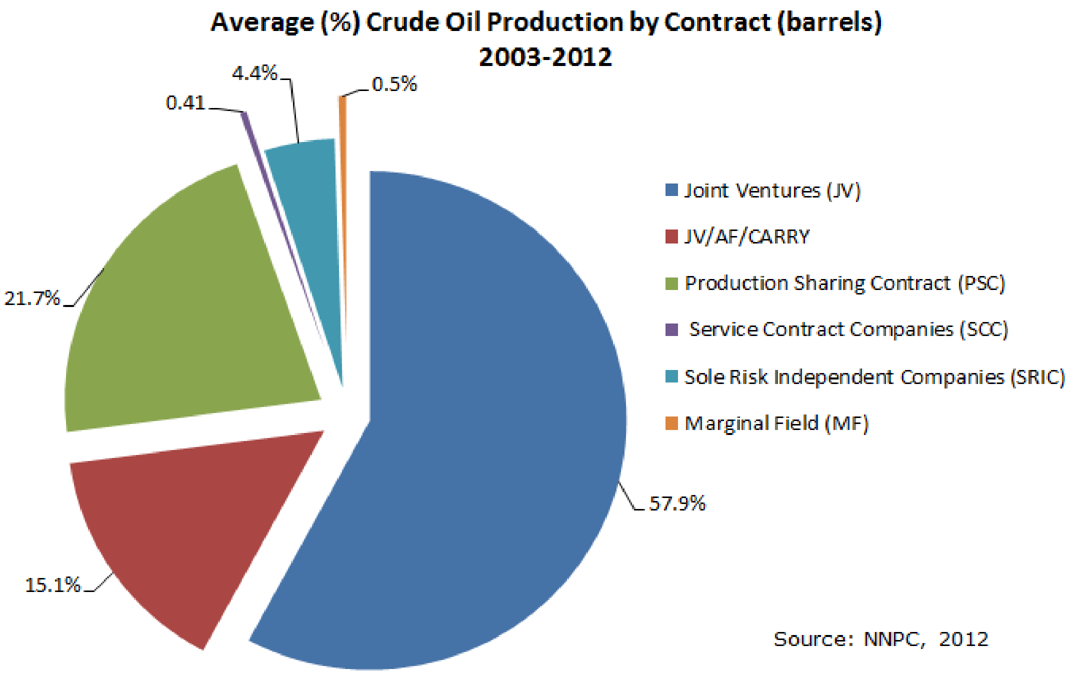

Figure 2-10: Contribution to total production by joint venture companies from 2003-2012 (Source: Nigerian National Petroleum Corporation, 2012).

From 2003-2012, the above companies produced 850,932,441 barrels of crude oil through the joint venture contract. Accordingly, Figure 2-10 shows that the largest quantity produced from 2003-2012 came from the joint contract regime with an average of 58%, followed by production sharing contract with an average of 22% (NNPC, 2012). This reveals the strong involvement of government in joint venture contracts in which participants share profits, and make contributions on a "cash call" basis on participating shares (holdings).

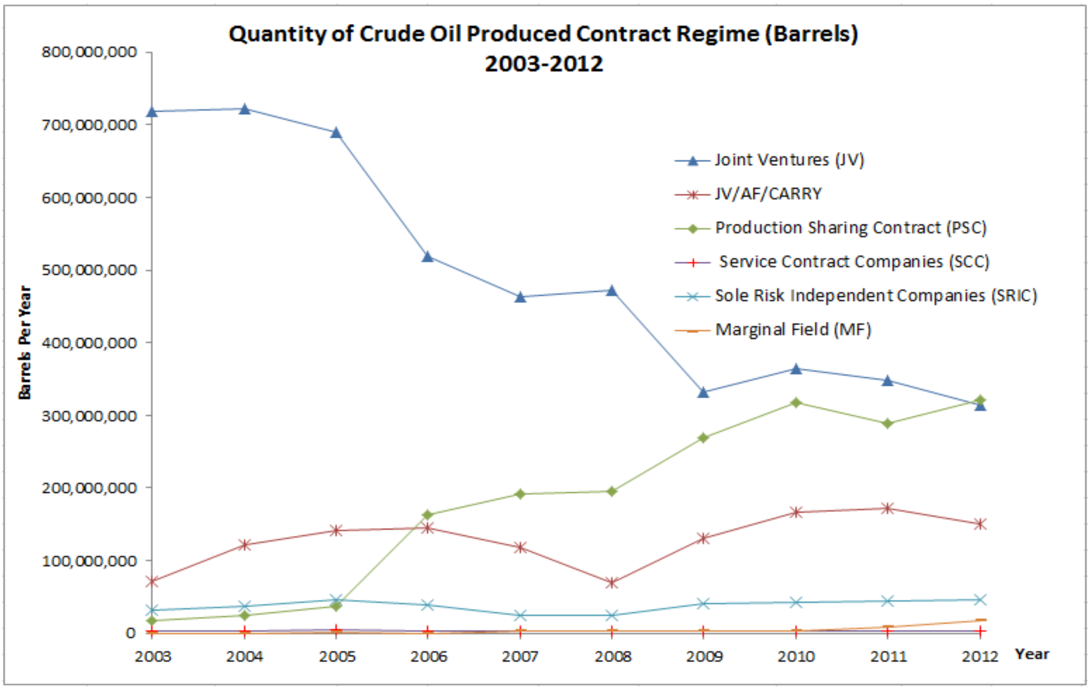

Figure 2-11: Production by contract regime from 2003-2012 (Source: NNPC, 2012).

This particular contract has been criticised for making the government complacent in executing its regulatory responsibilities in the oil and gas sector (Steiner, 2010), and is costly to the government. However, Figure 2-11 looks promising as production output from joint venture contract seems to be declining while production-sharing contract is rising. This may be attributed to a shift in policy in line with the proposed Petroleum Industry Bill (PIB) still undergoing deliberations in the national assembly. The PIB proposed the government's withdrawal from oil production to allow it to perform its regulatory functions more effectively and encouraged total deviation from JV agreement (HoganLovells, 2012).

2.2.3 Multinational Oil Companies' Societal Contribution

Although there are several MOCs like ExxonMobil, Chevron, ConocoPhillips, Total, Agip, Addax Petroleum, Pan Ocean, Elf etc. operating in the offshore and onshore dichotomy of Nigeria, the social performance of the Shell Petroleum Development Company (SPDC), a subsidiary of Shell Global in

Nigeria, is reviewed because, Shell is the main operator in the study area. The most important contribution Shell has made to society is through the federal government to which Shell paid about £38 billion in taxes and royalties during 2007-2011. In addition, Shell made a $59.9 million contribution to the Niger Delta Development Commission (NDDC) in 2011, which is an organisation established by the government to promote development in the Niger Delta. In the same year SPDC contributed $23.6 million to community development projects in the Niger Delta in addition to supporting small businesses, agriculture, skill training, education, healthcare, capacity building etc. (Shell Global, 2013).

For instance, in 2003 Shell started a training programme for youths (LiveWIRE) designed to provide entrepreneurial skills. So far, 5,231 youths have been trained and about 2,698 assisted to set up their own business. In the area of education, as at 2012, the company had invested $5.3 million in scholarships to secondary school students, university undergraduates, and postgraduates (Shell Nigeria, 2013a). Regarding the environment, Shell has begun implementing the UNEP recommendations in the area of clean drinking water supply to affected communities, and has launched a community health outreach programme in Ogoniland as well as an effective clean-up of oil spills from its facilities "irrespective of the cause of the spill" (Shell Nigeria, 2013b).

This is to say Shell is performing its corporate responsibilities even when a joint venture clause prohibits unilateral funding of projects (Field Interview, 2010).

2.2.4 Resource Conflict and Distributive Justice

The generation and distribution of revenue from crude oil is a sensitive issue that polarised the country along ethnic, language, and political divides. As a result, different governments at one time or another introduced a revenue sharing formula to accommodate their divergent interests (Ikeji, 2011). Most of the crude oil produced onshore in Nigeria comes from the Niger Delta, which comprises nine states, namely Abia, Akwa ibom, Bayelsa, Delta, Edo, Imo, Ondo and Rivers (Figure 2-12).

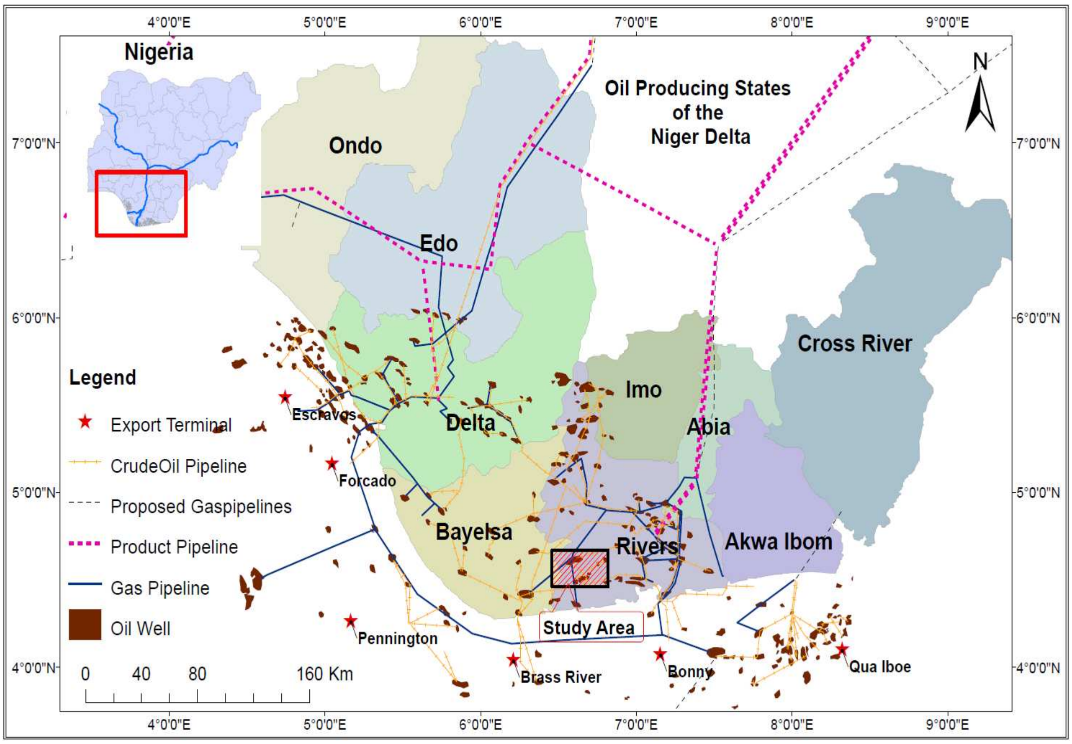

Figure 2-12: Offshore and onshore oil production infrastructure in the oil-producing Niger Delta States of Nigeria (Source: *The Petroleum Economist*, 2005).

However, revenue from crude oil goes to the Federation Account from where it is shared among the 36 states and the FCT Abuja (Figure 2-1) according to a sharing formula approved by the National Revenue Mobilisation, Allocation, and Fiscal Commission (NRMAFC).

Between 1946 and 1979 different formulas were established at different times. During this period, eight commissions on revenue allocation were constituted until the NRMAFC was created in 1988 to monitor, review and advise government on revenue allocation structure (Olofin et al., 2012). As a vertical revenue sharing[3] (VRS) formula, Federation Account Decree No. 36 of 1984 allocated 55% of the Federation Account to the federal government, 32.5% to state governments, 10% to local governments and 2.5% to mineral producing states. The NRMAFC in 1989 set horizontal revenue allocation[4] (HRA) among states on the basis of: i) equality of states 40%, ii) population 30%, iii) internal revenue 20%, and iv) social development 10% (Ikeji, 2011).

Meanwhile efforts by oil-producing states during the 1994 Constitutional Conference, to have allocation from revenue derived in their area restored to pre-1957, when it was 65%, failed as the government could only agree on 13% (Ikeji, 2011). Thus, failure to arrive at an amicable sharing formula through the years initiated the issue of resource control and revenue allocation, and questioned the federal system of government by the oil-producing states (Ikeji, 2011; Olofin et al., 2012). The unfavourable sharing formula led to complaints of deprivation and injustice in the distribution of costs and benefits of oil by local communities in the Niger Delta.

In other words, the communities bear the cost of i) loss of natural resources to crude oil depletion, and loss of vegetation and land use to petroleum production, ii) externalities of crude oil production such as pollution, increased cost of living, unemployment and destruction of means of livelihood through environmental degradation, iii) costs of breakdown in society and traditional value systems, and high crime rate (Ikeji, 2011; Ogwu, 2011). Thus, as communities bear the environmental consequences (costs) of oil production, other parts of the country benefit through the

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[3] VR is revenue shared among the three tiers of government, i.e. federal, states and local government.

[4] HR is the revenue shared among state governments.

federal revenue sharing arrangement, thereby raising ethical questions on distributive justice (Ogwu, 2011) and environmental justice. Environmental justice is concerned with how environmental benefits and costs are shared (Byrne et al., 2002); thus complaints against oil revenue distribution and environmental impacts associated with oil production have contributed towards the agitation and civil unrest in the Niger Delta.

2.3 Environmental Justice Movement in the Niger Delta

Environmental justice is a product of movement against unequal distribution of environmental benefits, risks, and externalities (Byrne et al., 2002). The movement epitomises the wrong in distributive justice and public frustration with the lack of receprocated benefit from oil production in the region (Benedict, 2011; Olukesusi, 2005 in Ogwu, 2011). The crisis is multifaceted and extensive because it transcends beyond a simple disagreement with MOCs but is rooted in the political structure and revenue-sharing system which lacks compensation principles (Ikeji, 2011). The following subsections discuss some of the salient issues hidden beneath the environmental movement and distributive justice campaign. Thus, resolving these is an ingredient for public goodwill in participation and cooperation of any kind.

2.3.1 Pre-independence Marginalisation and Revenue Allocation

Indirect rule in the colonial era created tribal and ethnic divisions because the colonials (Lugard, 1922; Nwabughhuogu, 1981; Ajayi and Owumi, 2013) delegated native governance to tribal leaders. By delegating adminitrative powers to the leaders, a framework for political domination began to develop along tribal and ethnic affiliations because all ethnic groups were subject to the authority of their local leaders (Lugard, 1922; Nwabughhuogu, 1981; Bruce, 1998). This gave the leaders the advantage of patronage (Bruce, 1998), which they used to arrange their subjects in stratigic positions over minority tribes (Ajayi and Owumi, 2013). The system helped elevate those from the majority tribes over other tribes in both political and economic spheres of the country (Mamdani, 1996); as a result, many minority tribes became marginalised and unable to participate in decision making and wealth creation (Ajayi and Owumi, 2013). Several tribes in the Niger Delta fall in the minority group who today are agitating for oil benefit and resource control.

Prior to 1958, revenue from minerals belonged to the region of production. Thus when the North produced tin, bauxite, cotton, groundnut etc. they were the sole beneficiaries, just as the West were the sole beneficiaries of revenue from cocoa, but the East was then left to "…develop other sources of income to survive" (Ikeji, 2011). However, the discovery of oil and introduction of a Federation Account that requires revenues to be paid into it for onward sharing among the federating units changed everything. Thus, the practice of giving back revenues to the region of production became obsolete. Subsequently, from 1958 revenue was shared to regions through the Federation Account (Subsection 2.2.3).

Even though current horizontal sharing gave mineral-producing states 13%, the oil-producing states prefer the pre-1957 formula, which was 65%. The 13% allocated to oil-producing states is considered inadequate, because the Niger Delta people bear all the negative externalities of oil production while other benefiting non-oil-producing states do not (Ikeji, 2011; Olofin et al., 2012).

2.3.2 Post-Independence Struggle for Environmental Justice

The discovery of oil in the late 1950s provided an immediate source of foreign earnings on which successive governments have depended. Local communities saw the influx of petroleum companies as an opportunity for socio-economic development and political transformation (Banks and Sokolowski, 2010); little was known of the ecological hazards associated with oil petroleum. For instance, in 1956, when the Shell crew spewed oil during their first drilling operation in Oloibiri, the people celebrated with a football match (Field Interview, 2010). The discovery of oil marked the beginning of a new dawn in oil activities as explorers began to discover oil, and by the mid-1960s oil had been discovered in several communities in the Niger Delta (Boro, 1982 cited in Akpan, 2005). However, despite the increasing importance of crude oil to the country's economy, there has been no reciprocal development in the region (Benedict, 2011).

This prompted people like Isaac Adaka Boro, Sam Owonaro and Nottingham Dick, in the mid-1960s, to start campaigning for the self-determination of the Ijaw people and ownership of their resources (Von Kemedi, 2003; Akpan, 2005). They formed the Niger Delta Volunteer Force (NDVF) and in 1966 began a secession bid, which was squashed by the federal government.

2.3.3 Internationalisation of Environmental Justice Movement

After the civil war and subsequent increase in oil production, oil-producing communities began to become aware of environmental hazards associated with petroleum production and financial benefits accruing to the federal government. This realisation intensified demand for more oil benefit and public agitation in the form of civil disobedience (Nzeadibe and Ajaero, 2010).

Consequently, the government has been accused of complacency for collaborating with MOCs to deal with public disobedience. For instance, government forces smashed protests against Shell in Iko village in 1987 and Umuechem in 1990 (Akpan, 2005; Bamat et al., 2011). Thus, lack of government ability to resolve the animosity between communities and MOCs led to the emergence of people like Ken Saro Wiwa in the 1990s. He formed the Movement for the Survival of Ogoni People (MOSOP) and the National Youth Council of Ogoni People (NYCOP) as pressure groups (Ikelegbe, 2001) to force the government to commit. Ken Saro-wiwa steered the environmental movement campaign into the international limelight; and, unlike Isaac Boro, Ken Saro-wiwa did not support the use of arms (Osha, 2006). Under the MOSOP, the Ogoni people demanded the right to control and use resources in Ogoniland for the development of Ogoni people (Akpan, 2005). However, the leadership of Ken Saro-wiwa did not last long as he was executed in 1995 (Osha, 2006). The execution attracted worldwide condemnation and provided the needed impetus for a global campaign and support for the environmental movement in the Niger Delta.

The pressure and support from the international community motivated the establishment and proliferation of environmental right groups across the Niger Delta (Akpan, 2005). Some of the emerging groups took to arms (Watts and Ibaba, 2011); groups like the Niger Delta People's Volunteer Force (NDPVF) that was re-invented after Isaac Boro's group of the 1960s (Subsection 2.3.2) and the Movement for the Emancipation of the Niger Delta (MEND), among others. Their aim was to impair the capacity of MOCs to function properly, in an attempt to force the federal government to accede to their demand for resource benefits (Onuoha, 2008).

2.3.4 Metamorphosis to Militancy (1999-Date)

Previous military regimes, especially under General Sani Abacha, were known for their notoriety in smashing public demonstrations (Ogbondah, 1994). There was little room for civil activism to prosper under various draconian rules enacted to suppress freedom of speech and the press (Ogbondah, 1994; Osha, 2006). However, the emergence of General Abubakar Abdulsallam's government in June 1998 re-integrated Nigeria back into the international community after it was side-lined under General Abacha (Banks and Sokolowski, 2010). Thus, in an effort to improve human rights and freedom of speech, the new government relaxed many laws, which encouraged civil societies to become more articulate and vocal than ever before. As a result, civil society organisations began to flourish, such that ethnic groups, national and international organisations, and human rights groups began to cash in on the Niger Delta environmental movement (Ikelegbe, 2001).

Meanwhile, with increase in youth unemployment, increased perception of marginalisation, lack of infrastructure, and loss of cultivable land in rural areas, people began to migrate to Port Harcourt and Warri (Joab-Peterside, 2007). The implication of the migration was the creation of grounds for mobilising youths into militant groups in the fight for resource benefits (Ikelegbe, 2001).

Conclusion

This chapter has provided an overview of the geography of Nigeria, describing the distribution of political administration as well as spatial distribution of ethnic groups in Nigeria. The review also highlighted oil and gas activities in Nigeria, joint venture agreement between government and MOCs, and location of the main source of petroleum energy. Even though the Niger Delta provides the government with a yearly average of 75% revenue from crude oil, the issue of marginalisation, distributive justice, environmental movement and resource control still persist, in addition to negative externalities of oil production in the Niger Delta.

The multi-ethnic, linguistic heterogeneity and tribal plurality of the country, which is the product of colonial legacy, has polarised the country into regional, ethnic, tribal, and even religious affiliations. Any advantage gained by majority ethnic or tribal groups in strategic positions makes it difficult for minority tribes to break through. This is typically the position that people of the Niger Delta finds themselves in; the leadership of the country is controlled by the majority ethnic groups that have failed over the years to provide succour to the environmental movement in the Niger Delta.

The fact that before oil was discovered, every region was allowed to enjoy maximum benefit from resources produced in their areas, and the Niger Delta which as at then had little or no natural resources was forced to source for other means of income (Ikeji, 2011), should be allowed to enjoy full benefit from the crude oil it now produce. Thus, the lopsided sharing formula that allocates just 13% to the oil-producing states cannot in any way equate compensation principles in view of environmental externalities suffered from oil production. The principle of compensation is a process of re-distributing gains of production to remove losses caused by externalities of production (Kemp, 2009).

This chapter has exposed the underlying political and economic factors responsible for human-induced interdiction in the Niger Delta, i.e. the government's revenue distribution policy (Subsection 2.2.3), complacency, and the government's involvement with MOCs (Subsection 2.2.1). These issues are very extensive and require an holistic resolution, which is needed to build and guarantee public corporation (participation) in the petroleum industry. Each stakeholder (government, host communities and MOCs) has their roles; the MOCs must be seen to deliver on corporate, social and environmental responsibilities, while the government must ensure equitable distribution of benefits from resource production. The following chapter reviews oil pipeline spills and the environmental impact in Nigeria.

CHAPTER 3

PETROLEUM ACTIVITIES, OIL SPILLS AND ENVIRONMENTAL IMPACTS

3.0 Introduction

Crude oil remains the most significant source of energy in the world, such that the size of an economy is correlated with the amount of crude oil being consumed (Fantazzini et al., 2011). Crude oil is utilised in transportation, heating, cooling and energy generation, and its by-products serve as feedstock in petrochemical industries (Hughes and Rudolph, 2011). Therefore, to meet global demand, sophisticated technologies for exploring and extracting crude have been developed, and research is still ongoing for improvements. Today, oil reserves are discovered almost daily around the globe, both offshore and onshore. Thus, since the cheapest means of moving bulk crude over a long distance is by pipe (Kandiyoti, 2012), the last couple of years have witnessed increased construction of oil and gas pipelines worldwide (Marcoulaki et al., 2012). This chapter reviews oil and gas activities and their impact on human health and the environment, with particular emphasis on the Niger Delta.

3.1 Pipelines, Oil and Gas Production

According to Marcoulaki et al. (2012), 193,100km of international pipelines were planned in December 2011 alone, compared to 28,885km and 39,059km for the same period in 2009 and 2010 respectively. In the United States of America (USA) alone states like Alaska, California, Louisiana, Michigan, Oklahoma, Texas, and Wyoming, among others, are major producers of crude oil (US Energy Information Administration, 2013). On the international scene are countries like Saudi Arabia, Iran, Iraq, Kuwait, Algeria, Angola, Ghana, Libya, Indonesia, Russia, Mexico, Venezuela, Canada etc. Despite known direct and indirect impacts of oil exploration and production on the environment and human health (Finer et al., 2013), the list of oil-producing countries and quantities produced globally keeps growing. The USA, China and Japan consume 18.9, 8.9 and 4.5 million barrels per day respectively ahead of other consuming nations (US Energy Information Administration, 2013).

The significance of oil production in national economic development cannot be over emphasised, as such MOCs and governments of producing countries work together to meet demand for crude oil in return for revenue and investment in socio-economic development of their countries (Kandiyoti, 2012). For instance, Nigeria patronises foreign oil companies to invest in the country because it is cheap; production of one barrel of crude oil costs about $3.5 onshore and $5.0 offshore (Oni and Oyewo, 2011; NAPMS, 2012).

The discovery of oil in 1956 in Nigeria led to the influx of companies like Chevron, Exxon, Gulf, Mobil, Royal Dutch/Shell and Texaco into the country (Section 2.2). The influx of these companies soon translated to more than 45,000km of multi-product pipelines linking oil fields and flow-stations to export terminals and refineries in the country (Ugochukuw and Ertel, 2008; Edino et al., 2009; Sojinu, 2010; Achebe et al., 2011).

3.1.1 Oil Pipeline Spills

Oil pipeline spills can be caused by structural failure, operation error and third party damage (TPD) (Achebe et al., 2012; Kandiyoti, 2012). TPD such as accidental rupture of pipelines is a common phenomenon, but recently intentional TPD such as sabotage and illegal bunkering of hostile and conflict pipelines is on the increase in places like Mexico, Columbia, the

Middle East, Asia and Africa (Steiner, 2010; Kandiyoti, 2012). The International Tanker Owners Pollution Federation (ITOPF) maintains data of oil spill incidents worldwide; its records indicate that vessel grounding, collision, hull failure, equipment failure, fire, and explosion are the main sources of oil spillage. Table 3-1 shows the number of crude oil spills less than 7 tonnes from 1974-2010, and from 7 to greater than 700 tonnes from 1970 -2010. This information showed that operational discharge accounts for about 63% of spills less than 7 tonnes, while accidents account for about 88.5% of spills greater than 700 tonnes (IOPCF, 2010).

Table 3-1: Number of oil spill incidents and their causes (ITOPF, 2010).

Cause of spill	**Tonnes**			
	<7	7-700	>700	**Total**
Operations				
Loading and Discharging	3157	385	37	3579
Bunkering	562	33	1	596
Other Operations	1250	61	15	1326
Accidents				
Collisions	180	337	132	649
Grounding	237	269	160	666
Hull Failure	198	57	55	310
Equipment Failure	202	39	4	245
Fire and Explosion	84	33	34	151
Others unknown	1975	121	22	2118
Total	7845	1335	460	9640

Despite global awareness of oil spill incidents, little attention is paid to onshore oil spills compared to offshore (Fingas, 2000; Reible, 2010; Chen, and Denison, 2011). The Exxon Valdez (1989), Braer (1993), Prestige (2002), and the BP Deep Horizon (2010) oil spill incidents among others are common examples. Although evidence showed a decrease in oil spills greater than 7 tonnes in the sea from 1970-2010 in Figure 3-1 (ITOPF, 2011), there is no record to compare oil pipeline spills on a global scale.

Figure 3-1: Seaborne crude and oil products trade and number of oil spills greater than 7 tonnes by tankers from 1970-2010 (ITOPF, 2011).

The demand for oil has increased the movement of crude and petroleum products from production platforms to end users. Movement involves transfers from one mode of transport such as tanker, pipeline, railcar, and truck tanker to another (Fingas, 2000). These inter-model transfers increase the potential for accidental discharge during the transfer and storage operations.

The increase in worldwide energy consumption is an indication that more pipelines would be required to transport additional supplies of crude and refined products. For instance, in 2010 global energy consumption increased by 3.8% metric tonnes with the USA leading (Enerdata, 2011), and in 2012 it dropped to 3.7% metric tonnes also with the USA still leading (Enerdata, 2013).

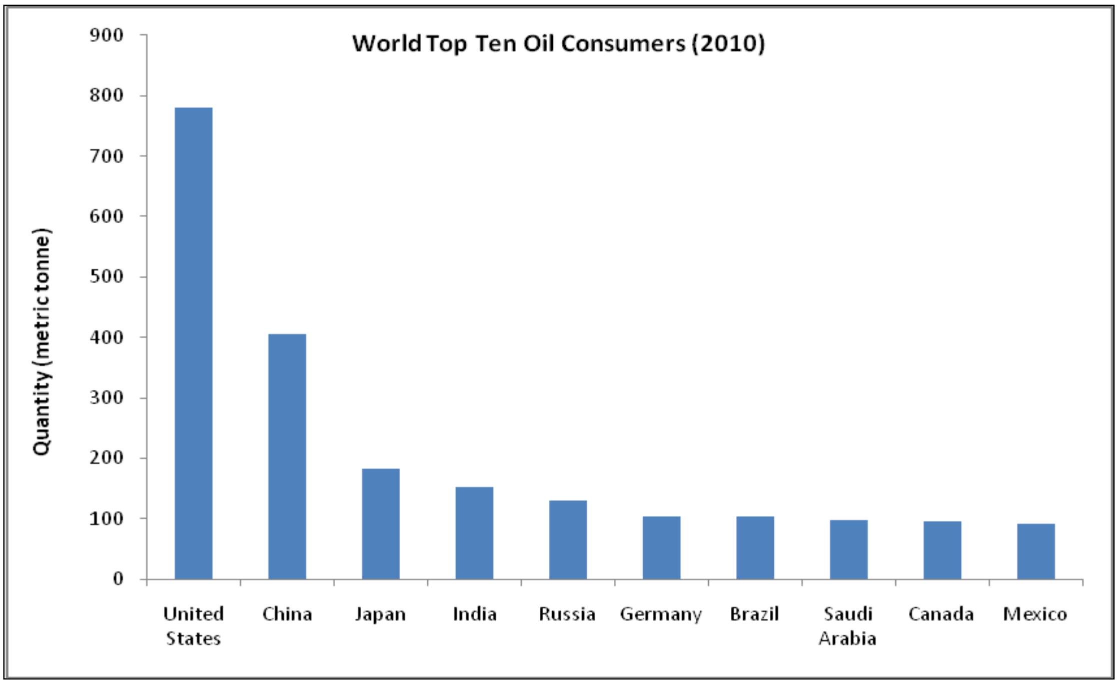


Figure 3-2: Top 10 oil-consuming countries in 2010 (Enerdata, 2011).

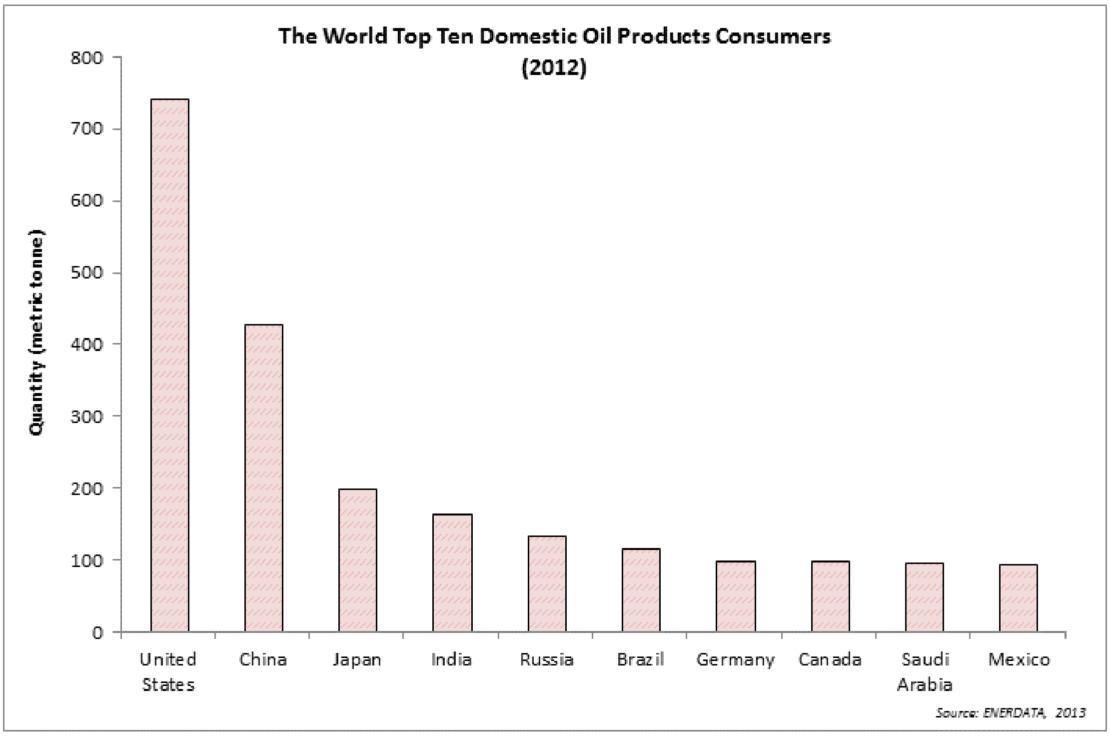


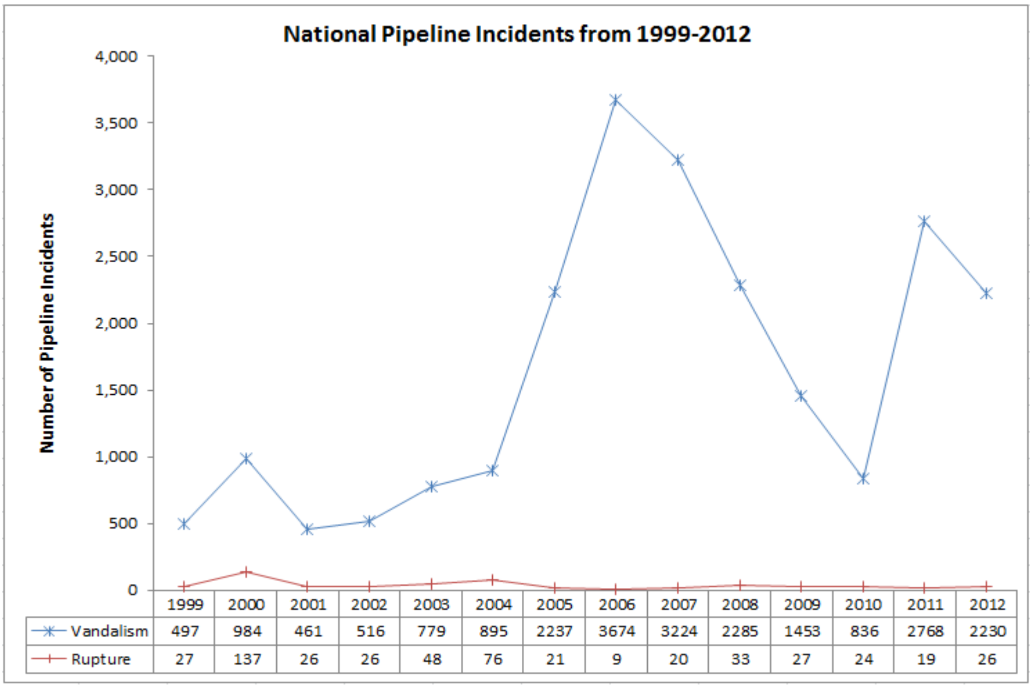
Figure 3-3: Top ten oil-consuming countries in 2012 (Enerdata, 2013).

Records show domestic consumption of oil products in countries like the USA dropping from 781 metric tonnes in 2010 to 739 in 2012, while China and Japan increased from 406 and 183 metric tonnes in 2010 to 427 and 198 in 2012 respectively (Figure 3-2 and Figure 3-3).

3.2 Oil Spill in Nigeria

The deteriorating condition of most pipelines constructed over the years is responsible for oil pipeline spills in Nigeria (Steiner, 2010; Benedict, 2011). Other reasons are indiscriminate disposal of oil waste and lack of 'good oilfield practice' by MOCs (Steiner, 2010; Amnesty International, 2013). In 2006, Shell Nigeria claimed an average of 250 oil spill incidents per year since 1997 while the Nigerian National Oil Spill Detection and Response Agency (NOSDRA) could confirm about 327 oil-polluted sites in the Niger Delta region.

Data from the NNPC in Figure 3-4 showed pipeline vandalism steadily decreasing from 2006 to 2010 and a sudden increase in 2011, while pipeline rupture remained steady for the best part of 14 years, except in 2000. There is no particular reason for this, as pipeline vandalism seems to occur across all regions of the country (Figure 3-5).



	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Vandalism	497	984	461	516	779	895	2237	3674	3224	2285	1453	836	2768	2230
Rupture	27	137	26	26	48	76	21	9	20	33	27	24	19	26

Figure 3-4: Cause of oil pipeline incidents in Nigeria from 1999-2012 (Data source: NNPC, 2008;2012).

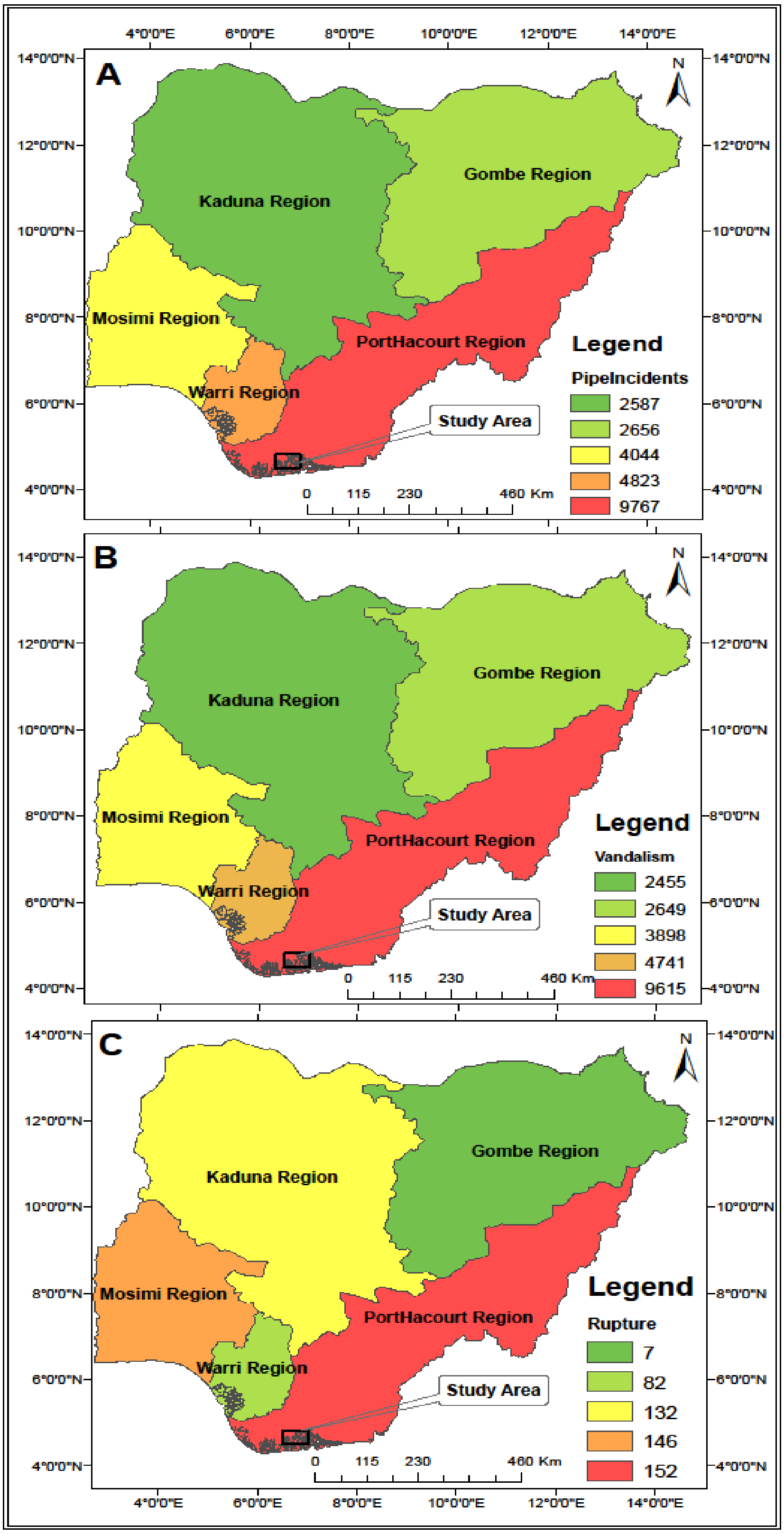


Figure 3-5: Pipeline incidents across all regions: a) total number of pipeline incidents, b) incidents caused by vandalism, c) incidents caused by rupture (Source of Data: NNPC, 2008, 2012; Source of Shapefiles: Map Library, n.d.).

Pipeline interdiction is so rampant that the SPDC (2007) claimed most of its third party incidents were caused by interdiction. Intentional TPD involving sabotage and illegal bunkering is a common feature in the Niger Delta; for example, between 1998 and 2009 the average percentage of TPD involving sabotage was about 58% according to Steiner (2010) in Table 3-2. This suggests that Shell has many more rupture problems as a whole than just in Nigeria (Figure 3-4 and Table 3-2), thereby raising questions on its pipeline asset integrity.

Table 3-2: Number of oil spills by Shell Nigeria (Steiner, 2010).

Year	**Total**	**Sabotage**		**Controllable**	
		Number	**Per cent (%)**	**Number**	**Per cent (%)**
1998	242	68	28.1	174	71.9
1999	319	160	50.2	159	49.8
2000	340	137	40.3	203	59.7
2001	302	147	48.7	155	51.3
2002	262	160	61.1	101	38.5
2003	221	141	63.8	80	36.2
2004	236	157	66.5	79	33.5
2005	224	138	61.6	86	38.4
2006	241	165	68.5	50	20.7
2007	330	221	67.0	109	33.0
2008	155	115	74.2	40	25.8
2009	132	95	72.0	38	28.8
Total	3,004	1,704		1,274	
		Average	58.5		40.6

There are inconsistencies in the number of oil spill incidents published by Shell from different sources; for instance, Amnesty International compared Shell's database with the NOSDRA as well as Shell's mother company, i.e. Royal Dutch Shell, and found remarkable inconsistencies (Table 3-3). These inconsistencies may be attributed to failure by regulatory agencies to harmonise data before publication or non-disclosure of spill incidents handled in-house. According to an interviewed source, spills of less than 100kg are not reported to the Department of Petroleum Resources (DPR) or NOSDRA but handled in-house; only spills greater than 100kg are reported to DPR for joint investigation (Field Interview, 2010). This buttresses the fact that data provided by MOCs and reported by DPR or NOSDRA do not represent the true magnitude of oil spills. According to Gay et al. (2010), this lack of accurate data prompted some experts in 2007 to establish an independent estimation of between 9 and 13 million barrels spilt over 50 years in the Niger Delta (roughly one Exxon-Valdes or 1.5 million tonnes spilled annually for half a century).

Table 3-3: The number of oil spills from Shell from different sources from 2007 to 2012 (Amnesty International, 2013).

Year	A	B	C	D	E
2007	171	320	249	320	171
2008	95	210	157	210	95
2009	118	190	132	190	118
2010	207	170	144	170	188
2011	207	207	182	207	207
2012	138	138	173	192	207

A) Shell on NOSDRA Database, B) Shell on Shell's website, C) Royal Dutch Shell Sustainability reports, D) Statistics on Shell's Nigeria web pages, E) NOSDRA.

Plate 3-1: Oil Pipeline attacked on 30th July 2008 (NAPIMS, 2010).

Plate 3-1 shows a typical interdiction on a 14-inch pipeline at Rumuekpe, along the Okordia to Rumuekpe Trunkline in Rivers state (NAPIMS, 2010).

Plate 3-2: Stolen oil being loaded onto a ship (Source: NAPIMS).

3.2.1 Third Party Oil Spills in Nigeria

Although some oil spills are caused by equipment failure and operational error, the Royal Dutch Shell, which is the mother company of SPDC Nigeria, claimed pipeline interdiction accounts for most of its oil spills in Nigeria (Shell, 2007). Figure 3-6 shows oil spill incidents reported by Shell Nigeria from January to November 2013, and Table 3-4 shows associated quantities discharged by cause per month for the same period. Obviously, the rate of interdiction (sabotage) is very high compared to operational causes.

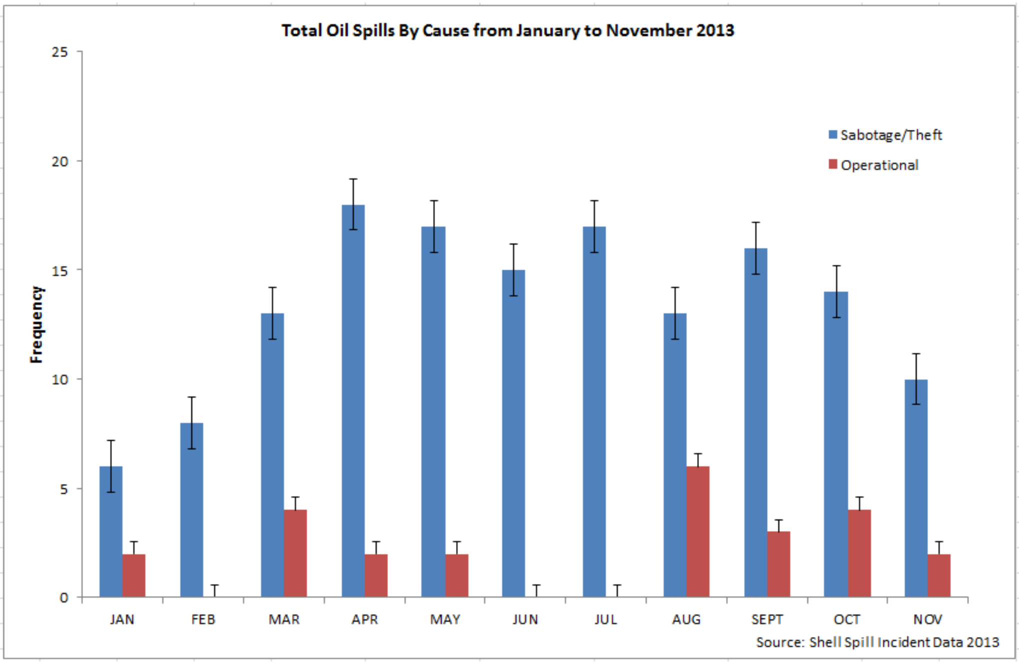


Figure 3-6: Oil spill incidents showing intensity of third party theft and vandalism (Source: Shell Nigeria, 2013[5]).

Table 3-4: Quantity of oil spills by cause (Shell Nigeria, 2013d).

Month 2013	TOTAL SPILLS		SABOTAGE	OPERATIONAL
	Frequency	Quantity (Bbl.)	Quantity (Bbl.)	Quantity(Bbl.)
JAN	8	330.7	315.7	15
FEB	8	209	209	0
MAR	17	1763.4	1709.3	54.1
APR	20	1023.34	982.1	41.24
MAY	19	458.2	449.2	9
JUN	15	4925.4	4925.4	0
JUL	17	1780.6	1780.6	0
AUG	19	1089.5	609.5	480
SEPT	19	2381.3	2368.3	13
OCT	18	2756.6	492.6	2264
NOV	12	1303.1	1301	2.1
TOTAL	172	18021.14	15142.7	2878.44

[5] Shell Spill Incident Data base <http://www.shell.com.ng/environment-society/environment-tpkg/oil-spills/monthly-data.html> Accessed 05/12/2013.

Officials categorised vandals into (Field Interview, 2010):

i) Bunkers (thieves):

These are experienced and well-connected individuals working in collaboration with security agents and oil workers to steal crude directly from pipelines. Large oil spills are rare with this group, because they possess skills required to regulate flow, usually by installing illegal fittings (Plate 3-3) and control valves (Plate 3-4) to control pressure and flow rate (Kandiyoti, 2012). They use hoses to load oil onto barges or smaller ships (Plate 3-2) and then take the oil through the creeks for onward transfer onto international-class 'mother ships' on the high sea for sale in the international market (Katsouris and Sayne, 2013). Plate 3-2 shows a reported oil theft in progress from a riser platform belonging to Nigeria Agip Oil Company (NAOC) in the Brass Akasa area.

ii) The Amateur Bunkers (thieves):

This group uses basic tools like a hacksaw to break or loosen pipe manifolds; they are mostly local unemployed youths without much experience or skills to handle large-scale crude theft. The stolen crude is usually collected in small quantities on canoes and small barges for sale to local refineries or companies that use crude oil to power their furnace. They care little about spills caused, as they often leave the ruptured pipes discharging crude oil into the environment. Plate 3-5 shows an 18-inch pipe hacksawed by thieves on the Assa-Rumuekpe trunkline at Egbeda. According to reports, about 34 cuts were made on this trunkline (pipeline) over two weeks in December 2004 (Field Interview, 2010).

Plate 3-3: Illegal fittings on a 24” Trans Niger pipeline; picture taken on 1st May 2013 (Shell Nigeria, 2013d).

Plate 3-4: Arrow pointing at an illegal valve on a 28” pipe; picture taken on 28th June 2013 (Shell Nigeria, 2013d).

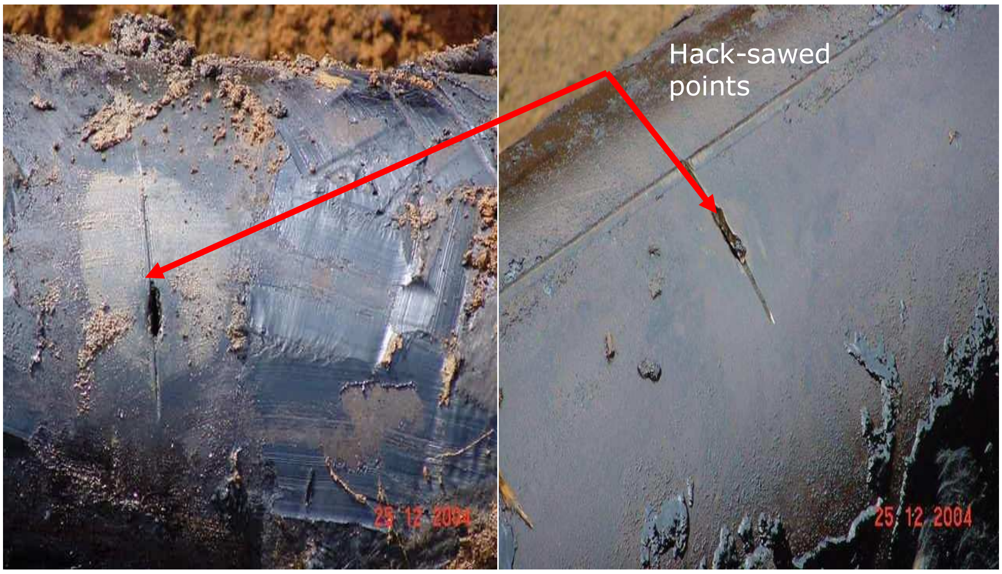


Plate 3-5: Hacksawed cuts by thieves/vandals (NAPIMS, 2010).

iii) *Saboteurs and Vandals*:

These groups are mainly interested in sabotaging operations of the MOCs. They are generally influenced by their grievances against the government and MOCs about the way and manner their agitation is ignored. Armed with tools, they go about breaking pipes with tools or explosives, as in Plate 3-1. Some of these groups work in collaboration with community leaders who seek attention or want to impede oil production in their areas (Field Interview, 2010). Benedict (2011), who reported the existence of gangs going from one community to another damaging pipelines, corroborates this claim.

3.2.2 Oil Spill Response and Contingency Plan in Nigeria

There are two approaches of oil spill contingency plan in Nigeria; the first manages spills in-house within the affected industry, while the second uses the NOSCP. Under the former, spills of less than 100kg (0.1 tonne) are not reported to the DPR but managed in-house according to tier 1 (Field Interview, 2010). However, spills above 100kg are reported to the DPR and a joint investigation team (JIT) constituted to investigate and appraise the site. The national contingency plan on the other hand is divided into tiers, i.e. company (tier one), cooperative (tier two) and government or major (tier three), based on quantity discharged (NOSCP, 2009).

i) Tier 1 plan (Company).

It is mandatory under this tier for producers and marketers to provide response facilities in their areas of operation. The quantity of oil specified for this tier is less than or equal to 7 tonnes (50 bbl[6]), which must be caused by the company's activities.

ii) *Tier 2 plan (Cooperative)*.

This category covers oil spills greater than 7 tonnes (50bbl) but less than 700 tonnes (5,000bbl) around the company's vicinity. In this category, other oil industries, government agencies and the Clean Nigeria Associates are involved.

iii) Tire 3 plan (Government).

This stage activates the national contingency plan if the spill surpasses tier 1 and tier 2 conditions. The quantity involved in tier 3 is greater than 700 tonnes (5,000bbl). The government is directly involved in terms of control and directives through the NOSDRA. Spills are not restricted to the vicinity of the company, but include all areas where the company conducts its operation.

3.2.3 Oil Pollution in the Niger Delta

In 2011, the UNEP presented the first-ever documented report on oil contamination in Nigeria, after a detailed analysis of contaminated sites in the Ogoni area of the Niger Delta. The report provided a concentration of TPH in samples analysed and gave recommendations for remediation (Table 3-8 and Appendix F). The project was conducted in four local

[6] Barrel = (bbl).

government areas of the Rivers state (Figure 3-7) over a period of 14 months, at the behest of the Nigerian Government (UNEP, 2011).

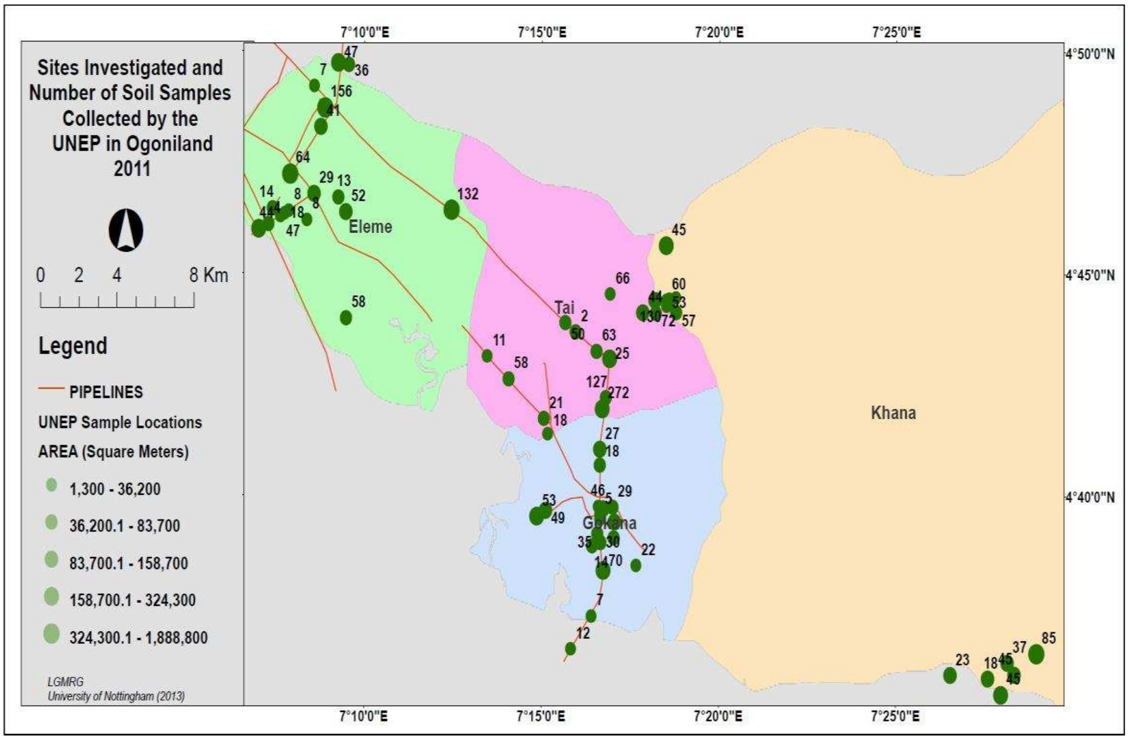


Figure 3-7: Area and number of soil samples collected in Ogoniland by the UNEP in 2010-2011 (Source of data: UNEP Site Specific Fact Sheet, 2011).

The 65 sites investigated include: 1 Bunkering Site, 22 SPDC Operating Sites, 4 PPMC Pipeline ROWs, 1 Remediated Site, and 34 SPDC Pipeline ROWs; 3,133 soil samples were collected at different depths (Table 3-5) and analysed for TPH concentration in accredited (ISO 17025) European laboratories (UNEP, 2011; p.9). About 188 of the soil samples had no TPH or were below detection limit (BDL)[7], while 2,945 showed significant concentrations of TPH several times above the EGASPIN[8] target value (Table 3-7). Figure 3-7 highlights the extent of oil pipeline spills and oil pollution in Ogoniland.

[7] There is no information on the detection limits the laboratories used in the analysis.
[8] Environmental Guidelines and Standards for the Petroleum Industry in Nigeria.

Benzene was the only hydrocarbon compound tested in groundwater and air based on the WHO guideline, due to lack of analytical guideline in EGASPIN. The result revealed a concentration of benzene 900 times above the WHO standard of 10μg/l (Table 3-6), and between 0.16–48.2μg/m^3 in air for most samples.

Table 3-5: TPH concentration in soil samples per depth (UNEP, 2011).

Depth (m)	**Samples**	**TPH Concentrations (mg/kg)**			
		Max.	Min.	Mean	Stdv.
0 - 0.9	777	139,000	0.35	2,392.59	9,253.30
1 - 1.9	569	33,900	0.29	1,628.17	3,865.77
2 - 2.9	568	31,400	0.27	1,825.03	3,881.34
3 - 3.9	391	28,300	0.24	2,091.32	3,982.38
4 - 4.9	310	29,600	0.2	1,936.63	4,144.76
5 - 5.9	324	43,600	0.1	2,048.46	4,385.09
≥6	6	4,580	1.03	893.92	1,663.21

Table 3-6: Benzene concentration in selected wells (UNEP, 2011).

Sampled well	**Benzene (μg/l)**
001-005-BH-102	9,280
001-005-BW-100	7,090
001-005-MED-101	8,370
001-005-GW-104	7,140

Table 3-7: TPH in soil above EGASPIN values (UNEP, 2011).

Sampled location	**Community**	**TPH(mg/kg)**
001-001	Ejama	12,100
009-010	Blara	19,600
104-004	Ataba	8,630
119-001	Bodo West	15,100
120-001	Kpado-Bodo	12,100
120-002	Bodo	6,570
121-001	Sugi-Bodo	12,100
122-001	K amd B Dere	12,000
123-001	K-Dere	16,500
130-100	Kolgba	17,900

For groundwater analysis, 218 samples were tested and 68 samples were below the detection limit (BDL) while 150 had an average TPH concentration of 112,422.86μg/l (Max. 2,740,000μg/l, Min. 12.00μg/l, and Sum 16,863,429.00μg/l). In addition, TPH concentration from 89 sampled wells indicates that 61 were below detection limit while 28 had an average TPH concentration of 4,499.30μg/l (Max. 42,200μg/l, Min. 10μg/l, and Sum 125,980.40μg/l). The report also revealed a high concentration of TPH farther away from points of discharge; for example, a TPH concentration of 95,300 mg/kg and 4,140 mg/kg was detected in soil samples collected at about 180 and 168 metres from source respectively.

This reveals the tendency of hydrocarbons to migrate far through the surface and/or subsurface migration. Groundwater investigations conducted in 180 monitoring wells also revealed the shallowest depth of the water table was around 0.7 metres, and the deepest around 14 metres (UNEP, 2011). General recommendations proposed by the UNEP for returning a polluted site in Ogoniland back to a pristine state can be found in Appendix F, while recommended stakeholders' responsibilities are enumerated in Table 3-8.

Table 3-8: UNEP recommendations for stakeholders (UNEP, 2011) with author's comments.

A. What government should do	Comments
✓ Create an Environmental Restoration Authority for Ogoniland. ✓ Create an Environmental Restoration Fund for Ogoniland. ✓ Create a Centre of Excellence for Environmental Restoration. ✓ Declare the intent to make the wetlands around Ogoniland a RAMSAR site. ✓ Mount a campaign against environmental degradation.	Ogoniland cannot be treated in isolation from other Niger Delta (see Section 10.2) communities that are already suffering negative externalities of oil production Federal and State Ministries of Environment can be funded, equipped, trained, and empowered to implement restoration of the Niger Delta; however, a new framework and political will is required to achieve this. Nigeria has about 11 RAMSER sites (UNEP, 2011; Adekola et al., 2012). Most areas in the Niger Delta satisfy the RAMSER Convention Secretariat (2007) definition and should be categorised as such. This might bring international attention, peer pressure to the area, and provide a framework for restoration and wetland management.
B. What Oil companies and operators should do	**Comments**
✓ Include social and health factors in EIA for oil operations. ✓ Re-evaluate location of existing oil wells. ✓ Complete drainage and groundwater management of new oil wells. ✓ Re-route pipeline to minimise environmental change by decommissioning pipelines that cut across mangrove, swamp. ✓ Enhance facilities with modern technologies for fast oil spill detection. ✓ Allocate percentage of project cost to environmental and sustainable development initiatives. ✓ Undertake regular reporting and public consultations on environment and social performance of activities. ✓ Encourage environmental due diligence culture.	The Environmental Impact Assessment (EIA) Decree 84 requires an EIA for pipelines in excess of 50km (Olokesusi, 2005). Nigerian planning laws and the oil pipeline regulations demand EIA reports for proposed major developments before a permit is given (Ogwu, 2011); however, the MOCs do not seem to comply with these legal requirements. Good oilfield practice and environmental due diligence are some virtues MOCs do not take seriously; because of ineffective enforcement of Nigerian laws (Steiner, 2010; Amnesty International, 2013). Rights of way (ROW) and land use restrictions around oil facilities should be enforced but in collaboration with host community leaders. Land use already existing on such areas (ROWs) should be relocated and the owner compensated, while severe penalties be imposed against future encroachment. MOCs need to establish high consequence areas and ensure that pipelines in the area satisfy the highest design factor (Subsection 5.5.3) Now there is no free flow of information between MOCs and communities, which has created breakdown in relations. Involving communities in decision making and giving them stakes in the business would give them a sense of belonging and open up a two-way channel for free communication (see Section 10.4).
C. What Communities should do	**Comments**
✓ Develop a culture of cooperation, and take advantage of potential benefits derivable from new investment, employment opportunities etc. ✓ Desist from preventing access to oil spills. ✓ Take a proactive stance against individuals engaged in bunkering, vandalism, artisanal refining, and other illegal activities.	The host communities are not likely to offer their cooperation because the present attitude and hostilities have evolved over the years (see Section 3.2). A holistic approach from the government and MOCs is needed to gain the trust of the people. Firstly, the government must address the political and revenue sharing issues (Section 3.2) and establish a limit where its relationship with MOCs ends and its responsibility to the people begins. Secondly, the MOCs must begin to exhibit their corporate social, environmental, and economic responsibilities to host communities. MOCs should show total compliance with ASME and API standards in their operation. It is only when the people begin to derive maximum benefits from resources and get good compensation for negative externalities of production can they offer their trust.

3.3 Environmental Legislation and Regulation in Nigeria

The National Policy on Environment of 1998 was developed from the 1992 United Nations Conference on Environment and Development (UNCED) held in Brazil. The policy provided the background for Nigeria's first effort in environmental legislation (NESREA, 2007) by its inclusion in Section 20 of the 1999 Federal Constitution. Prior to this, the Federal Environmental Protection Agency (FEPA) Decree 58 of 1988 empowered FEPA to initiate environmental regulations and monitor strategies, but an amendment in 1992 by Decree No 59 extends its powers and responsibilities to include natural resource exploitation and extraction (Omofonmwan and Osa-Edoh, 2008). The ineffectiveness of FEPA as an establishment paved the way for the creation of a Federal Ministry of Environment (FMENV) in 1999 under the 1999 Federal Constitution. The constitution also allowed states and local governments to establish relevant laws and regulations for their respective areas. However, the local councils and states could not achieve a meaningful result due to lack of funds and intellectual capacity, thereby depending on the federal government for initiatives and funding (Nwilo and Badejo, 2005).

3.3.1 Environmental Institutions and Legal Framework in Nigeria

The current legislation for the petroleum sector is known as the Environmental Guidelines and Standards for Petroleum Industry in Nigeria (EGASPIN), which was developed by the DPR in 1992 and updated in 2002 for use in the oil and gas industry (UNEP, 2011). This was based on a) the Corrective Action Applied at Petroleum Sites report prepared by the American Society for Testing of Materials and b) the use of intervention and target values copied from the Netherlands (UNEP, 2011) as an interim measure pending development of suitable parameters (EGASPIN, 2002).

Table 3-9: EGASPIN soil target and intervention values (EGASPIN, 2002).

Substance	Soil/Sediment *(mg/kg)*		Groundwater *(µg/l)*	
	Target	Intervention	Target	Intervention
A. <u>Aromatics</u>				
Benzene	0.05 (dt)	1	0.2	30
EthylBenzene	0.05 (dt)	50	0.2	150
Phenol	0.05 (dt)	40	0.2	2000
Toluene	0.05 (dt)	130	0.2	1000
Xylene	0.05 (dt)	25	0.2	70
B. <u>Metals</u>				
Arsenic	29	55	10	60
Barium	200	625	50	625
Cadmium	0.8	12	0.4	6
Chromium	100	380	1	30
Cobalt	20	240	20	100
Copper	36	190	15	75
Mercury	0.3	10	0.05	0.3
Lead	85	530	15	75
Nickel	35	210	15	75
Zinc	140	720	65	800
C. <u>Chlorinated Hydrocarbon</u> 1,2 dichloroethane	-	4	0.01(dt)	400
D. <u>Polycyclic Aromatic Hydrocarbons(PAH)</u>				
*PAH (Total of 10)**				
Napthalene	1	40	0.1	70
Anthracene			0.02	5
Phenantrene			0.02	5
Fluoranthracene			0.005	1
Benzo(a) anthrancene			0.002	0.5
E. <u>Other Pollutants</u>				
Mineral oil	50	5000	50	600

dt = detection threshold

**= Total of 10, Chrysene, benzo(a)pyrene, benzo(ghi)pyrene, benzo(k) fluoranthene, indeno (1,2,3 –cd) pyrene and those listed above. Based on 10% of soil organic matter (SOM) and 25% clay)*

The intervention value in EGASPIN defined situations in which quality of soil for human, animal and plant life is being threatened or impaired.

EGASPIN adopted two options for determining pollution; a) the use of Risk-based concentrations in excess of intervention values (Table 3-9) and b) the target values which:

> "*indicate the soil quality required for sustainability or expressed in terms of remedial policy, the soil quality required for the full restoration of the soil's functionality for human, animal and plant life*" (EGASPIN, 2002; UNEP, 2011).

Therefore, target values simply indicate desired soil quality levels, while intervention specifies the critical limit to which action or restoration is mandatory. EGASPIN's level of TPH concentration in soil or sediment that would trigger a clean-up, i.e. 5,000 milligrams per kilogram (mg/kg) is referred to as the "intervention value", while 50mg/kg of TPH concentration is the "target value", a value for which soil functionality is being impaired (EGASPIN, 2002; UNEP, 2011). Table 3-10 lists federal institutions involved in environmental administration in the oil and gas sector.

Table 3-10: Federal institutions responsible for environmental safety (compiled by the author).

Establishment	Purpose
Federal Ministry of Environment (FMENV)	This is the main regulator of environmental laws in Nigeria under the 1999 Federal Constitution. Agencies such as the National Environmental Standard and Regulations Enforcement Agency (NESREA) established in 2007 and the National Oil Spill Detection and Response Agency (NOSDRA) established in 2006 derive their delegated powers to enforce Section 20 of the 1999 constitution from the Federal Ministry of Environment.

Establishment	Purpose
National Environmental Standard and Regulations Enforcement Agency (NESREA)	Established under Act No 25 with gazette No 92, Vol 94 of 31st July 2007, the agency is empowered to enforce compliance with laws, guidelines, policies, and standards on environmental matters. The agency also coordinates and liaises with stakeholders within and outside the country on environmental standards, regulations and enforcement (NESREA, 2007).
National Oil Spill Detection and Response Agency (NOSDRA)	Established in 2006 to coordinate the implementation of the National Oil Spill Contingency Plan (NOSCP). NOSDRA is therefore the statutory agency responsible for ensuring timely, effective, and appropriate response to oil spills, clean up and remediation in the country (NOSDRA, 2006).
The Department for Petroleum Resources (DPR)	This is a unit under the Federal Ministry of Petroleum with primary responsibilities for supervising oil block allocation, refinery establishment, oil spill monitoring and other oil and gas related operations (onshore and offshore). The department's duties include environmental standard regulation and policies in the oil and gas sector under EGASPIN.
Clean Nigeria Associates (CNA)	In 1981 a consortium of 11 oil companies established the Clean Nigeria Associates (CNA), an outfit with the capacity to combat oil spills in members' or third party areas of operations (Nwilo and Badejo, 2005; Aroh et al., 2010; Adekola et al., 2012). The technical expertise, equipment,

Establishment	Purpose
	and resources for the outfit are drawn from member companies to support individual company needs in combating oil spills (Nnubia, 2008).

3.3.2 International Conventions and Regulations on Oil Pollution

Nigeria is a signatory to some international agreements and conventions on oil pollution (Table 3-11) (NOSCP, 2000, 2009). There are other oil and gas legal frameworks already in existence to provide guidelines for pollution prevention (Salu, 1999 cited in Badejo and Nwilo, 2004). However, according to Ukoli (2001) and Oshineye (2000) cited in Badejo and Nwilo (2004), the frameworks were designed for individual organisations to regulate their environmental impacts, i.e. enable them to monitor and enforce compliance.

Table 3-11: International conventions relating to oil pollution.

Conventions	Year signed	Purpose
The International Convention on Civil Liability for Oil Pollution Damage	29 November 1969	'*CONSCIOUS of the dangers of pollution posed by the worldwide maritime carriage of oil in bulk, CONVINCED of the need to ensure that adequate compensation is available to persons who suffer damage caused by pollution resulting from the escape or discharge of oil from ships, DESIRING TO ADOPT uniform international rules and procedures for determining questions of liability and providing adequate compensation in such cases*' (Centre for International Law, 1969)
The International Convention on the Establishment of International Fund for Compensation for Oil Pollution Damage	1992	'*The 1992 Fund operates within the framework of an international regime providing compensation for oil pollution damage caused by oil spills from tankers. The regime is created by two international treaties elaborated under the auspices of International Maritime Organisation (IMO), namely the International Convention on Civil Liability for Oil Pollution Damage, 1992 (1992 Civil Liability Convention) and the International Convention on the Establishment of an International Fund for Compensation for Oil Pollution Damage, 1992 (1992 Fund Convention. These treaties replace two previous treaties of 1969 and 1971 respectively. The Civil Liability Convention governs the liability of the ship owner, whereas the Fund Convention provides supplementary compensation when the amount paid by the ship owner or his insurer is insufficient to compensate all victims in full*' (IOPCF, 2010)
The Convention on the Prevention of Marine Pollution by the Dumping of Wastes and Other Matter	29 December 1972 Ratified with Protocol of 1978	'*The Contracting Parties to this Convention, Recognizing that the marine environment and the living organisms which it supports are of vital importance to humanity, and all people have an interest in assuring that it is so managed that its quality and resources are not impaired; Recognizing that the capacity of the sea to assimilate wastes and render them harm less, and its ability to regenerate natural resources, is not unlimited; Recognizing that States have, in accordance with the Charter of the United Nations and the principles of international law, the sovereign right to exploit their own resources pursuant to their own environmental policies, and the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other States or of areas beyond the limits of national jurisdiction*' (United Nations Treaty Series, 1977)
The International Convention for the Prevention of Pollution from Ships	17 February 1973 Ratified 1 June 1978	'*The Parties to the present Protocol, Recognizing the significant contribution which can be made by the International Convention for the Prevention of Pollution from Ships, 1973 2 , to the protection of the marine environment from pollution from ships, Recognizing also the need to improve further the prevention and control of marine pollution from ships, particularly oil tankers*' (United Nations Treaty Series, 1978)
The Convention for Cooperation in the Protection and Development of the Marine and Coastal Environment of the West and Central African Region	24 May 1978 and adopted by West and Central African region on 23 March 1981.	This is a regional approach to the control of marine pollution and management of marine and coastal resources under the 1974 Regional Seas Programme of UNEP. The action plan encompasses i) environmental assessment, ii) environmental management, iii) environmental legislation, iv) institutional arrangements and v) financial arrangements. To prevent release of substances or energy into the marine environment, including estuaries, resulting in such deleterious effects as harm to living resources, hazards to human health, hindrance to marine activities, including fishing, impairment of quality of use of sea water and reduction of amenities (United Nations Enviroment Programme, 1985)

The Basel Convention on the Control of Trans-boundary Movement of Hazardous Wastes and their Disposal	22 March 1989	'*The objective of the Basel Convention is to protect human health and the environment against the adverse effects of hazardous wastes. Its scope of application covers a wide range of wastes defined as "hazardous wastes" based on their origin and/or composition and their characteristics …, as well as two types of wastes defined as "other wastes" (household waste and incinerator ash …). The provisions of the Convention centre around the following principal aims: (i) the reduction of hazardous waste generation and the promotion of environmentally sound management of hazardous wastes, wherever the place of disposal; (ii) the restriction of trans boundary movements of hazardous wastes except where it is perceived to be in accordance with the principles of environmentally sound management; and (iii) a regulatory system applying to cases where trans boundary movements are permissible*' (United Nations Environmental Programme, 1989)
The International Convention on Oil Pollution Preparedness Response and Cooperation	30 November 1990	'*CONSCIOUS of the need to preserve the human environment in general and the marine environment in particular from threat posed to the marine environment by oil pollution incidents involving ships, offshore units, sea ports and oil handling facilities, MINDFUL of the importance of precautionary measures and prevention in avoiding oil pollution in the first instance, and the need for strict application of existing international instruments dealing with maritime safety and marine pollution prevention, particularly the International Convention for the Safety of Life at Sea, 1974, as amended, and the International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 relating thereto, as amended, and also the speedy development of enhanced standards for the design, operation and maintenance of ships carrying oil, and of offshore units, MINDFUL ALSO that, in the event of an oil pollution incident, prompt and effective action is essential in order to minimize the damage which may result from such an incident,* *EMPHASIZING the importance of effective preparation for combating oil pollution incidents and the important role which the oil and shipping industries have in this regard, RECOGNIZING FURTHER the importance of mutual assistance and international co-operation relating to matters including the exchange of information respecting the capabilities of States to respond to oil pollution incidents, the preparation of oil pollution contingency plans, the exchange of reports of incidents of significance which may affect the marine environment or the coastline and related interests of States, and research and development respecting means of combating oil pollution in the marine environment, TAKING ACCOUNT of the "polluter pays" principle as a general principle of international environmental law*' (Centre For International Law, 1990)

Table 3-12: National laws for preventing oil pollution.

Legislation	Year	Purpose
The Mineral Oil (Safety) Regulation	1963	This law was promulgated to regulate the discharge of inflammable gaseous substances in the environment. The regulation stipulates penalties for non-compliance and disobedience
Petroleum Regulation	1967	Prohibits the discharge of petroleum products in harbours, precautionary measures must be taken to ensure safe conveyance of petroleum products. The regulation also covers rules on safe pipeline operation.
Oil Pipeline Act	1956 amended in 1969	The law was established to prevent pollution of land and water traversed by pipeline.
Petroleum Drilling and Production Regulation	1969	This law requires operators to implement acceptable precautionary measures while relevant authorities provide equipment for preventing pollution of inland/territorial waters or high seas by oil or related fluids.
Oil in Navigable Waters Act	1968	This law prohibits the discharge of crude oil or any substance with oil content in territorial or navigable waters.
Oil Terminal Dues Act	1968	Prohibits the discharge of oil products in areas where the oil terminal is located.
Petroleum Refining Regulations	1974	Specifically deals with requirement for the construction of oil storage tanks; it is meant to minimise damage resulting from product leakage or discharge into the environment.
Associated Gas Re-Injection Act	1979	Provided for the utilisation of associated gas produced, directing the re-injection of unutilised gas back into the ground to discourage gas flaring.

3.3.3 The Petroleum Industry Bill (PIB)

The PIB is a piece of legislation that established a legal and regulatory framework for streamlining activities of institutions and regulatory authorities in the Nigerian petroleum industry (Hamid, 2012; HoganLovells, 2012). The PIB, which was first introduced in 2008, is currently in the National Assembly undergoing deliberation (NNPC, 2013); when passed into law the PIB would bring various legislative, regulatory, and fiscal policies, institutions and instruments governing the oil and gas sector under one law (Petroleum Industry Act, 2008; Hamid, 2012; HoganLovells, 2012; NNPC, 2013). The Bill shall clarify "*the rules, procedures and institutions to entrench good governance, transparency and accountability in the oil and gas sector*", which would not only enable the government to retain higher revenue from oil production but effectively regulate activities in the oil and gas industry (NNPC, 2013).

The objectives set out for the PIB (HoganLovells, 2012; NNPC, 2013) include the following:

i. to enhance exploration and exploitation of petroleum resources;
ii. to increase domestic gas supplies for power and industry;
iii. to establish a fiscal framework and encourage investment in the petroleum industry;
iv. to establish commercially-oriented and profit-driven oil and gas units;
v. to deregulate and liberalise the downstream petroleum sector;
vi. to create efficient and effective regulatory agencies;
vii. to promote openness and transparency in the industry;
viii. to encourage development of Nigerian local content; and promote and protect health safety and environment.

To achieve these, the PIB provides for, amongst other things (HoganLovells, 2012):

i. the restructuring and reorganisation of industry institutions and the regulatory framework;
ii. the establishing of a new fiscal regime for upstream oil and gas production;
iii. a review of the allocation of Domestic Gas Supply Obligations to licenses; and
iv. deregulation of the downstream sector.

The relevant objectives of the PIB in this study refer to environmental safety, which requires companies in the petroleum industry to conduct their operations in conformity with internationally accepted principles of sustainable development to ensure preservation of rights of present and future generations to a clean environment (Hamid, 2012). There is also the Petroleum Host Communities Fund, designed to recognise host communities as "important stakeholders" in the oil and gas industry. Thus, aside from assigning security of the oil and gas infrastructure to host communities, a monthly sum equalling 10% net profits of upstream petroleum-producing companies shall be paid to the fund for economic, social and infrastructural development of oil producing-communities. It is hoped, with their integration, vandalism and crude oil theft would reduce (HoganLovells, 2012; NNPC, 2013).

3.4 Environmental Impact of Oil Exploration and Production

Every stage of petroleum production has a direct and indirect impact on the environment. Direct impact includes deforestation, oil contamination, dredging of waterways, vegetation clearance, among many others; indirect impact effects include an increase in social conflicts, selective land use opportunities, and human colonisation of access routes (Finer et al., 2013). The severity of the impact depends on the size and complexity of the operation and, most importantly, the nature and sensitivity of the environment (UNEP, 1997). The impact on human health, environment, socio-economic and cultural wellbeing often ricochets from pollution of the atmosphere, biosphere, hydrosphere, and lithosphere (O'Rourke and Connolly, 2003).

3.4.1 Socio-Economic and Cultural Impact

Oil operations affect economic, social, and cultural fragments of societies in both positive and negative ways (Finer et al., 2008). Socio-economic impact relates to changes in land use pattern, influx of labour to change the local population structure, and introduction of new socio-cultural values (UNEP, 1997). The availability of quality water and fertile soils are important to agrarian communities (Subsection 2.2.4); damage to soils by hydrocarbon pollution affects their livelihood (Osuji and Opiah, 2007). Achudume (2009b) assessed the impact of oil effluence on water quality around Ubaji Creek in the Niger Delta. The research showed the extent to which contaminants caused localised ecological damage to near-shore villages. The resultant toxicity and increase in temperature was noticeable in the decrease of planktons and fish population in Ubaji creek (Achudume, 2009b). The reduction in fish population threatens fishing opportunities and human livelihood (Achuba and Osakwe, 2003 cited in Achudume, 2009b; UNEP, 2011).

3.4.2 The Impact on Human Health

Sebastian et al. (2001) observed that excessive cancer and leukaemia in workers and children living near petrochemical industries could be linked to contaminants from oil production. Petroleum contaminants can bio-accumulate in the food chain and, when ingested to a certain level, may cause carcinogenesis and mutagenesis of certain organs, mutilation of reproductive capacity, and haemorrhage in exposed population (humans). Contaminated groundwater and air (vapour) are some of the means through which humans, plants, and animals get exposed to hydrocarbon contaminants in the environment (Onwurah et al., 2007). Prescott et al. (1996) cited in Onwurah et al. (2007) reported that toxic compounds in oil contaminants can inhibit protein-synthesis, nerve synapse function, membrane transport system disruption and damage to the plasma membrane in humans. Short and Heintz (1997), collaborating with Prescott et al. (1996), report that exposures to hydrocarbon contaminants affect genetic integrity leading to carcinogenesis, mutagenesis, and are harmful to reproduction.

Onwurrah et al. (2007) extrapolated the risk of consuming petroleum-contaminated water from studies on rats, the rats developing haemorrhagic tendencies after exposure to water-soluble crude oil compounds. In addition, volatile components released from crude after a spill have been associated with an increase in asthma and bronchitis cases, and rapid ageing of lungs (Kaladumo, 1996 cited in Onwurah et al., 2007).

Furthermore, Anozie and Onwurah (2001) identified health hazards relating to liver, kidney and spleen weight problems arising from exposure to oil spills, based on data extrapolated from rats exposed to a contaminated medium. Meanwhile, different TPH fractions affect the body in different ways: exposure to smaller compounds such as benzene, toluene, and xylene can affect the human central nervous system; a higher dose can lead to death (ATSDR, 1999; Clements et al., 2009). Toxicologically, individual hydrocarbon compounds differ remarkably and chronic studies have only been done on a few hydrocarbons such as benzene, some PAHs which are carcinogens, and n-hexane, which has a tendency to cause “peripheral neuropathy” responsible for numbness in the legs and feet and in extreme cases paralysis (ATSDR, 1999; Nathanail et al., 2009).

Inhalation of lighter constituents of petrol, such as benzene and toluene, can affect the central nervous system, cause fatigue, headache, and nausea, e.g. breathing 100 parts per million of toluene for several hours (ATSDR, 1999). Ingestion of hydrocarbons, such as petrol, can cause irritation of the throat, depression of the central nervous system and difficulty in breathing. Chronic exposure to hydrocarbons can affect blood, liver, spleen, kidney, lungs, and the immune system (ATSDR, 1999). Skin contact with hydrocarbons can cause removal of fats from the skin to cause irritation and possibly dermatitis (Nathanail et al. 2009).

3.5 Classification and Behaviour of Oil in the Environment

The two main processes that crude oil pass through when spilt in the environment are movement and weathering (see Subsection 3.5.4) processes (Fingas, 2000). The two can occur simultaneously or overlap but their effectiveness depends on the type of oil spilt and prevailing environmental conditions (Fingas, 2000; Wang et al., 2006; Belore et al., 2011). Ambient temperature plays a significant role in the behaviour of oil, for instance the evaporation of volatiles from Class B oil may transform it to Class C oil (USEPA, 2011).

3.5.1 Classification of Crude Oil

Classification of crude oil based on geographic origin does not give information about toxicity, physical state and changes during weathering (USEPA, 2011). Therefore, spill responders grouped crude oil into four classes (Table 3-13) on the bases of temperature, hydrocarbon content, solubility in water, and volatility (NOAA, 2010).

Table 3-13: Classification of crude oil based properties (NOAA, 2012).

Class Category	**Observation**
Class A: *Light, Volatile Oils*	This category is highly fluid and can evaporate rapidly or spread easily on surfaces (USEPA, 2011). They contribute about 95% of water-soluble hydrocarbon fractions with less bioaccumulation due to high evaporation rate, thus are less persistent in the environment except in a matrix with materials (McIntosh et al., 2010; USEPA, 2011). The alkanes and cycloalkanes in this class have relatively low solubility and low acute toxic potentials, but the mono-aromatic hydrocarbons like benzene, toluene, and xylene dissolve in water and are toxic substances (Michel, 2001; USEPA, 2011). Most refined products and light crudes are in this category (USEPA, 2011).
Class B: *Non-Sticky Oils*	These are less toxic than class A; they can adhere to surfaces and penetrate porous surfaces with an increase in temperature. Evaporation of volatiles in this category can transform them to class C or D residue (USEPA, 2011). The medium weight hydrocarbon compounds in this category pose serious health risks, because they can persist in the environment and are biologically available. The poly-aromatic compounds are toxic while the alkanes (aliphatic hydrocarbons) degrade well in favourable conditions. Generally, medium-weight hydrocarbons are between 10-22 carbon atoms with boiling points between 150^0C and 400^0C. This class contains less water-soluble fractions hence evaporation takes longer, while the unvaporised compounds remain as residue due to the high amount of paraffin (McIntosh et al. 2010; USEPA, 2011). The toxicity level is

Class Category	Observation
	chronic because of diaromatic hydrocarbons (naphthalenes), and bioaccumulation potential is moderate (Michel, 2001; Reible, 2010).
Class C: *Heavy-Sticky Oils*	Oils in this class are "…viscous, sticky or tarry, and brown or black" (UNEPA, 2011). The density of oil may be near that of water hence it is liable to sink and is difficult to penetrate on a porous surface. The heavy crude components pose little toxic risk because of low solubility; however, their ability to degrade slowly makes them more persistent than other hydrocarbons. The hydrocarbons in this group are those with more than 20 carbon atoms, which do not evaporate easily and are almost insoluble in water. Bioaccumulation occurs only through sorption onto sediments (Reible, 2010); the chronic toxicity of this class is linked to the presence of polynuclear aromatic hydrocarbons, i.e. phenanthrene, anthracene and others. The heavy-weight components persist in the environment by forming a protective surface of tar balls and asphalt, which contain a high amount of wax, asphaltenes and non-polar compounds (Fingas, 2000).
Class D: *Non-Fluid Oils*	The oils in this class are relatively non-toxic and do not penetrate a porous surface. They can melt or coat surfaces when subjected to high temperature, otherwise they are relatively solid. Residual oil, heavy crude oil, some high paraffin oils, and weathered oil belong to this class (USEPA, 2011).

3.5.2 Movement of Oil on Water

Less dense oil such as gasoline floats on water while the much denser oil such as heavy oil sinks (Prince and Lessard, 2004; Ramseur, 2010); generally, the density of oil is determined by the length of hydrocarbons it contains. *Spreading* on water is much more common with oil under the influence of wind and wave action, causing lighter fractions to evaporate leaving behind the much heavier hydrocarbons mixed with water to form "chocolate mousse" (Fingas, 2000; ITOPF, 2002; Fingas and Fieldhouse, 2009). The action of wind current speeds up spreading such that the slicks begin to elongate towards the wind direction (Belore et al., 2011). *Sinking* is another common behaviour of oil on water, where heavy crude sinks to the bottom of water. For instance, warm fresh water can override denser seawater, if the fresh water has a density of 1.00g/ml and the seawater has density of 1.03g/ml. Hence, oil with a density between 1.00g/ml and 1.03g/ml would not flow on the fresh water but inbetween the two layers and eventually appear at a different location where the density of water has increased to 1.03g/ml (Fingas, 2000; Wang et al., 2008).

3.5.3 Movement of Oil on Land and Subsurface

When oil is discharged on land, the lighter less viscous oil would penetrate the top soil faster than the much heavier fraction due to viscosity or remain on the surface and subsurface strata (Fingas, 2000). The behaviour of oil on land is thus determined by type, composition, habitat, and prevailing weather conditions (Fingas, 2000; ITOPF, 2002). The vertical and horizontal movement of oil through soil and rock formation is unpredictable, unlike on a water surface (Fingas, 2000; Molins et al., 2010). The properties of the media on which oil is spilt, e.g. soil type, porosity, moisture content, slope level, and rate of ground water flow, vegetation and temperature, act to retard or support oil migration (Fingas, 2000).

Therefore, the ability of oil to move in soil or adhere to soil material is a function of the properties of oil and nature of the soil material. Low viscous oil can penetrate easily and faster into porous soil material than viscous oil. The arrangement of soil materials determines the degree of connectivity (porosity) and compactness of a soil formation and by extension, the ease with which oil can percolate (Fingas, 2000; Allaby et al., 2008; Molins et al., 2010). Thus, when oil is spilt on land, it will flow horizontally in the direction of gravity, forming pools in depressions (ITOPF, 2002) as in Plate 3-6. Fingas (2000) suggested that oil spilt on agricultural loamy soil would saturate the upper 10-20cm, and may not penetrate beyond 60cm except in a depression.

Plate 3-6: Surface spread and pooling of discharged crude oil in the Niger Delta (UNEP, 2011).

3.5.4 Oil Weathering and Changes in Chemical Composition

Weathering is a combination of physical, chemical and biological processes acting to transform oil spilt in the environment (Prince and Lessard, 2004; Wang et al., 2006; Lamberts et al., 2008). When crude oil is spilled, weathering processes such as evaporation, emulsification, natural dispersion, dissolution, microbial degradation, photochemical oxidation, microbiological degradation, sedimentation, and adhesion onto the surface of suspended materials change physical and chemical properties of crude oil (Wang et al., 2006; Lamberts et al., 2008; Bellas et al., 2013). These weathering processes continuously degrade crude oil until only the persistent hydrocarbons are left; thus, the knowledge of weathering processes can be used to predict oil dissipation after a spill (Qimin et al., 2009).

Evaporation significantly influences the fate of oil after a spill; for instance, gasoline can evaporate completely within days at 15^0C, diesel fuel about 60%, light crude about 40%, heavy crude about 20% and bunker C about 3% (Fingas, 2000; ITOPF, 2002). Emulsion in water transforms liquid oil into a viscous heavy substance. Although weathering processes begin immediately after a spill, their rates are not uniform but are fastest in the immediate phase of the spill (Fingas, 2000; ITOPF, 2002; Farwell et al., 2009). Research in understanding how weathering processes change oil composition and influence the fate and behaviour of oil after a discharge is well established (Farwell et al., 2009; Qimin et al., 2009; Belore et al., 2011). Weathering and biodegradation can be treated differently because biodegradation takes longer and involve biological organisms. Fingas (2000) estimates recovery time for oil-affected habitats according to years taken to recover with or without clean up, as shown in Table 3-14.

Table 3-14: Estimated habitat based on clean-up (Fingas, 2000).

Habitat	Recovery time and Clean-up intensity per Years		
	Without(Years)	Minimum(Years)	Optimal(Years)
Urban	1 to 5	1	<1
Roadside	1 to 5	1	<1
Agricultural land	2 to 10	1 to 3	1 to 2
Dry grassland	1 to 5	1 to 2	1
Forest	2 to 20	2 to 5	1 to 3
Wetland	5 to 30	3 to 20	2 to 10
Taiga	3 to 20	2 to 10	2 to 8
Tundra	3 to 10	2 to 8	1 to 5

Oil degrades rapidly in the presence of oxygen and nutrients (Bayoumi et al., 2009; Fingas and Fieldhouse, 2009) but the rate of biodegradation varies according to oil properties. For instance, while 50% of diesel can biodegrade in weeks, it would take years to degrade 10% of crude oil under similar conditions (Fingas, 2000).

Although weathering changes the physical properties and chemical composition of oil, the degree and rate depend on: a) type, chemical composition, and concentration of components in the oil; b) the environmental condition of the site where the spill occurred; and c) the population of natural bacteria. Wang et al. (2006) divided oil samples according to degree of changes in chemical composition during and after weathering, as follows:

i) Lightly-weathered oil (less than 15% naturally weathered), where the low-end n-alkanes are reduced significantly while benzene, toluene, Ethylbenzene, xylene and benzene compounds are lost completely.

ii) Moderately-weathered oil (between 15-30% weathered), where there is a significant loss of n-alkanes and low-molecular weight isoprenoids. Benzene, Toluene, Ethylbenzene, Xylene (BTEX), C_3-benzene may be lost completely as well as the C_0 and C_1-napthalenes.

iii) Severely-weathered oil, where n-alkanes, branched and cyclo-alkanes are deemed to be lost completely with the BTEX and alkyl benzenes. PAHs and their alkylated homologous series may be seriously degraded leading to a profile where each alkylated PAH family is distributed with $C_0\text{-}<C_1\text{-}<C_2\text{-}<C_3\text{-}$.

Conclusion

Pipelines are very important components of oil transport around the world, because they convey bulk oil across difficult terrain to markets and end users but expose people to danger (Brito and de Almeida, 2009; Kandiyoti, 2012). However, the spate of third party damage on hostile pipelines and operational accidents seems to be increasing even though there is no central database for analysing pipeline incidents on international, national, and regional scales (Kandiyoti, 2012). For instance, inconsistencies in the number of pipeline incidents recorded by Shell Nigeria, its mother company Dutch Shell, NNPC, and NOSDRA are an indication of how complacent MOCs and regulators in Nigeria regard pipeline incidents (Section 3.2, Table 3-2 and Table 3-3).

The oil spill contingency plans of DPR, MOCs, and NOSDRA are in conflict with each other; while NOSDRA operates the NOSCP, it also operates the EGASPIN procedure during join investigation of oil spills. Meanwhile, allowing MOCs to handle spills of less than 100kg (0.1 tonne) in-house when it is within the purview of Tier 1 (i.e. ≤ 7 tonnes) is confusing. As a result, NOSDRA may not be aware of such spills since MOCs handle them in-house (Subsection 3.2.2). This practice would greatly affect accountability and transparency in data management.

The adoption of two standards for determining pollution by EGASPIN (Subsection 3.3.1) also creates conflict and confusion. A standard reflecting the environmental conditions in Nigeria should be developed not only for soil, surface, and ground water but also for different land uses. The "target and intervention" standards adopted by EGASPIN were developed for soil and groundwater remediation purposes alone; they indicate when the functionality of soil is seriously impaired and do not necessarily indicate the human toxicological effect in terms of exceeding tolerable daily intake (TDI) for non-carcinogens or carcinogens. Meanwhile, ASTM based RBCA is a three-tiered structured framework designed to match corrective action with potential risk to human health. The higher the tier, the more specific is the assessment for corrective action (Vorhees et al., 1999).

The environmental impact of oil production in oil-producing areas of the Niger Delta is serious, based on the UNEP (2011) report which revealed levels of TPH in air, soil, surface, and underground water. Although the analysis was informative, not doing it according to the Equivalent Carbon (EC) number makes it impossible to appraise risk because TPHs represent the amount of petroleum hydrocarbons measurable in an environmental media, which is a mixture that does not indicate direct risk to humans or the environment (ATSDR, 1999). Zemo and Foote (2003) observed that the most reported concentration of TPH in groundwater does not represent dissolved petroleum hydrocarbons but represents non-dissolved petroleum or polar non-hydrocarbon compounds, even though soluble petroleum hydrocarbon constituents such as benzene, toluene, ethylbenzene, or xylenes (BTEX), alkylated benzenes, or polynuclear aromatic compounds (PNAs) may be present. TPH composition and concentration is influenced by the analytical method used; as a result there is no TPH toxicity criterion for human health risk-based clean-up (Vorhees et al., 1999), but the EC fractions would have provided the amount of toxic hydrocarbons present in the environmental media for developing toxicity criteria.

Finally, due to lack of "Good Oil Field Practice" or "Best Practice" on the part of oil operators on the one hand, and failure of government agencies to regulate oil pollution on the other, host communities are continually facing unnecessary exposure opportunities. Presently, Nigeria cannot boast of one indigenous risk assessment guideline for petroleum hydrocarbons; in fact, the concept of contaminated land management is alien. Consequently, the next chapter explores human health risk assessment criteria developed for dealing with hydrocarbons in the United Kingdom and the United States of America, in an attempt to propose one for rural land use in the Niger Delta.

CHAPTER 4

HUMAN EXPOSURE AND RISK ASSESSMENT

4.0 Introduction

There are several opportunities for exposure to petroleum hydrocarbons in land use; such exposure may come from hand-to-mouth, tracking of contaminants back home, etc. (Kimbrough et al., 2010). Despite this, there are "*no reliable quantitative data to support Human Health Risk Assessment for activities associated with receptors living in rural areas, or for lifestyles and occupations such as farming, where there is potential for high exposure*" (Doyle et al., 2010). It is in fact common knowledge that rural lifestyles predispose people to several exposure opportunities, yet there is limited information for detailed risk assessment. This chapter reviews procedures and principles of risk assessment, with emphasis on petroleum hydrocarbon contaminants. The purpose is to study relevant criteria for use in evaluating rural land-use exposure scenarios in the Niger Delta region of Nigeria.

4.0.1 Risk Assessment

Human health risk assessment evaluates the probability and frequency of hazard, and the magnitude of the consequence (Nathanail, 2013). The procedure examines the presence of and concentration of chemical substances to determine if risk is acceptable or not. In general, the risk assessment procedure follows four basic steps explained in Table 4-1.

Table 4-1: The general procedures for human health risk assessment.

Hazard Identification	This defines the source of hazard and risk in relation to contaminants composition, environmental medium affected, potential migration routes, nature of exposure pathways, and receptor at risk. The information is described on a site conceptual model for further assessment if required (Petts et al., 1997; Environment Agency, 2004).
Hazard Assessment	The information from the previous step is used to analyse acceptable risk (Petts et al., 1997; Swartjes and Cornelis, 2011), what pathway and receptor are present, the pollutant linkages that may develop and the effects (Environment Agency, 2004; Mcalary et al., 2011; Elert et al., 2011). Hazard assessment does not quantify risk but generates data for comparing standards (Petts et al., 1997) in order to ascertain the level of acceptability.
Risk Estimation	Risk estimation predicts the magnitude and probable consequence based on frequency and level of exposure to a contaminant (Petts et al., 1997; Langley, 2011) by using exposure and effect assessment to establish the dose-response relationship (Langley, 2011; Swartjes and Cornelis, 2011). i) *Exposure assessment* measures intensity, frequency, magnitude, and duration of exposure as well as determining the rate of the contaminant's migration through soil, air, and surface or ground water (Langley, 2011) to predict a possible decrease in the contaminant's concentration over time (Petts et al., 1997). Finally, the quantity of contaminant available through "exposure-dose-response relationship" (Langley, 2011; Swartjes and Cornelis, 2011) is estimated. ii) *Effect assessment* quantifies the relationship between exposure and adverse effect from contact by defining contact occurrence, frequency, and duration (Petts et al., 1997). The effect assessment provides detailed characteristics of the receptor in terms of age, gender,

	bodyweight and size (Petts et al., 1997).
Risk Evaluation	Risk evaluation is developed from the result of hazard assessment and risk estimation, particularly where further risk assessment has been decided (Petts et al., 1997; Gay and Korre, 2006). The risk evaluation states the uncertainty of the risk assessment, the magnitude of risk, and the resolution of the uncertainty (Petts et al., 1997; Smith and Petley, 2008), in addition to stating how changes in assumption can alter the estimation (Petts et al., 1997).

4.0.2 Land Use Risk Assessment Models

Cheng and Nathanail (2009) identified 17 risk assessment models used to calculate exposure via ingestion, inhalation, and dermal contact in land uses. According to Cheng (2009), some models are deterministic while others are probabilistic. The models that allow their inbuilt parameters to be changed are referred to as "probabilistic models" and can be used to develop new land use scenarios. In contrast, the deterministic models do not allow changes to be made to their parameters; they are restrictive and cannot be used to develop new land use scenarios. Some risk assessment models are listed in Table 4-2 but only the CLEA (Contaminated Land Exposure Assessment) model is discussed in detail because of its familiarity, suitability, and flexibility in generating new assessment criteria. Although Cheng and Nathanail (2009) evaluated six models based on four criteria listed below, they found SNIFFER[9] more suitable at the time; however, the present version of CLEA (v1.06) has undergone tremendous improvements to satisfy these criteria:

i. ability to modify and create new parameters;
ii. inbuilt exposure scenarios for intended purpose;

[9] Developed by the Land Quality Management Ltd UK for SNIFFER (http://www.sniffer.org.uk) (Cheng and Nathanail, 2009).

iii. access and use of the model, and

iv. familiarity with the model.

Table 4-2: Some human health risk assessment models (Nathanail and Bardos, 2004; Cheng and Nathanail, 2009).

Tool		Receptor	Developer	Medium
1	CLEA	People	Developed for UK soil guideline values (DEFRA and UK Environmental Agency)	Compiles software
2	SNIFFER	People	Developed for site-specific assessment (Land Quality Management Ltd UK)	Spread sheet and paper worksheet
3	GASSIM	People	Determine site-specific assessment criteria for risk from landfill gas (Golder Associates for UK Environmental Agency)	Compiled probabilistic software
4	RBCA	People and groundwater	Developed site-specific assessment criteria (American Society for Testing and Materials UK)	Programmed spread sheet
5	BP RISC	People and groundwater	Developed site-specific assessment criteria (Space Engineering Pleasanton, California and BP Oil International Ltd UK)	Compiled probabilistic or deterministic software

4.1 Contaminated Land Exposure Assessment (CLEA)

The CLEA model is a probabilistic tool used to drive generic assessment criteria for contaminated soil in the UK. The model does not estimate human exposure emanating from contaminated surface water or groundwater, meaning receptors other than humans are not considered (Environment Agency, 2002; Cheng, 2009). Due to its probabilistic nature, the user can modify existing substances or add new ones to the database.

The model considers only on-site human receptors from 0-75 years. Children from 0-6 years are the default for all land uses except commercial/industrial land use, which has class 17 representing ages 16-65 as the default (working-class adult). The pathways can be switched on and off depending on land use, contaminant, and relevant pathway (Environment Agency, 2002, p.2).

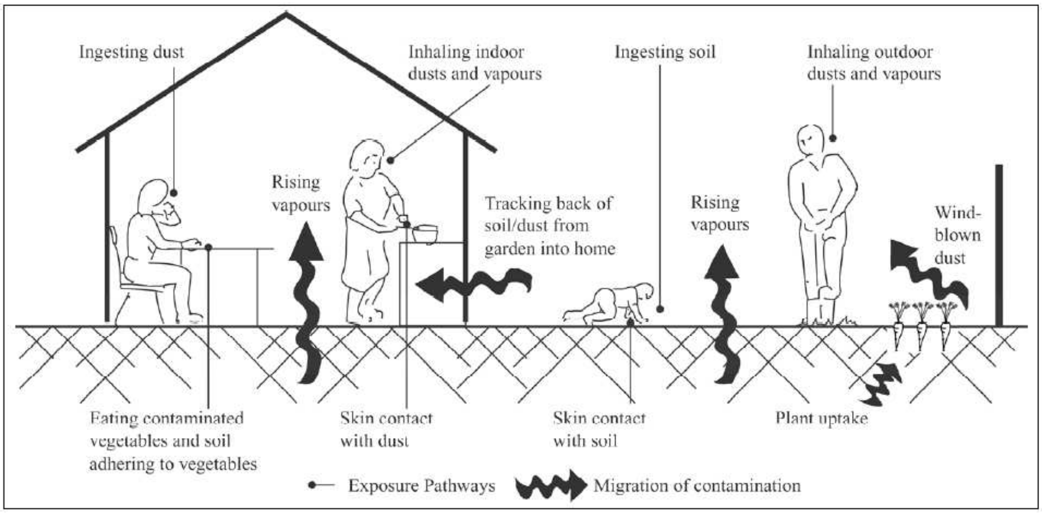


Figure 4-1: Possible exposure pathways recognised by CLEA model (Environment Agency, 2009).

The CLEA v1.6 model is available free on the Environment Agency website. Land use types include i) residential (with plant uptake), ii) residential (without plant uptake), iii) allotment, and iv) commercial and industrial. Exposure pathways illustrated in Figure 4-1 are:

i) direct ingestion of soil and dust;

ii) ingestion of soil attached to garden vegetable;

iii) consumption of contaminated home-grown garden vegetables;

iv) dermal contact with soil outdoors;

v) dermal contact with soil derived dust indoors;

vi) inhalation of soil-derived dust outdoors;

vii) inhalation of soil-derived dust indoors;

viii) inhalation of soil vapours outdoors; and

ix) inhalation of soil vapours indoors.

4.1.1 Exposure Assessment

Exposure assessment estimates the amount of contaminant available via intake and uptake routes (IPCS, 2000) using information on the contaminant's concentration, exposure magnitude, exposure frequency and exposure duration (USEPA, 2008). Exposure assessment *"is an integral component of risk assessment"* used for evaluating human exposure and risk in land use (IPCS, 2004; Environmental Agency, 2009). For this reason, the Environment Agency (2009) developed the Average Daily Exposure (ADE) model in the CLEA to derive the maximum concentration in the soil as an average sum of intake through inhalation, ingestion and dermal exposure routes with Equation 4-1 (Gay and Korre, 2006; Environment Agency, 2009).

Equation 4-1

$$\mathrm{ADE} = \frac{\left(IR_{ing} \times EF_{ing} \times ED_{ing}\right)}{BW \times AT} + \frac{\left(IR_{inh} \times EF_{ing} \times ED_{inh}\right)}{BW \times AT} + \frac{\left(IR_{derm} \times EF_{derm} \times ED_{derm}\right)}{BW \times AT}$$

Where:

ADE = average daily exposure to chemical from soil (mgkg/bw/day)

IR= chemical intake/uptake rate (mg/day)

EF= the exposure frequency (days year^{-1})

ED= the exposure duration (year)

BW= the human body weight (kg)

AT= the averaging time (days)

NB: *ing*= ingestion, *inh*= inhalation and *derm*= dermal contact.

i. *Exposure Duration (ED)* is the length of time a receptor is exposed to a contaminant; it is calculated in day/week/year or lifetime (IPCS, 2000; Environment Agency, 2009).

ii. *Averaging Time (AT)* Environment Agency (2009, p.15) in SR3 assumes AT to be equal to exposure duration. For instance, a six-year-old child's averaging time would be 2,190 days, being the years of the child multiplied by 365 days.

iii. *Exposure Frequency (EF)* is the number of days exposure occurs in a given year. EF can be continuous, intermittent or random (IPCS, 2000). Notwithstanding, the Environment Agency (2009) assumes EF for inhalation of household dust to be 365 days a year. Intake of in-door air and uptake of contaminated home-grown fruits and vegetables is also 365 days a year whether a receptor consumes a small portion of fruits or vegetables most days and a larger portion once or twice a week (Environment Agency, 2009).

4.2 Exposure Pathways

Exposure pathways represent routes through which contaminants enter into the human body. The routes can be one of three or both occurring simultaneously:

i. ingestion by oral intake of contaminated substances;

ii. inhalation by intake of contaminant during breathing; and

iii. dermal contact by uptake of contaminant through physical contact with skin.

The magnitude of exposure through a particular exposure route is quantified in terms of quantity of contaminant that finally got through to the organs such as lungs, skin, and mouth, via points of exchange (Morra et al., 2006).

4.2.1 Exposure by Inhalation

Exposure by inhalation is measured in microgram per cubic meters ($\mu g/m^3$): "*is the product of the number of breathing cycles and respired air volume for each cycle*" (USEPA, 1997b cited in Environment Agency, 2009). The knowledge of time spent on a location and body weight of the receptor are important in modelling exposure through inhalation (Semple, 2004; Licari et al., 2005; IPSC, 2006). However, since concentration of a contaminant can vary in time and space (indoor or outdoor) due to diffusion, exposure would not be uniform either. Therefore, where a receptor spends most time is used to quantify the amount of air inhaled, taking into consideration the rate of inhalation which is directly proportional to age, body weight and activity performed (IPSC, 2006). Inhalation rates differ according to age and intensity; for instance, infants and young children have higher resting metabolic rates, hence they consume more oxygen per unit of body weight than adults (USEPA, 2008).

The Environment Agency (2009) compared the recommended inhalation rate for short-term exposure in USEPA (United States Environment Protection Agency) (1997) the works of the International Commission on Radiology Protection (ICRP), Layton (1993) and Lordo et al. (2006). The USEPA (1997) based its recommendation on the work of Layton (1993) for estimating inhalation according to physical activities. The USEPA also investigated energy expenditure, activity pattern, metabolic rate and weight average oxygen uptake using a different approach to explain variation in inhalation rate according to age and gender, and got similar results as Layton (1993) (Environmental Agency, 2009). Consequently, the recommended estimated rates for short- and long-term exposure through inhalation are in Table 4-3 and Table 4-4 respectively.

Table 4-3: Short-term exposure inhalation rate in relation to activity (USEPA, 1997b cited in Environment Agency, 2009).

Activity	Inhalation rate (m^3 $hour^{-1}$)	
	Children (age 0-16)	Adults (aged greater than 16)
Rest	0.3	0.4
Sedentary	0.4	0.5
Light	1.0	1.0
Moderate	1.2	1.6
Heavy	1.9	3.2

Table 4-4: Inhalation rates recommended for long-term exposure according to age (USEPA, 2009a).

Long-term Inhalation Rates (m^3/day)		
Year	Mean	95th Percentile
0 - <1	8.0	12.8
2 - <3	8.9	13.7
3 - < 6	10.1	13.8
6 - < 11	12.0	16.6
11 - < 16	15.2	21.9
16 - < 21	16.3	24.6
21 - <31	15.7	21.3
31 - <41	16.0	21.4
41 - < 51	16.0	21.2
51 - < 61	15.7	21.3
61 - <71	14.2	18.1
71 - <81	12.9	16.6
≥ 81	12.2	15.7

4.2.2 Exposure by Oral Ingestion

Exposure by ingestion is of two types, i.e. dietary and non-dietary. Dietary exposure refers to direct consumption of contaminated food. To assess dietary exposure, consumption pattern, food ingestion rate by age, and level of food contamination is required. The exposure assesses intake of contaminant in food, drinking water etc. by calculating intake as a product of mass of food consumed and concentration of the contaminant (IPSC, 2006). Dietary exposure can be expressed as the sum of:

i. original contaminant residue in food item before handling;

ii. surface-to-food contamination when the food makes contact with contaminated surface before consumption; and

iii. surface-to-hand-to-food contamination, i.e. touching contaminated surface before handling and eating (Cohen Hubal et al., 2000).

Non-dietary exposure on the other hand is the ingestion of contaminated non-food material like soil and dust. Ingestion of soil and dust are important exposure pathways for pollutants adhering to hands, toys and objects (IPSC, 2006).

4.2.2.1. Soil and Dust Ingestion

Soil and dust ingestion can be a significant route of exposure through the mouth (Cohen Hubal et al., 2000; Egeghy et al., 2007). According to Egeghy et al. (2007), children ingest soil 10 times more than adults on a per kilogram body weight basis if the child suffers from pica i.e. *"a psychopathological condition that refers to the persistent and purposeful consumption of soil, often in relative large quantities"* (World Health Organisation, 1990 cited in Environment Agency, 2009).

According to Calabrese et al. (1997a), Stanek, et al. (1998), and Paustenbach, (2000) cited in Environment Agency (2009), short-term ingestion or exploratory mouthing in children can be a "*normal temporary phenomenon among some children*", but only few ingestion studies were able to differentiate between childhood exploratory mouthing and pica. In a study of children age 3-6 years, Ozkaynak et al. (2010) reported a total mean ingestion of soil and dust, soil ingestion, hand-to-mouth dust ingestion, and object-to-mouth dust ingestion of about 68mg/day, 41mg/day, 20mg/day and 7mg/day respectively. They conclude that their result was slightly lower than the central value of 100mg/day recommended by USEPA (2008), also reproduced by USEPA (2009) in *the "Exposure Factors Handbook"* in Table 4-5.

Table 4-5: USEPA (2009) recommended soil and dust ingestion.

Year	Soil			Dust	Soil and Dust
	Upper Percentile				
	Central Tendency mg/day	Soil-Pica mg/day	Geophagy mg/day	Central Tendency mg/day	Central Tendency mg/day
6mth-<12mth	50	-	-	30	60
1 -<6	50	1,000	50,000	60	100
6 -<21	50	1,000	50,000	60	100
Adult	50	-	50,000	-	-

The amount of soil or dust ingested by adults can be high if the individual is prone to hand-to-mouth, as pica is very rare in adults (Environmental Agency, 2009). A study of adult soil ingestion by Calabrese et al. (1990) cited in Environmental Agency (2009), conducted on six adults revealed that adults can ingest about 50mg day^{-1} of soil. Similarly, Stanek et al. (1997) cited in Environmental Agency (2009) observed ten adults ingested an average of 10mg of soil a day over a period of four weeks in a different study. Davis and Mirick (2006) investigated the rate of soil ingestion among 19 families for comparison between adults and children; they observed that adults ingest an average of 52.5mg soil a day and concluded that it is consistent with the 50mg day^{-1} recommended by USEPA for risk assessment. Stanek and Calabrese (2000) cited in Environment Agency (2009) therefore presented a long-term soil ingestion rate shown in Table 4-6.

Table 4-6: Long-term soil ingestion from tracer studies by Stanek and Calabrese (2000) cited in Environment Agency (2009).

Time Period[1]	95th Percentile of true average soil ingestion rate (mg/day)
7days	177
30days	135
90days	127
365days	124

4.2.2.2. Exposure via Fruit and Vegetable Ingestion

The ingestion of contaminated fruits and vegetables can transfer contaminants into the human body (Environment Agency, 2009). Plants accumulate chemicals from contaminated soils through the root system (Environment Agency, 2009; USEPA, 1997, 2009a) and make them available when consumed. Therefore, information on fruit and vegetable ingestion rates is required to assess exposure through this pathway. The following terms are used to define intake of fruits and vegetables:

i) consumer-only-intake: is the quantity of fruits and vegetables consumed by an individual;

ii) per-capita-intake-rate: is the average of consumer-only-intake over an entire population;

iii) total-fruit-intake: is the sum of all fruits consumed in a day from canned, dried, frozen and fresh fruits; and

iv) total-vegetation-intake: refers to the sum of all vegetables consumed in a day including canned, dried, frozen, and fresh vegetables (USEPA, 1997, 2009a).

Table 4-7 shows the recommended values for per capita and as consumed intake of fruits and vegetables provided by USEPA (2009a). The values are based on assumptions from the Continuing Survey of Food Intake by Individuals (CSFII) in the USA from 1994-96 and 1998.

Table 4-7: Fruit and vegetable intake (USEPA, 2009a).

Recommended values for intake of fruits and vegetables “As Consumed”								
Year	Total Fruits (g/kg-day)				Total Vegetables (g/kg-day)			
	Per Capita		Consumers Only		Per Capita		Consumers Only	
	Mean	95^{th}	Mean	95^{th}	Mean	95^{th}	Mean	95^{th}
0 - 1	5.7	21.3	10.1	26.4	4.5	14.8	6.2	16.1
1 -<2	6.2	18.5	6.9	19.0	6.9	17.1	6.9	17.1
2 -<3	6.2	18.5	6.9	19.0	6.9	17.1	6.9	17.1
3 -<6	4.6	14.4	5.1	15.0	5.9	14.7	5.9	14.7
6 -<11	2.4	8.8	2.7	9.3	4.1	9.9	4.1	9.9
11 -<16	0.8	3.5	1.1	3.7	2.9	6.9	2.9	6.9
16 -<21	0.8	3.5	1.1	3.7	2.9	6.9	2.9	6.9
20 -<50	0.9	3.9	1.2	4.4	2.9	6.8	2.9	6.8
≥50	1.4	4.8	1.6	5.0	3.1	7.0	3.1	7.0

The Environment Agency (2009) on the other hand derived estimates for some home-grown produce (Table 4-8) for indirect ingestion of soil material attached to home-grown produce. The values are based on soil loading and preparation factor (Oatway et al., 2003) designed for radioactive contaminated land. The consumption rate in Table 4-9 by the Environment Agency (2009) is a 95^{th} percentile estimate from the Food Standard Agency data reported in per unit body weight using standard meal recipe information. The value is not fresh weight because it does not consider the amount of water loss during cooking; meanwhile, the consumption rate is based on age provided by the National Diet and Nutrition Survey (NDNS) in the UK (Environment Agency, 2009).

Table 4-8: The values of entrained soil according to produce category (Environment Agency, 2009a).

Produce Category	Soil Loading (g/g/dw)	Preparation Factor Dimensionless	Dry-weight Conversion Factor (g/dw/g/ fw)
Green vegetables	0.001	0.2	0.096
Root vegetables	0.001	1.0	0.103
Tuber vegetables	0.001	1.0	0.210
Herbaceous fruit	0.001	0.6	0.058
Shrub fruit	0.001	0.6	0.166
Tree fruit	0.001	0.6	0.157

Table 4-9: Consumption rate for produce by age (Environment Agency, 2009).

Age Class	NDNS Survey	Consumption Rate (kg^{-1} bw day^{-1})					
		Green	Root	Tuber	Herb.	Shrub	Tree
1	Infant 1986	7.12	10.69	16.03	1.83	2.23	3.82
2-4	Toddler 1992	6.85	3.30	5.46	3.96	0.54	11.96
5-16	Young person 1997	3.74	1.77	3.38	1.85	0.16	4.26
17-18	Adults 2000	2.94	1.40	1.79	1.61	0.22	2.97

4.2.3 Exposure by Dermal Contact

Dermal exposure occurs when there is contact between skin and contaminated material, i.e. water, soil, sediment, liquid, vapours/fumes, while undertaking "*activities in different environmental media and microenvironment*" (USEPA, 1997, 2009a). Dermal exposure can also emanate from volatile substance deposition on the skin, or through direct/indirect transfer to the skin and then absorbed into the human body

(Kimbrough et al., 2010). Factors considered in estimating dermal exposure are:

i) concentration of contaminant in contact with skin;
ii) duration of exposure (contact);
iii) surface area of body part; and
iv) skin surface adherence.

The chances of soil adhering to skin, according to USEPA (1997, 2009a), is dependent on soil properties, part(s) of the body, and soil adherence factor. In general, dermal exposure estimates the quantity of contaminant in contact with the skin and the quantity absorbed over a period of time (Semple, 2004; IPCS, 2005; USEPA, 1997, 2009a) from immersion or deposition. Dermal exposure through bathing, showering, swimming etc. can be expressed in terms of occurrence and duration; hence, the quantity of contaminant absorbed from water is influenced by the concentration of the contaminant. However, a short-term exposure scenario can yield significant results compared to long-term exposure irrespective of duration because of concentration.

Semple (2004) argued that the transfer rate of chemicals through the skin is directly proportional to the concentration gradient of the contaminant, and the rate regulated by chemical permeability constant. In contrast to oral or inhalation exposure, only the absorbed dose is calculated. Dust transfer efficiency varies according to pressure and movement of body parts against a contaminated surface, or duration of skin-to-surface contact and the affinity of the contaminated particles to stick on the skin surface (Semple, 2004). Most models estimate dermal contact as the product of the surface area of the exposed skin, the amount of medium retained on the skin (adherence), and the weight fraction of the contaminant in the mixture (IPCS, 2005).

Table 4-10: USEPA (2009a) Recommended Values for Surface Area of Body Parts.

Recommended Values for Surface Area of Body Parts (m^2)																		
Months	Head			Trunk			Arms			Hands			Legs			Feet		
	M1	M2	95th	M1	M2	95th	M1	M2	95th	M1	M2	95th	M1	M2	95th	M1	M2	95th
0 to 1	18.2	0.053	0.062	35.7	0.104	0.121	13.7	0.040	0.047	5.3	0.015	0.018	20.6	0.060	0.070	6.5	0.019	0.022
1 to<3	18.2	0.060	0.069	35.7	0.118	0.136	13.7	0.045	0.052	5.3	0.017	0.020	20.6	0.068	0.078	6.5	0.021	0.025
3 to<6	18.2	0.069	0.080	35.7	0.136	0.157	13.7	0.052	0.060	5.3	0.020	0.023	20.6	0.078	0.091	6.5	0.025	0.029
6 to<12	18.2	0.082	0.093	35.7	0.161	0.182	13.7	0.062	0.070	5.3	0.024	0.027	20.6	0.093	0.105	6.5	0.029	0.033
Years																		
1 to<2	16.5	0.087	0.101	35.5	0.188	0.217	13.0	0.069	0.079	5.7	0.030	0.035	23.1	0.122	0.141	6.3	0.033	0.038
2 to<3	14.2	0.087	0.099	38.5	0.235	0.270	11.8	0.072	0.083	5.3	0.032	0.037	23.2	0.142	0.162	7.1	0.043	0.050
3 to<6	13.7	0.104	0.130	31.7	0.241	0.301	14.2	0.108	0.135	5.9	0.045	0.056	27.3	0.207	0.259	7.3	0.055	0.069
6 to<11	12.6	0.136	0.186	34.7	0.375	0.514	12.7	0.137	0.188	5.0	0.054	0.074	27.9	0.301	0.413	7.2	0.078	0.107
11 to<16	9.4	0.149	0.194	33.7	0.536	0.694	12.9	0.205	0.266	5.3	0.084	0.109	31.3	0.498	0.645	7.5	0.119	0.155
16 to<21	7.8	0.144	0.182	32.2	0.592	0.750	15.3	0.282	0.356	5.4	0.099	0.126	32.2	0.592	0.750	7.1	0.131	0.165
Adults																		
Males≥21	6.6	0.136	0.154	40.1	0.827	1.10	15.2	0.314	0.399	5.2	0.107	0.131	33.1	0.682	0.847	6.7	0.137	0.161
Females≥21	6.2	0.114	0.121	35.4	0.654	0.850	12.8	0.237	0.266	4.8	0.089	0.106	32.3	0.598	0.764	6.6	0.122	0.146

Note: to convert to cm^2, multiply by 10,00cm^2/m^2

M1 = mean percentage of total surface area (calculated as mean percentage of body part times mean total body surface area)

M2 = mean surface area by body part (calculated as mean percentage of body part times 95th percentile total body surface area)

95th = percentile surface area by body part.

A recommended value for the body parts surface area by USEPA (2009a) is presented in Table 4-10. The values came from a USEPA analysis of National Health and Nutrition Examination Survey (NHANES) in 1999-2006 for children under 21 years, while values for adults above 21 years were based on a USEPA analysis of NHANES data from 2005-2006.

4.3 Total Petroleum Hydrocarbon Fractions

The development of EC numbers by the Total Petroleum Hydrocarbon Criteria Working Group (TPHCWG) for assessing TPH provided a means of evaluating different hydrocarbon fractions (Edwards et al., 1997; Vorhees et al., 1999). The work is necessary because hydrocarbons exist in thousands of different forms that are difficult to assign toxicology values and behaviour to each (ATSDR, 1999; Brown et al., 1999; Kamnikar, 2001; Nathanail et al., 2007, 2009). The TPHCWG's EC number is based on the classification of hydrocarbon fractions according to length of the carbon chain, solubility, boiling point, and toxicity (ATSDR, 1999; Vorhees et al., 1999). Hence, fractions are grouped into aromatic and aliphatic, as in Table 4-11 (Vorhees et al., 1999; Kamnikar, 2001; Nathanail et al., 2009; UNEP, 2011).

However, the hydrocarbon fractions classification in the UK shown in Table 4-12 has an addition of $EC_{>44}$–EC_{70}, not available in the TPHCWG fractions (Nathanail et al., 2007, 2009). Each of these fractions corresponds to specific hydrocarbon compounds, e.g. aromatic such as benzene ($>EC_5$-EC_7), toluene ($>EC_7$-EC_8), ethylbenzene ($>EC_8$-EC_{10}) and xylene ($>EC_8$-EC_{10}), among others.

Table 4-11: Fate and Transport Properties of TPHCWG Petroleum Fractions (Vorhees et al., 1999).

Equivalent Carbon Number[a]	Solubility (mg/L)	Vapor Pressure (atm)	log K_{oc} (c/c)	Boiling Point (°C)	Henry's Law Constant[b] (cm^3/cm^3)	Molecular Weight (g/mole)	Diffusivity in air (cm^2/s)	Diffusivity in water (cm^2/s)
Aliphatic Fractions								
>5–6	3.6E+01	3.5E–01	2.9E+00	5.1E+01	3.3E+01	8.1E+01	1.0E–01	1.0E–05
>6–8	5.4E+00	6.3E–02	3.6E+00	9.6E+01	5.0E+01	1.0E+02	1.0E–01	1.0E–05
>8–10	4.3E–01	6.3E–03	4.5E+00	1.5E+02	8.0E+01	1.3E+02	1.0E–01	1.0E–05
>10–12	3.4E–02	6.3E–04	5.4E+00	2.0E+02	1.2E+02	1.6E+02	1.0E–01	1.0E–05
>12–16	7.6E–04	4.8E–05	6.7E+00	2.6E+02	5.2E+02	2.0E+02	1.0E–01	1.0E–05
>16–21	2.5E–06	1.1E–06	8.8E+00	3.2E+02	4.9E+03	2.7E+02	1.0E–01	1.0E–05
Aromatic Fractions								
>5–7 (benzene)	1.8E+03	1.3E–01	1.9E+00	8.0E+01	2.3E–01	7.8E+01	1.0E–01	1.0E–05
>7–8 (toluene)	5.2E+02	3.8E–02	2.4E+00	1.1E+02	2.7E–01	9.2E+01	1.0E–01	1.0E–05
>8–10	6.5E+01	6.3E–03	3.2E+00	1.5E+02	4.8E–01	1.2E+02	1.0E–01	1.0E–05
>10–12	2.5E+01	6.3E–04	3.4E+00	2.0E+02	1.4E–01	1.3E+02	1.0E–01	1.0E–05
>12–16	5.8E+00	4.8E–05	3.7E+00	2.6E+02	5.3E–02	1.5E+02	1.0E–01	1.0E–05
>16–21	6.5E–01	1.1E–06	4.2E+00	3.2E+02	1.3E–02	1.9E+02	1.0E–01	1.0E–05
>21–35	6.6E–03	4.4E–10	5.1E+00	3.4E+02	6.7E–04	2.4E+02	1.0E–01	1.0E–05

Source:
TPHCWG Volume 3, Table 8 and Section 4.3.5.
Notes:
[a]Equivalent Carbon Number (EC)—carbon number correlated with the retention time of constituents in a boiling point gas chromatography (GC) column, normalized to the *n*-alkanes.
[b]Calculated Henry's law constant based on vapor pressure, solubility, and molecular weight relationship.

Table 4-12: Petroleum hydrocarbon fractions used in UK human health risk assessment (Nathanail et al., 2009).

Petroleum Hydrocarbon Fractions	
Aliphatic	Aromatic
$EC_{>5}$ - EC_6	$EC_{>5}$ - EC_6
$EC_{>6}$ - EC_8	$EC_{>7}$ - EC_8
$EC_{>8}$ - EC_{10}	$EC_{>8}$ - EC_{10}
$EC_{>10}$ - EC_{12}	$EC_{>10}$ - EC_{12}
$EC_{>12}$ - EC_{16}	$EC_{>12}$ - EC_{16}
$EC_{>16}$ - EC_{35}	$EC_{>16}$ - EC_{21}
	$EC_{>21}$ - EC_{35}
$EC_{>35}$ - EC_{44}	$EC_{>35}$ - EC_{44}
$EC_{>44}$ - EC_{70}	

4.3.1 Toxicity of Petroleum Hydrocarbons

The toxicity of petroleum hydrocarbons increases with the quantity of low boiling compounds (Michel, 2001). Clements et al. (2009) suggest that toxicity increases in ascending order of alkanes, alkenes and aromatics. BTEX has greater environmental and toxicity concerns than other hydrocarbon compounds; BTEX stands for benzene, toluene, Ethylbenzene and the xylene isomers (p-, m- and o-xylened) (Wang et al., 1995). BTEX are common aromatic compounds found in crude oil; they are the most soluble, most mobile fraction of crude oil. BTEX concentration has greater influence on the physical and chemical properties of oil, e.g. density, viscosity, flash points, dispensability, emulsion stability, solubility, and weathering processes (Wang et al., 1995). The significance of these compounds is that they easily penetrate soil, sediments, and groundwater when discharged from underground facilities such as pipelines, storage tanks etc. to pose a serious health risk. Already BTEX has been classified as hazardous carcinogenic and neurotic compounds regulated by Environment Canada and the USEPA (Wang et al., 1995; ATSDR, 1999). (for the health impact of hydrocarbons, see Subsection 3.4.2).

Toxicology data are available for a few hydrocarbons and so far only 25 are reliable (Clements et al., 2009; UNEP, 2011). Clements et al. (2009) argued that the impact of hydrocarbon compounds is affected by weathering, which acts to change their composition and exposure data, thereby preventing accurate measurement of the actual fraction humans are exposed to, e.g. petrol and jet fuel. Due to the complex nature of hydrocarbon compounds in crude oil (Udoetok and Osuji, 2008), some have been given priority in toxicology research, e.g. Volatile Organic Compounds (VOC) such as benzene, xylene, toluene, ethylbenzene (BTEX), which are considered common volatile constituents that are easily inhaled (Sebastian, 2001). The UK Environment Agency TOX report provides background concentration for these aromatic hydrocarbons, e.g. BTEX and naphthalene (Table 4-13).

Table 4-13: Background concentration of some aromatic compounds (Nathanail et al., 2009).

Benzene	>EC5-EC7 has a mean daily intake from food and water estimated at 3µg/day, and 200µg/day in ambient air. Human exposure is through inhalation of vehicle exhaust and tobacco smoke. However, the level of ambient benzene vapour has declined in recent years due to enforcement of catalytic converters and reduced benzene levels in petrol.
Toluene	>EC7-EC8 estimated mean daily intake from food and water of 10µg/day. Toluene is a significant constituent of petrol; therefore its concentration at filling stations was reviewed. As a result, the mean daily intake through inhalation was increased from 124µg/day to 520µg/day, while the mean daily intake through oral ingestion was retained at 10µg/day (Nathanial et al., 2009).
Ethylbenzene	>EC8-EC10 is given a mean daily intake in food of 0.3 to 4.2µg/day and drinking water <0.2µg/l. Ethylbenzene is also significant in petrol and cigarettes; the current recommended mean daily intake via oral ingestion is 5µg/day and 130µg/day for inhalation.
Xylene	>EC8-EC10 estimated mean daily intake from food and water is approximately 11µg per day based on estimated background intake of all xylene isomers from food, which is <5µg/day (maximum of 10µg/day), and drinking water 3µg/l (or 6µg/day) as a worst case scenario. However, the mean daily intake by inhalation is 140µg/day.
Naphthalene	>EC10-EC12 daily intake is 7µg/day and 60µg/day for drinking water. The major source of atmospheric

	naphthalene is vehicular exhaust; naphthalene also has a higher concentration indoors than outdoors.
Benzo(a)pyrene	EC21-EC35 UK dietary intake is 0.25μg/day, the mean annual concentrations of benzo(a)pyrene in urban air is estimated at 1.3μg/m^3.

4.3.2 Effects of Weathering on Toxicity of Petroleum Hydrocarbons

Weathering is a term describing a series of processes (Subsection 3.5.4) working to change the physical and chemical properties of oil (Prince et al., 2004; Wang et al., 2006; Lamberts et al., 2008; Bellas et al., 2013). A process like evaporation alters the material balance and causes loss of lighter saturate and aromatic (e.g. mono-aromatic and light PAHs) components of crude oil. Evaporation on the other hand increases the amount of toxicity contributed by PAHs (National Research Council, 2003), while photo-oxidation of aliphatic and aromatic fractions generates more polar and water-soluble compounds such as ketones, aldehydes, carboxylic acids and esters (National Research Council, 2003; Rial et al., 2013).

Thus, because crude oil consists of a complex mixture of organic compounds, physicochemical properties and their proportion in a mixture can be used to determine the relative content of saturated hydrocarbons, aromatics, resins, and asphalt. Saturated hydrocarbons such as paraffin, iso-paraffin and naphthene have low aqueous solubility which makes them less toxic. The aromatic and PAH fractions on the other hand have been identified with acute toxicity (Neff and Stubblefield, 1995). Consequently, change in toxicity would depend on the physicochemical characteristics of the crude oil and the predominant weathering process. Although several studies have been conducted on weathering in order to validate the assumption that toxicity decreases with weathering (Neff et al., 2000; Perkins et al., 2003; Barron et al., 2005; Di Toro et al., 2007), no clear pattern emerged for estimating a specific increase or decrease in oil toxicity, perhaps because the studies used different weathering treatments. For instance, using the heating and distillation method to simulate weathering is not environmentally realistic (Neff et al., 2000; Perkins et al., 2003; Barron et al., 2005; Bellas et al., 2013). Generally, weathering removes the more volatile, low-molecular weight and potentially high toxic components of the crude oil mixture (e.g. BTEX), leaving behind the much higher molecular weight and potentially less toxic ones such as phenanthrene (Di Toro et al., 2007).

In other words, change in toxicity because of weathering can be viewed in terms of relationship between toxicity and aqueous solubility of oil components. The concept of toxic potential explains that lower log (K_{OW})[10] compounds are more toxically potent than higher log (K_{OW}) chemical; thus, as weathering removes the lower log (K_{OW}) chemicals, they are replaced with the higher log (K_{OW}) chemicals (increase in log (K_{OW}) causing decrease in solubility and by extension decrease in toxicity). Thus, the replacement of more toxically-potent compounds with less toxically-potent compounds lowers the toxicity (Di Toro et al., 2007). Hence, long-term accumulation of compounds due to weathering processes can increase toxicity if the higher log (K_{OW}) components become dominant in an aqueous medium. As a result, BTEX and naphthalene have acute toxic effects, due to their low log (K_{OW}) and high solubility in water (Zhibing et al., 2010)

Conclusion

A better way to assess TPH is by EC number in which hydrocarbons are grouped according to similarities in boiling point, volatility, viscosity, length

[10] Log (k_{ow}): octanol /water partition coefficient.

of carbon chain etc. This way toxicity and threshold values are assigned for risk assessment. Lack of baseline data in Nigeria (UNEP, 2011) made it necessary to review risk assessment models and recommendations from the United States of America and the United Kingdom. The exposure equations and recommended values can serve as a baseline for human health risk assessment in Nigeria, although the rates may differ remarkably from a Nigerian perspective because of weather conditions, work ethic and non-use of protective clothing at work. For instance, wearing less clothing can promote dermal contact, but excess heat requires exposing parts of the body for ventilation when at work. This can lead to direct and indirect transfer of substances from clothes to skin areas like hands, fore-arms, upper hands, front torsos, back torsos, upper and lower legs and the face (Cohen-Hubal et al., 2000).

Having identified exposure routes and the procedure for assessing human exposure, the following chapter reviews some GIS-based techniques used to map areas susceptible to pipeline hazard.

CHAPTER 5

LITERATURE REVIEW OF RELEVANT METHODOLOGIES

5.0 Introduction

This chapter reviews relevant methods and techniques utilised to achieve the aim of the thesis. The use of a Geographic Information System (GIS) as a spatial modelling tool and Multi-Criteria Decision Making (MCDM) in the decision-making process is reviewed. Following their successful integration and implementation in a spatial decision support system, the robustness of these techniques was extended to mapping pipeline hazard radius. Because pipeline accidents have consequences on human life and the environment, the PIR, HCA and Location Class concepts were reviewed with a view to demonstrating their purpose in pipeline integrity management and hazard mitigation. These techniques and methods provide the framework with which land use hazard areas and high consequence areas were mapped.

5.1 Geographic Information System/Science

Given that GIS is a computer-based system for storing and processing geographic data, it is effective in information handling. The science part of GIS determines how results add value to the interpretation of geographic application, wisdom, knowledge, and theory underpinning the procedure taken (Longley et al., 2011).

It is difficult to provide a definitive definition for GIS, because different fields in which GIS have been used align the definition to reflect their fields or purpose for which GIS was used. However, most definitions accept the fact that GIS is a computer-based system that uses *"spatially referenced geographical data … to perform analytical tasks"* (Heywood et al., 2006).

Chang (2010, p.1) defined GIS as "*a computer system for capturing, storing, querying, analysing and displaying geospatial data*." Kennedy (2009) described GIS as "*an organised collection of computer hardware and software, people, money, and organisational infrastructure that makes possible the acquisition and storage of geographic and related attribute data, for the purpose of retrieval, analysis, synthesis, and display to promote understanding and assist decision making.*" Maguire's (1991) work reviewed several definitions from different authors; the difference in most can be traced to the background of the authors (Heywood et al., 2006), as well as the application to which GIS was used (Nathanail, 1994). However, regardless of the orientation of a definition, there is a consensus lending credence to GIS's capability to perform the functionalities described in Table 5-1.

Table 5-1: GIS functionalities.

Function	**Description**
Data input	Datasets are introduced into the system through a keyboard, mouse, digitiser, scanner, or direct transfer from another computer file. Depending on the package, some datasets may require conversion to make it suitable for use (Heywood et al., 2006).
Data storage and management	The database allows updates, expansion, retrieval, and information sharing among users (Nobre et al., 2009). The two data storage models are raster and vector (Nathanial, 1994; Heywood et al., 2006; Chang, 2010).
Data manipulation and analysis	This process underpins GIS's capability to perform spatial and non-spatial analysis. The results may be an outcome of a problem, or an input for further data manipulation (Heywood et al., 2006).
Data output	Output is presented in a form of maps, tables, or diagrams (Heywood et al., 2006), which can be in hard-copies, softcopies or an on-screen display.

	Hardcopies are printed on paper, e.g. maps, tables and graphs, while soft-copies are displayed on screens or transmitted to other computers as files. A standard GIS output has a title, legend, north arrow, scale and symbology (Kraak and Ormeling, 2010).

5.1.1 Types of GIS Data

Data are a valuable component of all GIS projects and can sometimes account for up to 90% of the project cost (new), leaving as little as 10% for hardware and personnel (Uluocha, 2007). All data held in GIS is geo-referenced and recorded as spatial or non-spatial data (Wise, 2002). A relational database of spatial and non-spatial (attribute) data (see Figure 5-1) is required for any GIS analysis and presentation.

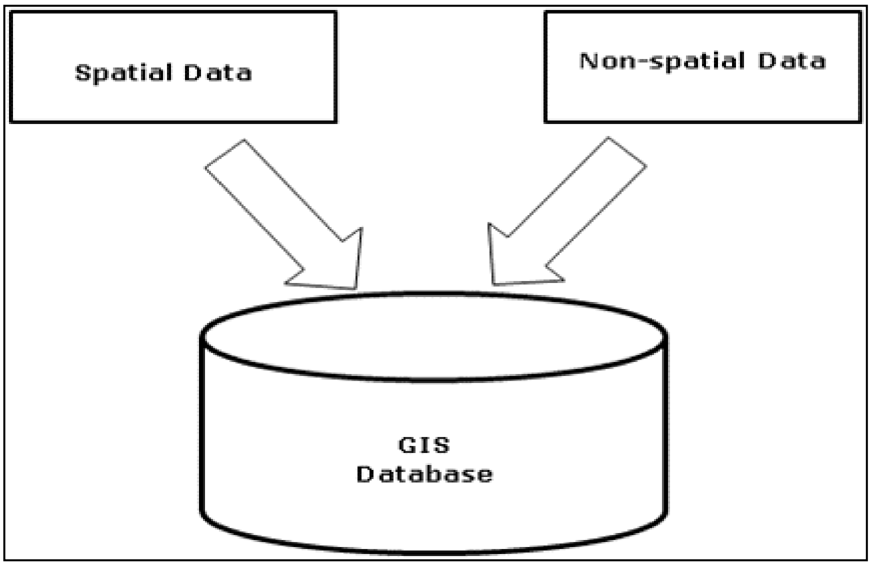


Figure 5-1: Data components in a GIS database.

Spatial datasets are graphical representations of true world features constructed to show size (extent, dimensions), shape, location, and relationship with neighbouring features (Uluocha, 2007). Non-spatial datasets, also known as attribute data, contain information relating to specific features contained in the spatial data component (Wise, 2002; Uluocha, 2007). Attribute data are stored in tables or spread-sheets defining the characteristics of elements associated with the spatial feature, e.g. name, address, history, type, function etc.

Raster and vector are two formats for representing spatial features in GIS (Chang, 2010; Longley et al., 2011). They format code fields and discrete objects to conceptualise a geo-referenced true world situation. Longley et al. (2011) opine that the raster format is more of field objects while vector is of discrete objects (discrete objects represent features with well-defined shapes and a precise location).

5.1.2 Raster and Vector Models

Information in raster format is presented in a series of grids or cells, with each cell containing a value that describes the characteristics of the feature being represented (Chang, 2010; Longley et al., 2011). According to Chang (2010), time and energy are invested in developing better data compression and structure for raster data. Usually, raster data are gathered from remote sensing, satellite images, digital orthophotos, scanned maps, and graphic files (Chang, 2010; Longley et al., 2011). Computer memory-wise, raster consumption of memory depends on data resolution. A high resolution requires a small cell size for detailed information (Kraak and Ormeling, 2010) but occupies large memory space.

Vector data on the other hand consist of points and lines based on x-, y-coordinates referred to as polylines and polygons (Longley et al., 2011). Due to extensive research on vector data, new models have been introduced unlike in raster. For example, ESRI introduced new vector models with every new software package developed, i.e. Arc/info came with coverage; ArcView came with shapefiles; and ArcGIS came with a geodatabase (Chang, 2010). The coverage and shapefiles are examples of a georelational data model using split systems to store geometric and attribute data. In contrast, a geodatabase is an object-based data model, which stores geometric and attribute data in a single file system (Wise, 2002; Chang, 2010). In vector data format, points are connected to form a line or arc, while raster consists of grid cells with values describing the feature each cell represents (Wise, 2002; Kraak and Ormeling, 2010). Langley et al. (2011) list some application advantages of raster and vector data files (table 5-2)

Table 5-2: The advantages of raster/vector (Langley et al., 2011).

Issue	Raster	Vector
Volume	Depends on cell size	Depends on density of vertices
Source	Remote sensing, imagery	Social and environmental data
Application	Resources, environmental	Social, economic, administrative
Software	Raster GIS, image processing	Vector GIS, automated cartography
Resolution	Fixed	Variable

5.2 Multi-Criteria Decision Making (MCDM)

Multi-Criteria Decision Making (MCDM) or Multi-Criteria Decision Analysis (MCDA) are terms used interchangeably to the describe problem-solving procedure in which sets of alternatives are evaluated on the basis of conflicting criteria (Malczewski, 1999; Gomez and Lins, 2002; Chakhar and Mousseau, 2008). MCDM emerged as a procedure in economic planning in the early 1970s (Carver, 1991). The procedure allows decision makers to introduce qualitative and subjective information during evaluation or solution operation (Ascough II et al., 2002). The approach depends on available information and interpretation of alternatives based on scientific or subjective, certain or uncertain, deterministic or probabilistic and/or fuzzy theories (Malczewski, 2006).

In decision-making analysis, values are articulated in the form of goals initiated by individuals or groups of decision makers. Invariably, decision making involves making a choice from multiple conflicting options (Malczewski, 1999), by evaluating each choice (alternative) against a set of measurable criteria, i.e. yes/no, or present/absent (DurgaRao, 2005). The outcomes of decision alternatives are organised in rows and columns, the rows representing decision alternatives while the columns represent criteria. The values in the intersection (of rows and columns) are outcomes that predict interaction of the decision alternatives (Ascough II et al., 2002).

Thus, the main goal of MCDM is to provide decision makers with the capacity to make decisions using past (experience) or present (available) information in predicting future outcome (Malczewski 1999; Monprapussorn et al., 2007). This is relevant in sustainable development as the process allows decision makers to predict possible future risk, and/or vulnerability of a particular population to hazards from natural and human action (Monprapussorn et al., 2007) using experience and knowledge from past occurrences. Naturally, the data is transformed so that the result and participation in the decision-making process is transparent (Store and Kangas, 2001) and auditable.

MCDM is divided into Multi-Attribute and Multi-Objective Decision Making based on single or multiple decision problems, which can be deterministic, probabilistic, and/or fuzzy. The difference between Multi-Attribute Decision Making (MADM) and Multi-Objective Decision Making (MODM) "*is based on* *the classification of evaluation criteria into attributes*[11] *and objectives*[12]*.*" The multi-objective approach is mathematically oriented, while the multi-attribute decision making is data oriented (Malczewski, 1999; Chakhar and Mousseau, 2007). Multi-attribute decisions are discrete because they are predetermined and have a limited number of alternatives, while a multi-objective decision is continuous assuming that the best solution is anywhere among the alternatives (Malczewski, 2006). Consequently, some writers refer to multi-attribute and multi-objective problems as discrete and continuous decision problems respectively (Hwang and Yoon, 1981; Goicoechea et al., 1982 cited in Malczewski, 2006).

MODM defines a set of alternatives in a decision model of two or more objectives with a constraint set on the variables. An objective represents a statement regarding the desired state of a system and the direction for improving one or more of its attributes to achieve completeness (Malczewski, 1999). The multi-objective model is done by converting objectives into a single objective problem and is solved using either (i) linear-integer programming, (ii) goal programming/reference point algorithms, or (iii) heuristic search/evolutionary/genetic algorithms (Diamond and Wright, 1988; Malcweski, 2006). This research is concerned with MADM; therefore, only the aspect of MADM is discussed.

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[11] Attributes are properties of elements of a real-world geographic system; they are measurable quantity or quality of a geographic entity or a relationship between geographic entities.

[12] An objective is a statement about a desired condition under consideration, an indication of the direction of improvement for one or more attributes.

5.2.1 Multi-Attribute Decision Analysis (MADA)

Multi-attribute decision analysis uses measurable attributes to quantify or qualify entities representing properties of an *"element of a real-world… system"* (Malczewski, 1999). The use of this approach in solving practical MADA problems produces consistent outcomes, which help decision makers understand the implication of their decision and promote confidence in the decision maker's ability to make a better decision (Manoharan et al., 2011). Over the years the multi-attribute evaluation method has been implemented in the GIS environment through Weighted Linear Combination (WLC) (Eastman et al., 1995; Jiang and Eastman, 2000), ideal point methods (Jankwoski, 1995; Malczewski, 1999), concordance analysis (Joerin et al., 2001), and the analytical hierarchy process (Boroushaki and Malczewski, 2008; Geneletti, 2008). In this research, WLC and the analytical hierarchy process were used; these are discussed in the following subsections.

5.2.2 Weighted Linear Combination (WLC)

This approach combines Boolean overlay operators like intersection (AND) and union (OR). WLC is based on the concept of weighted averaging, in which a decision maker assigns weights of relative importance to attributes in a map layer (Malczewski, 1999; Eastman, 2003 cited in Wood and Dragicevic, 2007) to obtain scores for alternatives. By multiplying weights of an attribute on a scale, weights are produced for the other attributes. The overall score is then calculated and the alternative (attribute) with the highest weighted score is chosen as the best. It is imperative that the sum of all weights be equal to one (Durga Rao, 2005). The overlay technique allows map criterion layers (input maps) to be combined into one composite map (output map) in raster or vector format. Some GIS systems have an in-built routine for the WLC method; however, there are fundamental limitations linked to this procedure, but Jiang and Eastman (2000) offered that the Ordered Weighted Averaging (OWA) approach could provide an extension for generalisation of the conventional map combination method in GIS.

5.2.3 Analytical Hierarchy Process (AHP)

Another multi-attribute technique incorporated in the GIS procedure is the AHP, developed by Saaty (1980); the process allows experts to develop prioritisation strategies for judging criteria and alternatives in a system (Saaty, 1980, 1987, 2008; Dawotola et al., 2010). The method is used in two distinctive ways; first, it is used to derive weight for attribute map layers that are then combined with other attribute layers in a procedure similar to the linear addictive combination method (Boroushaki and Malczewski, 2008); secondly, it is used to aggregate priorities at each level of the hierarchy of alternatives, so that corresponding criteria weights can be obtained (Dai et al., 2001; Store and Kangas, 2001; Chang et al., 2008; Nobrega et al., 2009). The AHP procedure ranks alternatives in such a manner that the best alternative that meets the goal is selected. The goal is broken down (decomposed) into sets of criteria (goal, objective, and attributes), and the three major steps are:

i) AHP hierarchical design;
ii) pairwise comparison of elements; and
iii) priority rating (Boroushaki and Malczewski 2008).

This approach is suitable for solving raster-based problems with a large number of alternatives, especially where pairwise comparison of alternatives is not possible (Eastman et al., 1995).

5.2.3.1. Pairwise Comparison

Thomas Saaty developed this technique for MADA in the context of AHP. Pairwise comparisons incorporate ratio matrix (Malczewski, 1999; Saaty, 1980, 2008) to compare two components according to the following steps (Boroushaki and Malczewski, 2008):

i) develop a comparison matrix for each level of the hierarchy from top to bottom;
ii) weight computation for each component in the hierarchy; and
iii) consistency ratio estimation.

Table 5-3: Saaty pairwise comparison scale (Malczewski, 1999).

Degree of Importance	Definition
1	Equal importance
2	Equal to moderate importance
3	Moderate importance
4	Moderate to strong importance
5	Strong importance
6	Strong to very strong importance
7	Very strong importance
8	Very to extremely strong important
9	Extremely important

The technique scores items from 1 to 9 by assigning relative preference to components in the hierarchy according to: i) the criterion that is more important; and ii) how important is the criterion relative to the lesser one. The allocation could fall in the region of “less important” or “more important” in the rating scale presented in Table 5-3.

5.2.3.2. Pairwise Matrix

The construction of a pairwise matrix involves assigning a preference score to every criterion and comparing two at a time (Malczewski, 1999) using

Saaty’s scale (Table 5-3). To derive weights for the criteria, the following approach is followed:

i) the values in each column of the matrix are summed up;

ii) the column score is divided by the column total to normalise the value; and

iii) normalised values on each row are summed and divided by the number of criteria to obtain an average estimating a criterion’s relative weight (Malczewski, 1999).

5.3 Integrating MCDM in GIS

MCDM can be a standalone tool for handling spatial problems in data models like raster, where cells (pixel) are the alternative (choice), and vector, where alternative evaluation is based on points, lines and polygons. The actions are in stages, i.e. i) creation of a suitability map layer, ii) ranking and ordering the alternatives (Makropoulos and Butler, 2006; Chakhar and Mousseau, 2008). Multiple criteria overlay (proposed by Jankwoski, 1995; Gomez and Lins, 2002; Gomez-Delgado and Tarantola, 2006; Meyer and Grabaum, 2008; Meyer and Haase, 2009) identified physical, economic, and environmental criteria as major determinants in deciding the type of overlay technique in geographic analysis. The common operation employs Boolean logical operators “AND”, “OR”, and “NOT”, corresponding to intersection and union. If the decision factors involve different levels of significance, weighted overlay is used but a special score aggregation procedure is performed in order to get the desired result (Chakhar and Mousseau, 2008). Jankowski (1995), Ascough II et al. (2002) and Gomez and Lins (2002) proposed two strategies for integrating GIS with the MCDM technique i.e. loose coupling and tight coupling.

5.3.1 Loose and Tight Coupling

i. *Loose coupling:* files are exchanged between software performing separate tasks. Criteria selection is done in a GIS environment while criteria evaluation is done on an MCDM platform then transferred back to GIS for visualisation. The loose coupling has three stage-linked modules (Figure 5-2).

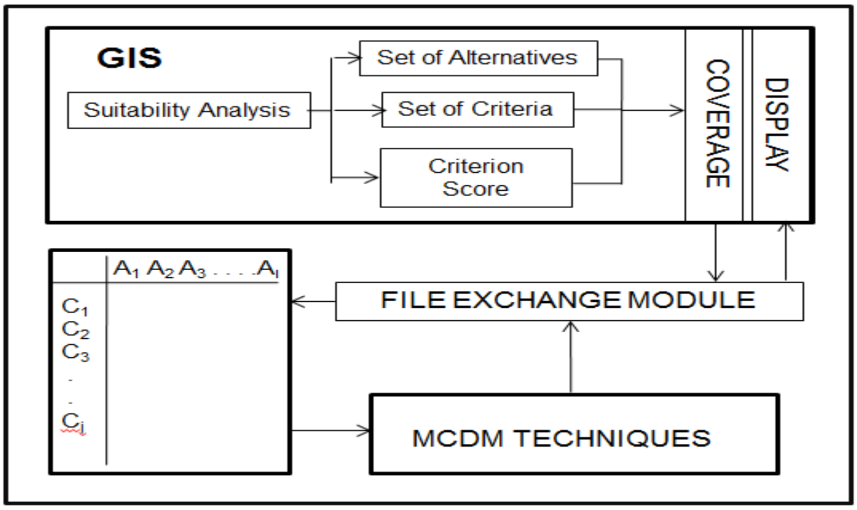


Figure 5-2: The loose coupling GIS and MCDM (Jankowski, 1995).

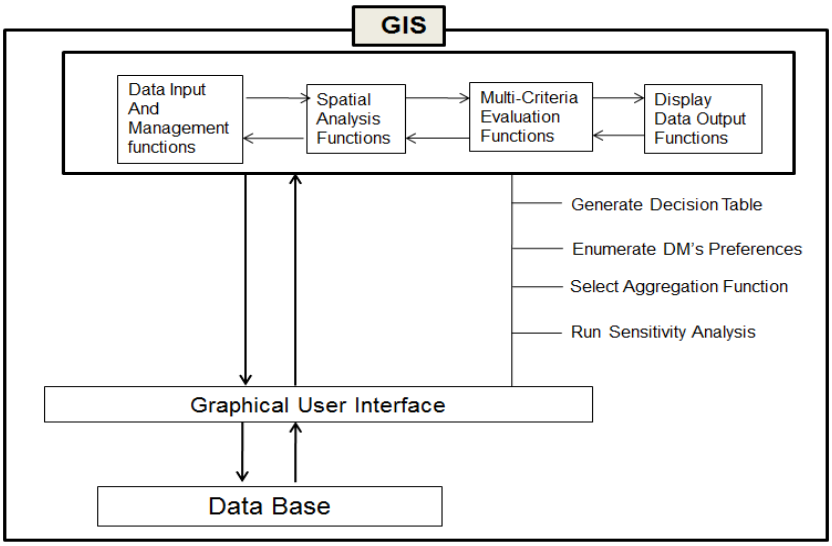


Figure 5-3: The tight coupling architecture for GIS and MCDM (Jankowski, 1995).

i. *Tight coupling:* combines both GIS and MCDM on a common platform, providing a shared database and common user interface for GIS functions. The functions are: a) decision table generation;

b) enumeration of decision maker preference; c) selection of aggregation strategy; and d) sensitivity analysis. Rather than use the MCDM technique elsewhere (as in the loose coupling), a command in the GIS user interface is issued to create multiple criteria evaluation as a GIS tool. The advantage is that all functions are embedded on one GIS platform, thereby avoiding data exchange. Figure 5-3 describes the architecture of a tight coupling technique described in Jankwoski (1995).

Zhou and Civco (1996) identified some problems with implementing MCDM in GIS, one of which is the inaccuracy, imprecision and ambiguity encountered when performing data input for a GIS multi-criteria evaluation procedure. However, the problem can be solved by combining the GIS multi-criteria procedure with sensitivity analysis (Lodwick et al., 1990), error propagation analysis (Hevelink et al., 1989) and fuzzy logic to deal with imprecision and ambiguity in the data input. Another problem concerns criteria standardisation; there are many standardisation methods in GIS-based multi-attribute analysis, and each has tendency to produce a different pattern. Thus, the best approach for addressing the standardisation problem is linear transformation, even though there is no theoretical or empirical justification for doing so (Jiang and Eastman, 2000).

Given that criteria evaluation is a proxy measure of the decision maker's preference, a difference in criterion value will reflect the level of preference. If the values change or become distorted by the transformation process, the intra, and inter-attribute of the preference structure may be compromised (Jiang and Eastman, 2000). Thus, it is difficult to say which method is best suited for a particular problem, since there are varieties of

MCDM rules that studies have shown generate considerably different patterns (Carver, 1991; Heywood et al., 1993). For instance, Heywood et al. (1993) used the multi-criteria procedure in IDRISI and SPANS (GIS software) to evaluate housing suitability, and concluded that the degree of agreement in the result was 34.8%. Therefore, Carver (1991) introduced the application of two or more methods to dilute the effect of technique bias.

5.3.2 GIS-Based MCDM Methods

The integration of MCDM techniques in GIS improved the conventional method of performing map overlay in decision analysis (Malczewski, 1999), by transforming spatial and non-spatial data into decision output. The MCDM procedure defines the relationship between data input and data output according to the decision-maker's preference, data manipulation and decision rules. Accordingly, two considerations are sacrosanct in spatial MCDM (Ascough II et al., 2002):

i) the capability of GIS to perform data acquisition, storage, retrieval, manipulation and analysis; and
ii) the capability of MCDM to combine geospatial data and the decision-maker's preference into one (alternative) decision.

Criterion evaluation is a general term in multi-attribute criteria decision problem (Malczewski, 1999); some refer to them as decision criteria or factors or scores (Carver, 1991). Attributes contain measures for assessing the level at which an alternative has met the criteria; evaluation criteria in GIS are presented as thematic maps or data layers (Malczewski, 1999, 2006).

Decision attributes are expected to conform to certain requirements such as measurability (easy to assign numerical values), must clearly indicate to what degree the objective is achieved (unambiguous and understandable to the decision maker), referred to as comprehensiveness of an attribute. Furthermore, according to Malczewski (1999), Burrough and McDonnell, (1998) cited in Store and Kangas (2001), Rashed and Weeks (2003), and Makropoulos and Butler (2006), a set of attribute must be:

i) *operational*: if the attribute is understandable, the decision maker can accurately describe the relationship between the attribute and its level of achievement relative to the overall goal, which can be used constructively in the decision-making process;
ii) *complete*: meaning it must cover all aspects of the decision problem;
iii) *minimised* to the smallest possible form;
iv) *non-redundant*: avoid double counting of decision consequence; and
v) *decomposable*: suitable for partitioning into subsets.

5.3.3 Multi-Criteria Evaluation (MCE) in GIS

The application procedure for MCDM in GIS involves the following steps:

i) *Criteria selection*: is the identification of relevant data layers required for solving a problem. In GIS, these layers are presented as separate thematic layers representing specific features or attributes.

ii) *Criterion score standardisation*: this allows data measurement on similar units or scales. By standardisation, the data layers are converted to similar comparable units, often standardisation in raster is done by linear stretching, to re-scale between maximum and minimum value. This way beneficial factors can be represented "*on a scale that gives a high value to high benefit and low value to low* *benefit, whilst cost factors are represented on a scale that gives a low value to high cost and a high value to low cost*" (Heywood et al., 2006).

iii) *Weight allocation*: this reflects relative importance of the data layer to the goal. Thus, data layers attract the highest weight score if it is considered important. Weighting can be in percentage or from zero to one.

The final stage is the application of the MCE algorithm, where standardised scores are multiplied with weights assigned to each thematic layer to produce a final score/map on which the decision is based.

5.4 GIS and MCDM Application in Spatial Decision Making System

MCDM and GIS method has been successfully applied by decision makers in spatial decision making (Malczewski, 1999). GIS enables decision makers to define a set of criteria in an overlay process (Heywood et al., 1993), while multi-criteria decision analyses evaluate the alternatives so that a compromise can be made (Malczewski, 1996). The efficiency of map exploration with GIS and MCDM analysis became a viable platform for decision makers to understand the link between spatial related problems and human behaviour (Malczewski, 2006).

5.4.1 Application of GIS-MCE Method in Spatial Decisions

The development of applications and analytical methodologies that incorporate human behaviour, socio-economic and environmental variables in decision making is widely used in land use planning research (Meyer and Grabaum, 2008). GIS spatial multi-criteria analysis is a product of such development, integrating GIS with multi-criteria analysis to allow geographically defined sets of alternatives to be evaluated (Jankowski, 1995; Malczewski, 1999; Girard and De Toro, 2007). As a result, GIS spatial analysis with multi-criteria analysis have advanced in recent years to support decision making and criteria evaluation in different research fields. Store and Kangas (2001) used GIS-based MCE to improve habitat suitability evaluation for large areas. The technique produced suitability indices for large areas and species without empirical statistical data or suitability models. Joerin et al. (2001) also used GIS-MCDM to develop a land suitability map for housing in Switzerland from multidisciplinary data sources. The map lends credence to negotiation and is useful for dealing with conflict in land-use planning. By integrating GIS with an outranking multi-criteria method (ELECTRE-TRI) they harmonised different criteria to assess land suitability for housing, even when the criteria were heterogeneous (scales). Integrating GIS with multi-criteria analysis using AHP was applied in selecting the location for housing sites in a complex scenario involving physical, economic, social, environmental and political parameters that were capable of generating conflicts (Al-Shalabi, 2006).

The approach has also been used to identify potential conflicts emanating from heterogeneous land uses. Brody et al. (2006) applied multi-criteria spatial decision tool in identifying potential conflict areas associated with oil and gas activities in the coast of Texas. The study identified sites with the least contention for oil and gas production and activities within the leased tracts, or in selecting a comparatively advantageous landfill site from others according to specified factors (Gomez-Delgado and Tarantola, 2006; Chang et al., 2008). Carver (1991) used GIS-MCE to evaluate alternatives for nuclear waste sites, while Monprapussorn et al. (2007) evaluated possible routes for hazardous waste transportation. Dai et al.

(2001) demonstrated the suitability of GIS-based MCE for developing a suitability map category using algorithms that combine factors in weighted linear combination to integrate multiple data layers in evaluating urban land-use planning for Lanzhou City in China. Genelletti and Duren (2008) on the other hand believe that MCE can be transparent to facilitate communication with stakeholders.

The multi-dimensional and multi-disciplinary requirement of environmental, socio-economic and management risk at different spatio-temporal scales in natural hazard risk-based decision making was demonstrated in a GIS-MCE methodology. An MCE-RISK by Chen and Denison (2011) utilised the WLC method to resolve group and individual decision making in risk management decisions for hazard communities. The methodology assists risk managers and the public to comprehend the complication and cost of hazards to susceptible communities (Chen et al., 2001). Lapucci et al. (2005) also integrated spatial multi-criteria AHP with knowledge discovery in database (KDD) to evaluate and analyse woodland fire risk. The AHP performed damage evaluation and data mining to determine the possibility of fire outbreak while the KDD assessed fire risk.

Meyer and Haase (2009) in their work developed a GIS-based multi-criteria flood risk assessment. In other related studies, an MCE method was used to analyse flood vulnerable areas in northern Turkey (Yalcin and Akyurek, 2004). In the study, MCE was integrated in GIS using seven spatial criteria layers in ArcView 8.2 to generate criterion values. The criteria map was then converted to a grid for mathematical manipulation with a map calculator, after which the criterion was ranked to match the decision maker's preference. The Pairwise Comparison Method (PCM) was interfaced for calculating weights from input preferences in a Visual Basic

Application (VBA) embedded in ArcGIS 8.2. At the end, composite maps were developed with Boolean operators, Ranking and the PCM.

Carver (1991) also evaluated several alternatives against the effectiveness of three MCDA techniques for best nuclear waste location, the result being put through sensitivity analysis. The purpose was to examine how a choice can be affected by changes in criteria weights. This is useful in a situation where there are uncertainties in defining importance for the factors (Lodwick et al., 1990; Rashed and Weeks, 2003; Yalcin and Akyurek, 2004; Gomez-Delgado and Tarantola, 2006).

5.4.2 Multi-criteria Decision Evaluation (MCDE) in Pipeline Management

Pipelines are an economical and effective means of transporting dangerous and flammable substances. Hence several methods have been applied to identify and estimate risks using MCDE-AHP (Brito and de Almeida, 2009; Alencar and de Almeida, 2010; Batzias et al., 2011). Yet there is a lack of consensus among researchers and professionals on the best model for assessing pipeline-associated risks (Brito, de Almeida and Mota, 2010). Dey (2002, 2010) developed an integrated framework using an analytical hierarchy process and multi-criteria decision-making technique to assess cross-country pipelines based on technical, socio-economic and environmental alternatives for oil pipeline construction in India. Good pipeline system integrity management depends on monitoring, detection, and maintenace of deteriorating pipelines. To improve this, Batzias et al. (2011) developed a fuzzy multicriteria analysis for selecting the best biosensor design appropriate for a targeted analyte and micro-environment for prompt and reliable leak detection. Although pipelines are safe and economical, the catastrophic consequences linked to pipeline accidents motivated Alencar and de Almeida (2010) to propose a multicriteria decision model using the multi-attribute utility theory to incorporate decision makers' behaviour in assessing human, financial and evnironmental risk dimensions in a multidimensional risk assessment framework for pipelines transporting hydrogen. In a similar approach Brito and de Almeida (2009) developed a risk-based ranking of natural gas pipeline segments using the multi-attribute utility theory, while Lins and de Almeida (2012) incorporated the decision maker's preference in decision structure using MCDE to assess risk in hydrogen pipelines also by ranking pipeline segments in terms of risk. Dawotola et al. (2010) on the other hand developed a decision-based method for managing oil and gas pipeline risks, using the MCDA framework and AHP to prioritise pipelines for design, construction, inspection and maintenance.

5.5 Pipeline Hazard Proximity Determination

Oil pipeline spill is a form of hazard along pipeline ROWs which constitutes risk to communities close by. While several methods like Pipeline Impact Radius, Pipeline Location Class and simple buffering have been used to determine potential vulnerable areas, the Thiessen polygon uses hypothetical boundaries constructed around centroids to determine area and proximity. This section reviews each of these approaches.

5.5.1 Area Demarcation Based on Thiessen Polygon

Thiessen polygon is a GIS interpolation technique created by subdividing lines joining the nearest neighbouring points with perpendicular bisectors, and triangulating the same points with connected straight lines to form a series of triangles (triangulation). The side of each triangle is then bisected at midpoint by perpendicular lines to make a Thiessen (Chang, 2010; Heywood et al., 2011). Thiessen polygon is an abrupt interpolation with strong sharp boundaries between polygons (Heywood et al., 2011); it is assumed that any area in a polygon is closer to the centroid (point) than any other (Ratcliffe and Taniguchi, 2008). Figure 5-4 shows the transformation of points to Thiessen polygons; clearly the area of each Thiessen polygon is closer to the centroid on which the polygon is drawn (Teerarojanarat and Tingsabadh, 2011). The red lines represent Thiessen polygons while the black represent a Triangulated Irregular Network (TIN) from which Thiessen polygons were propagated.

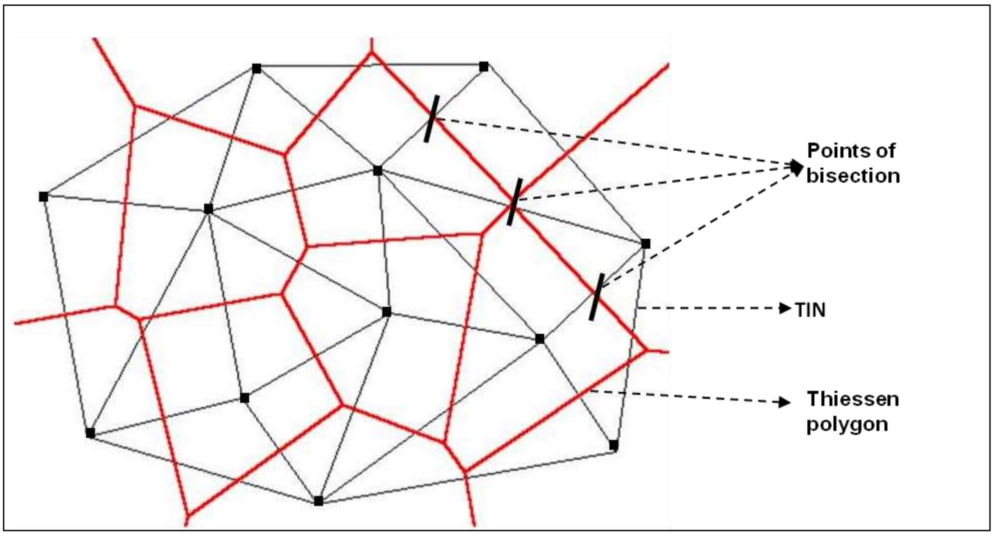


Figure 5-4: Transformation of points to Thiessen polygons.

The size of a polygon depends on the distribution of points; if points are regularly spaced, a regular lattice of square polygons will develop. Irregularly-spaced points on the other hand would result in irregular polygons (Ratcliffe and Taniguchi, 2008; Heywood et al., 2011). Therefore, Thiessen polygons will produce polygons with smaller areas if points are closer, and larger polygons for points farther apart, i.e. "*a larger polygon means greater distances between home locations and a public service provider*" (Chang, 2010).

A Thiessen polygon has been used to establish territories for sets of points, for instance in the transformation of climate station points to watersheds and construction of areas of influence around population centres (Heywood et al., 2011). According to Teerarojanarat and Tingsabadh (2011), the transformation of point features to Thiessen polygon (Voroni network and Delauney triangulation) is done where field data are collected and stored as points. By using this technique, the area of each point is divided proportionately and distributed into regions according to the Delaunay criterion (ESRI, 2004 in Teerarojanarat and Tingsabadh, 2011).

Teerarojanarat and Tingsabadh (2011) used the Thiessen polygon method to demarcate dialect boundaries for Thai central regions and non-central regions because the dialects were presented in points. In addition, Alegria, et al. (2011) applied a Thiessen polygon in landmine impact mapping at settlement level in Colombia. However, since there was no spatial extent (boundary shapefiles), they used a Thiessen polygon to construct boundaries around geocode settlements within existing municipal boundaries. By doing this, they were able to estimate the density of landmine impact for specific settlements according to the area defined by the Thiessen polygon. Ratcliffe and Taniguchi (2008) on the other hand used the Thiessen polygon method to study urban crime by allocating crime events to intersections in a city (representing a centroid) on the basis that "*a point falling within a Thiessen polygon will be closer to the polygon's centroid than to centroids of any other polygon*." Thus, the Thiessen polygon was generated to enclose areas closer to the centroid (intersection). The street intersections form a lattice of polygons enclosing street corners (drug and crime corners), with crime events closer to a particular intersection. Although Ratcliffe and Taniguchi (2008) expressed doubt as to the idealness of using a Thiessen polygon to represent boundaries because the size of polygons is influenced by space between points (centroid), a Thiessen polygon is better than simple buffering because it eliminates the introduction of "subjective knowledge or experience" by the user.

5.5.2 Pipeline Impact Radius (PIR)

According to the Pipeline and Hazardous Material Safety Administration (PHMSA) of the US Department of Transportation, discharge from pipeline failure not only affects human health and safety, it also causes environmental degradation and damage to properties. Hence, pipeline safety experts have developed the concept of "pipeline Impact Radius" and "High Consequence Area" to determine places where a pipeline hazard can cause significant adverse effects. Thus, a designated PIR buffer is an estimated distance beyond which humans and ecological receptors have about 90% chance of survival (US Department of Transportation, 2011). Experts and regulators in the USA developed the procedure for periodic integrity monitoring of pipeline systems, and for protecting human health and the environment (Steiner, 2010; U.S. Department of Transportation, 2011). From early 2002, a United States of America law requires pipeline operators to perform regular pipeline integrity assessment every five years on liquid-carrying pipelines and every seven years for natural gas (Kramer, 2013). The perimeter of a PIR is defined by the radius of a circle within which potential failure of a pipeline could have significant impact on people or property base on Equation 5-1 (ASME, 2004; US Department of Transportation, 2010; Kiefner, 2011).

Equation 5-1

$$r = 0.69\ x\ \sqrt{pp}\ x\ pd$$

Where:

r : is the impact radius in feet,

pp : is the pipe pressure in pound per square inch,

pd : is the pipe diameter in inches, and

0.69 is a constant for natural gas.

The formula works out PIR values (Table 5-4) for respective pipe diameters (Kiefnar, 2011) while Figure 5-5 illustrates how HCA are demarcated.

Table 5-4: Pipeline impact radius calculation (Kiefner, 2011).

Diameter *(Inch)*	Pressure *(psig)*	PIR *(fts)*	PIR *(m)*
16″	1,440	419	127.71
30″	1,000	654	199.34
36″	1,000	786	239.57

The potential consequences of natural gas and liquid oil pipeline discharge are different, so are the criteria for establishing HCAs along those pipelines. For liquid (e.g. crude oil) pipelines, the HCAs are defined as populated areas, sources of drinking water and sensitive ecological resources intersecting pipeline buffers. For natural gas pipelines on the other hand, the HCAs are determined by impact zones calculated using Equation 5-1 to estimate possible distance where a gas pipeline explosion could lead to death, injury or cause damage to properties (Pipeline and Hazardous Materials Administration (PHMSA) website.

Consequently, according to the United States Pipeline Safety and Regulatory Certainty Act of 2011, operators are required to maintain up-to-date records of pipelines in HCAs by calculating PIRs along their pipelines, and identifying the population within the impact radius (Kramer, 2013). HCAs are potential impact circles such as in Figure 5-5 containing structures intended for human occupancy or outdoor areas occupied by people.

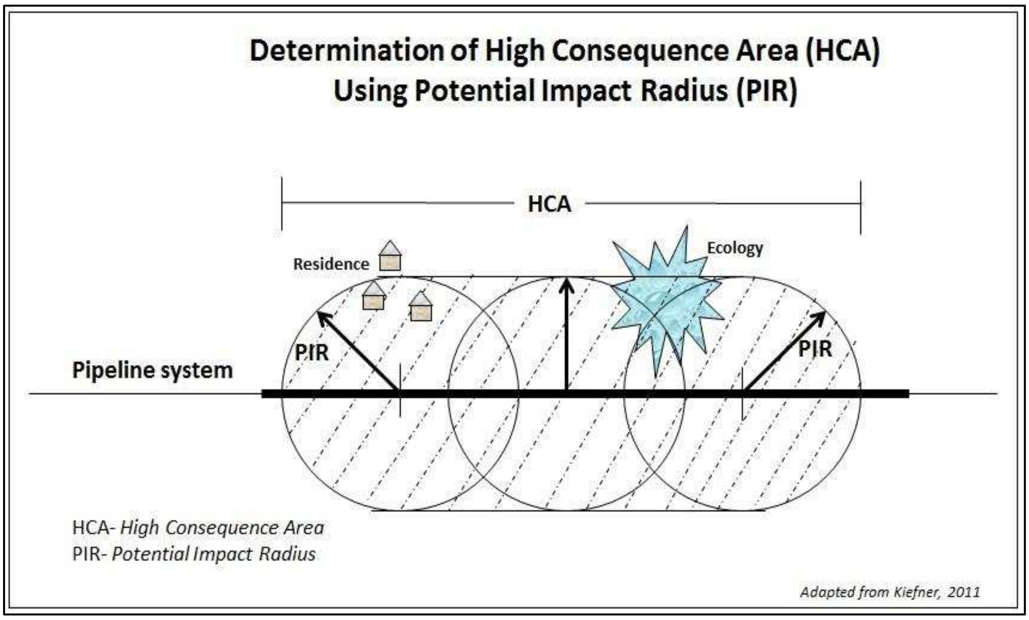


Figure 5-5: Illustrating pipeline PIR showing HCA elements (adapted from Kiefner, 2011).

For proper designation of areas of concern, the US Department of Transportation employs 'Location Class or High Consequence Area' to describe potential impact areas located within pipelines buffers. Thus, while the HCAs identify areas within PIR buffers, the location class uses population density and number of dwellings (buildings) within a fixed distance on either side of a continuous one mile (1.6 km) length of pipeline (Foust and Keppel, 2011), as illustrated in Figure 5-6.

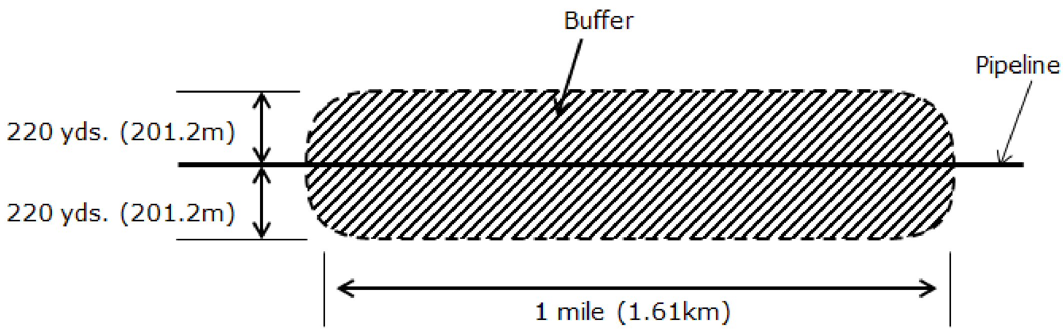


Figure 5-6: Fixed pipeline buffer distance for class location units.

5.5.3 Location Class.

The US Deptartment of Transportation Office of Pipeline Safety categorised class location units into the following categories (49 CFR1.192, 2004):

Class 1: is any location within 220 yards (201.2m) of a pipeline containing 10 or fewer dwellings.

Class 2: is any location within 220 yards (201.2m) of a pipeline containing more than 10 and fewer than 46 dwellings.

Class 3: is any area within 220 yards (201.2m) of a pipeline containing 46 or more dwellings, or the pipeline is within 100 yards (91.44m) of a small, well-defined outdoor area (e.g. playground, place of assembly, recreational area, outdoor theatre etc.) occupied by 20 or more people on at least five days a week for 10 weeks in any 12-month period.

Class 4: includes any area located within 220 yards (201.2m) of a pipeline where buildings with four or more stories above ground are common.

Thus, while the 'Location Classes' use fixed distance, the HCAs are variable distance calculated using a combination of pipe pressure and diameter. According to Kiefner (2011), if the number of dwellings in a class 1 location increases due to increase in population, the existing pipe must be replaced with a pipe greater in wall thickness or its operational pressure reduced. He suggest that the required specification for a typical 30-inch-outside-diameter pipeline for each class location would be: Class 1: 0.375inch, Class 2: 0.450inch, Class 3: 0.540inch and Class 4: 0.675inch. A change in dwelling circumstance would require reciprocal change matching the next appropriate Class in order to accommodate the expansion. Class location is now an integral component in pipeline basic design factors (DF), incorporated in the safety margin for pipeline integrity management (ASME, 2007; Kiefner, 2011). The basic DF is defined by Equation 5-2 based on pressure, pipe grade (yield strength), diameter, and thickness.

Equation 5-2

$$\mathrm{DF} = \frac{\text{Maximum Operating Pressure (MOP)}}{\text{Specified Minimum Yeild Strength (SMYS)}}$$

The higher a DF, the greater the pressure in the pipe and the greater the risk of failure; thus, a lower DF has reduced risk of failure. Consequently, DF=0.8 pipelines tend to be located along low consequence areas, but 'good oil field practice' requires DF=0.3 for HCAs for greater protection of populated areas or where there is a high risk of rupture or spill (Steiner, 2010). Risk of oil spill is the product of the probability and consequence of pipeline rupture (ASME, 2004); suffice to say the higher the probability of risk, the higher the consequence (exposure) for human receptors living in high consequence areas.

From Table 5-5 it is evident that Nigeria has a high tendency of pipeline failure compared with other regions; this is of serious concern to inhabitants of oil communities. Rapid population growth and expansion in open space in the Niger Delta place serious doubt on the workability of the "Location Class" criteria in the region.

Table 5-5: Pipeline failure rate in Nigeria with some world regions (Healy et al., 2004).

Region	Product	Failure Rate per 1000km-years	Year
United States	Gas	1.18	1984-1992
United States	Oil	0.56-1.33	1984-1992
Europe	Gas	1.85	1984-1992
Europe	Oil	0.83	1984-1992
Western Europe	Oil	0.43	1991-1995
Western Europe	Gas	0.48	1971-1997
Canada	Oil & Gas	0.35	N/A
Hungary	Oil & Gas	4.03	N/A
Nigeria	Oil	6.4	1976-1995
Niger Delta (Nigeria)*	Oil	1.14	1999-2005

* Achebe et al. (2012).

Conclusion

It is obvious that the last decade witnessed wide-ranging applications integrating multi-criteria decision making in different disciplines, e.g. urban and regional planning, nature conservation, natural hazard risk management, and transport (Chen et al., 2001; Geneletti, 2004; Malczewski, 2006; Girard and De Toro, 2007).

Suffice to say, the GIS technique is important for solving spatially referenced problems. MCDA on its own provides the technique and procedure for organising, designing, evaluating, and prioritising decision alternatives. GIS-MCDA combines or transforms geographic data to provide a value judgement (preferences) for better decision making (Malczewski, 2006). As a result, the concept of MCDM has been successfully integrated into GIS to enable it to perform complex decision functions in spatial decision making.

The use of GIS in visual representation of a true world situation gives problem solvers instant capability to identify pattern, location, direction, and magnitude of a problem and enable them to make objective decision choices from many. It is these capabilities that the present research extends further by integrating GIS-MCDA into the context of AHP to perform area demarcation using criteria generated from physical, human, and economic attributes to develop an alternative method for mapping PIR.

Pipeline impact is caused by pipeline failure, which leads to the discharge of content into the environment to harm or destroy vulnerable receptors. The impacts being investigated are cumulated oil pipeline spill incidents that span a period of 24 years in an area located in the Niger Delta. The next chapter is the methodology chapter in which a description of methods and approaches adopted in data collection, analysis, presentation, and modelling are discussed.

CHAPTER 6

METHODOLOGY

6.0 Introduction

This chapter describes the methods and techniques used in the research. The investigations utilise secondary and primary data gathered through oral interviews, questionnaire administration, and desktop review of relevant literature materials. The following sections present a description of the study area, source and type of data, interview, and questionnaire process, as well as site inspections and methods of data preparation, processing, analysis, and presentation.

6.0.1 Description of the Study Area

The research investigated locations of oil pipeline spills in the Degema oil fields located in south-western parts of the Rivers state, Nigeria. The area covers approximately 1,939km^2 consisting of about 374 communities and a population of around 1.26 million (NPC, 2002). There are eight local government areas in the area, namely: Abua/Odual, Akuku Toru, Asari Toru, Degema, Emuoha, Portharcourt, Okirika and Obio/Akpor (Figure 6-3).

The vegetation comprises of mangrove forests and fresh water swamps; land availability for cultivation and settlements increases towards the northern area. The land cover can be categorised into three broad zones from north to south, i.e. the freshwater zone, the mangrove swamp and the coastal sand ridge zone (UNEP, 2011). The land areas are generally between 2 and 5 metres above sea level, and soil materials are poor to moderately drained, consisting of sand, loamy sand, clay and sometimes gravels subsoil (Subsection 2.2.3).

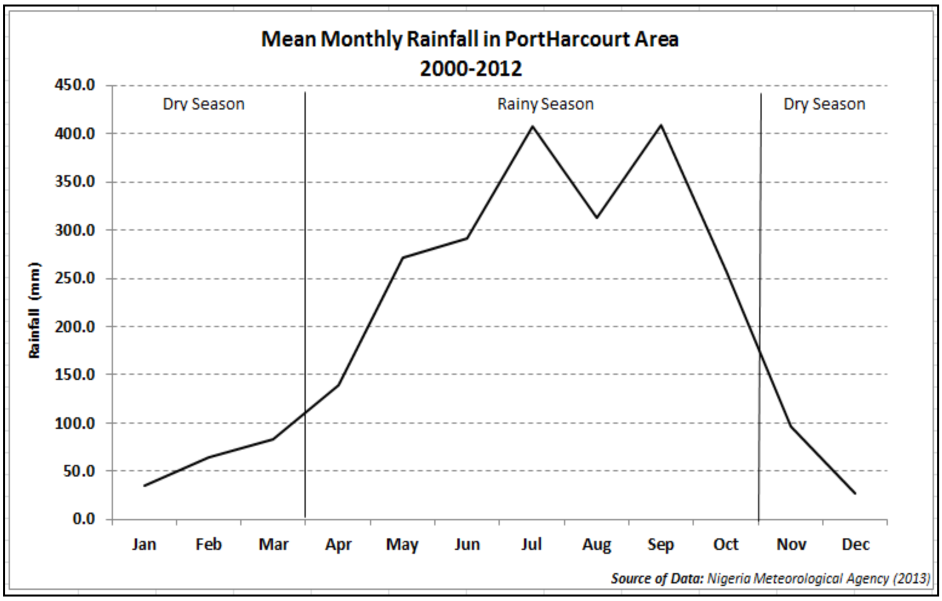


Figure 6-1: Mean monthly rainfall of the study area.

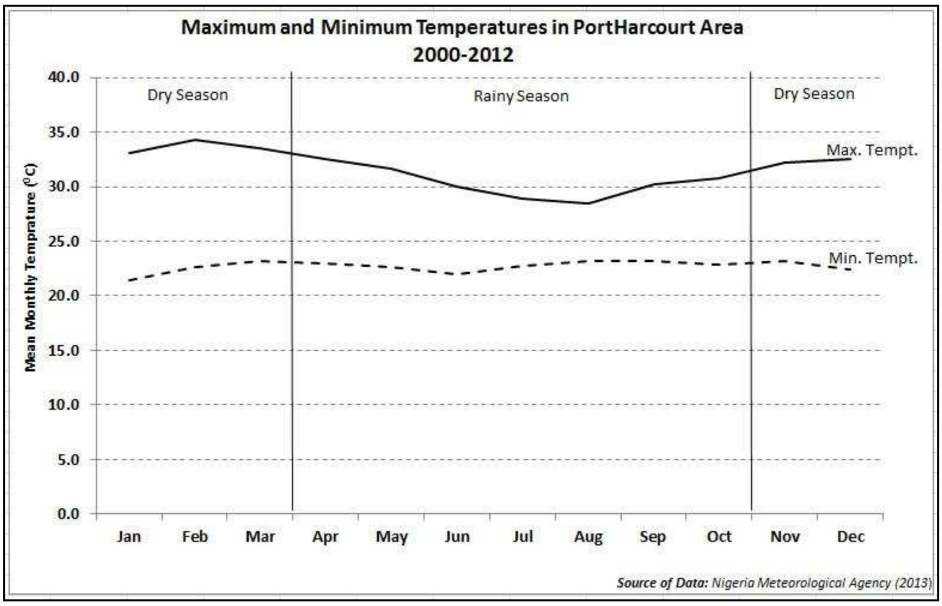


Figure 6-2: Mean monthly temperature of the study area.

The average rainfall and temperature regime in the Port Harcourt zone during the two main seasons in the country are shown in Figure 6-1 and Figure 6-2 above. The data represent average weather conditions in the area over a period of 13 years, recorded and provided by the Nigerian Meteorological Agency in Abuja in March 2013.

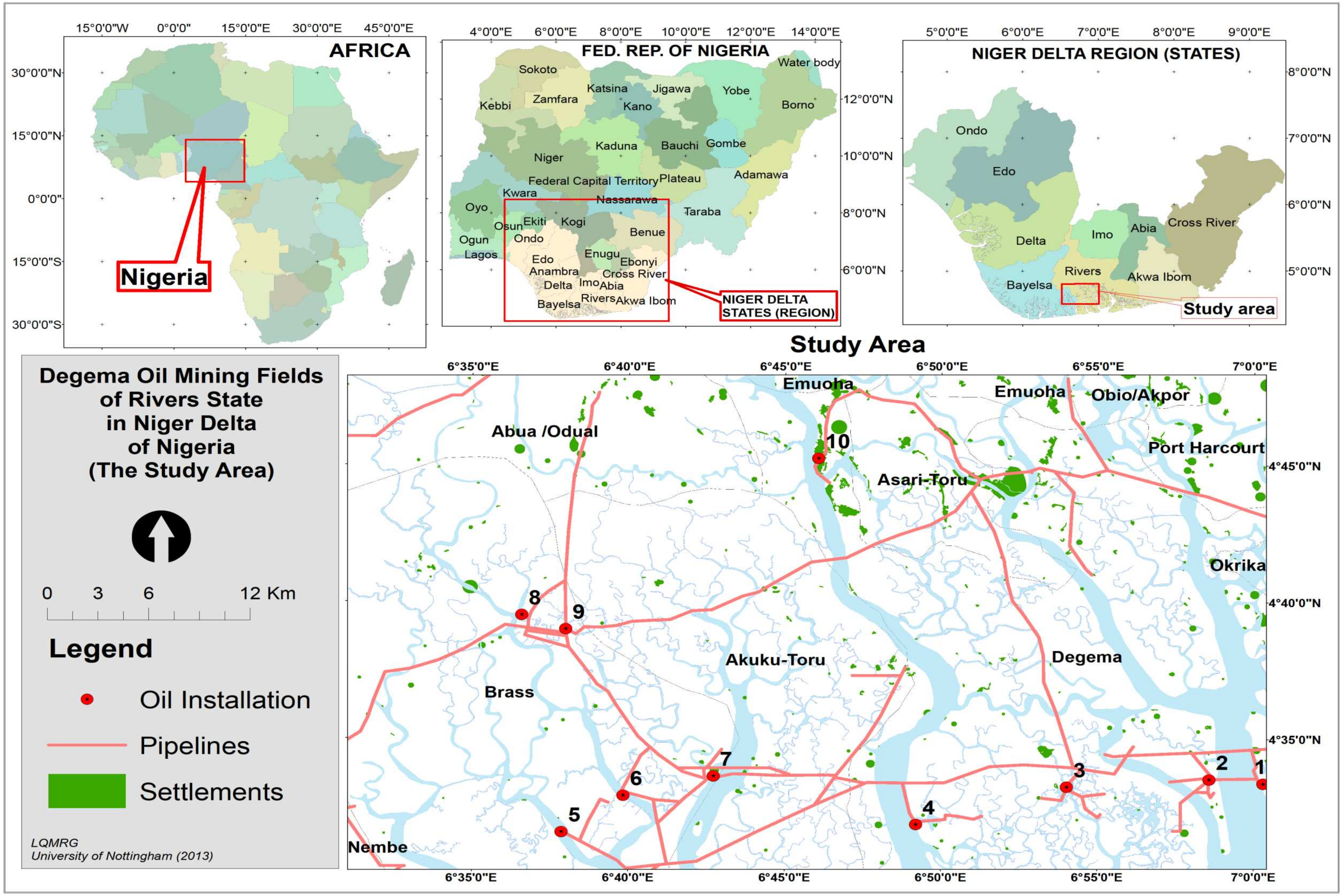


Figure 6-3: The study area showing pipelines and location in the Niger Delta (insert) Africa, Nigeria, and Niger Delta states (prepared by author from digitised image and Map Library).

The high rainfall regime (Figure 6-1), flat terrain, and tide cause recurrent seasonal inundation (Ministry of Environment, 2003; UNEP, 2011), which means contaminated water and sediment can easily spread over "*communities, roads, and farmlands that are partially or totally submerged*" (Gay et al., 2010), as shown in Plate 6-1.

Plate 6-1: A typical village surrounded by oil pollution in the Niger Delta (UNEP, 2011).

The housing structures are usually made of stilt materials, constructed with wood, bamboo and roofed with fronds of raffia palms; the houses hang over creeks and swamps in compensation for scarce dry land. The people travel through the creeks by boat, canoe and practise small-scale subsistence farming, fishing, herding and hunting. Plate 6-1 shows material used in housing construction and homes surrounded by an oil plume, which may likely engulf the community during inundation.

The settlements are mostly small scattered fishing and farming communities located on the banks of water bodies (Ministry of Environment, 2003; Nzeadibe and Ajaero, 2010).

6.0.2 Selection of the Study Area

The choice of study area was influenced by oil spill data made available through the Department of Petroleum Resources (DPR) Lagos, Nigeria by operators of the oil-mining lease (Shell Petroleum Development Company; SPDC). Because the time of the field work and data collection coincided with the UNEP project on assessment of polluted sites in Ogoniland in 2010-2011, the management of SPDC decided to provide data from another oil field located in the western part of the state (Figure 10-3), which is opposite where the UNEP conducted their assignment. Therefore, the author had no input on choice of location, source, and timeframe of oil spill data provided.

6.0.3 Software and Hardware

ESRI GIS software packages 9.0, 9.1, 10.0, and 10.2 versions served as a platform for spatial analysis in vector and raster modelling at various points during the research. Microsoft Excel and SPSS were incorporated as standalone tools for routine statistical analysis and generation of new data for update and/or graphical construction where appropriate. To do this, attribute tables were exported from ArcGIS to Excel and SPSS then back to ArcGIS for spatial analysis in a process described as the loose coupling method (Subsection 5.3.1).

6.1 Source and Type of Data

The spatial datasets were acquired from secondary sources in Nigeria and some were generated or updated by supervised classification and onscreen digitisation by the author using the ArcGIS package versions mentioned in Subsection 6.0.3. The spatial and non-spatial datasets (Table 6-1) were obtained from private and organised sources in Nigeria and online.

Table 6-1: Types of data collected and their sources.

Data	Type	Source
Rainfall and Temperature Port Harcourt Region	2000-2012	Nigerian Meteorological Agency Abuja Headquarters
National and Regional shapefiles -Political -Vegetation -Geology -Land Cover -Communities (Points) -Communities (Polygon) -Oil Spill Site (points) -Pipeline	Spatial	University of Lagos Map Library Scotland UK[13] Private Vendors (Lagos & Abuja) SPDC through DPR
Spot Satellite Image	Spatial	Private Vendor Google Earth
Population -2002 Projection -2005 Census	Communities States/LGs	National Population Commission (NPC)
Bodyweight	Literature	Ayoola et al., (2010)
Interviews Conducted	Oral Questionnaires	May/June 2010 March/April 2013
Site Inspection	Oil Spill Site	June 2010
Photographs		NAPIMS (2010) UNEP (2011), Google Map

The 2002 projected population for Bayelsa and Rivers state was collected from the NPC Abuja for use because the 2005 national census had yet to be segregated to community level, while local government and state-wide population data from the 2005 census was obtained from the NPC.

[13] Map Library is a charity organisation that provides free shapefiles for research and non-profit utilisation (http://www.mapmakerdata.co.uk.s3-website-eu-west-1.amazonaws.com/library/)

A 2005 SPOT image with 5m resolution was acquired from a vendor in Lagos, and used to generate new land cover, additional pipeline network, and rivers and creek shapefiles by onscreen digitisation and supervised classification. This was done to improve the resolution of the previous project, i.e. from 100m to 5m; although the choice of satellite image was majorly influenced by cost and availability, the 5m resolution satisfied the requirement because of the size of the area being studied. High-resolution images are expensive and suitable for smaller areas; Table 6-2 lists examples of image sensors, resolution, and suitable applications.

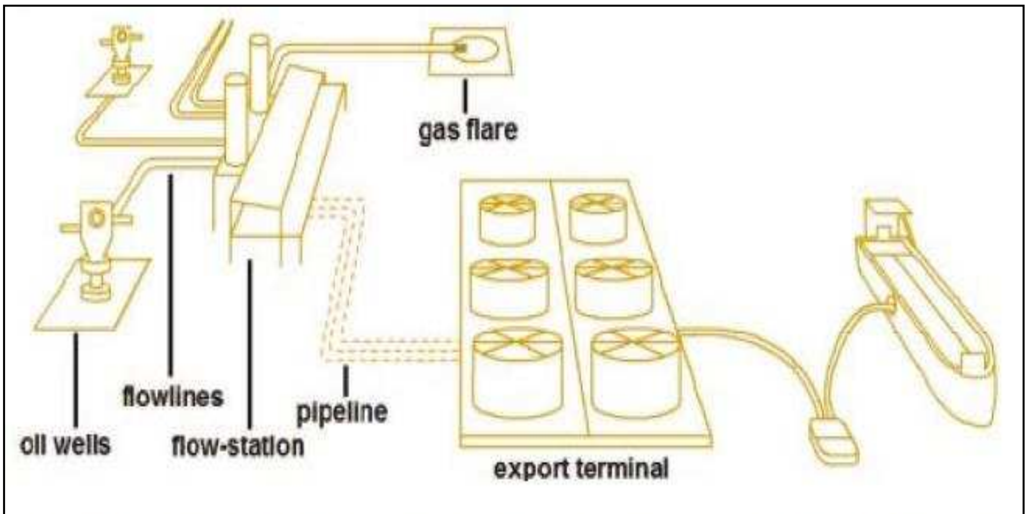
Table 6-2: Satellite images and resolution.

<table>
<tr><th>Resolution and Sensor</th><th>Advantage</th><th>Application and Cost</th></tr>
<tr><td>Low-resolution
(30m-1km)
SPOT 4-5 Vegetation</td><td>Provides global vegetation trends</td><td rowspan="2">Mostly Free Access
Land cover classification
Mapping and change
Detection oil spill hydrocarbon detection and mapping
Commercial sold per square metres; can be acquired freely with right access</td></tr>
<tr><td>Medium-resolution
(4m-30m)
Landsat TM,
SPOT 5 and
ENVISAT</td><td>Regional land-cover mapping
Suitable for large area
Requires super resolution mapping</td></tr>
<tr><td>High-resolution
(0.5m – 4m)
Ikonos, Quockbird and WorldView 2</td><td>Suitable for mapping small areas with high accuracy
Provides detailed information of features in smaller areas</td><td>Used to validate medium resolution satellite data
Spectral analysis of polluted sites change detection and validation
Commercially sold per square metres and generally expensive, based on resolution</td></tr>
</table>

Due to absence of materials on human health risk assessment in Nigeria, the values recommended for assessment by the United States Environmental Protection Agency (USEPA), the Environment Agency in the United Kingdom and other stakeholders were reviewed (Chapter 4) and, where found relevant, have been adopted in deriving the generic assessment criteria (GAC) in Chapter 8.

6.1.1 Oil Spill and Pipeline Data

The GPS point locations of 443 oil spill incidents from 1985 to 2008 and pipeline polylines were provided by the operators of the Oil Mining Lease (SPDC) in Port Harcourt through the DPR. The oil-spill attribute table provides information on the coordinates of each spill incident, date of spill, date of survey, quantity spilt, cause of spill and material spilt.



A flow-station receives the oil and gas transported through flowlines after extraction from the wells. At the flow-station, oil and gas are separated. The gas is usually flared (burned), but in some cases it is captured into a pipeline. The oil is pumped into a main, high-pressure pipeline for transport to an export terminal, through several other flow-stations where pumps maintain pipeline pressure.

Figure 6-4: A schematic representation of a typical oil production system in the Niger Delta (Steiner, 2010).

The satellite image revealed other pipeline segments not included in the ones given by the operators; thus, additional segments of pipelines were digitised from the SPOT image by tracing pipeline footprints (onscreen digitisation). Consequently, about 314.3km of pipelines representing high-pressured pipeline systems, i.e. pipelines connecting flow-stations and export terminals as illustrated in Figure 6-4 (Steiner, 2010), were incorporated in the study. Thus, pipeline parameters such as dimension size, depth of placement (underground/aboveground), year of construction and coating properties are not available.

6.1.2 Community and Population Data

In addition to community data collected from SPDC, more were obtained from the Department of Geography in the University of Lagos, Nigeria in 2010 and 2011 respectively to update the SPDC record, because some were missing. The University of Lagos data are of two types, a table containing X and Y coordinates of 354 settlements and a polygon shapefile for 235. All datasets were harmonised together after preparation. For population distribution, a 2002 projected population dataset was collected from the NPC Abuja because the 2006 census figures were yet to be segregated to community levels (Section 6.1). Thus, the projected population data were used in conjunction with the Rivers state 2006 population statistics from the NPC website to derive a population estimate for communities, and this was used to develop polygon shapefiles for point-based communities (Subsection 7.0.2).

6.1.3 Interviews, Site Inspection, and Questionnaires

Structured informal and individual oral interviews were designed to generate information on oil spill situations and response strategies put in place by operators and regulators on the one hand, and public perception of the situation on the other. The people interviewed (i.e. three regulators and one operator) were selected on the basis of their official positions as experts in oil spill management in their respective organisations, while two other individuals interviewed were private citizens (farmers) with relevant experience on the impact of oil spill and operational attitude of MOCs and government (Table 6-3).

Table 6-3: People interviewed during the fieldwork.

Interviewee	Date	Organisation	Designation
No.1	2-June-2010	SPDC	Lead-Oil Spill Response Team
No.3	5-June-2010	SPDC	Env. and Safety Officer
No.2	17-May-2010	DPR	Technical Officer Environment and Safety
No.3	26-June-2010	NAPIMS	Environment Health and Safety Officer
No.4	10-June-2010	NOSDRA	Oil Spill Inspector
No.5	3-June-2010	Akpajo Ward	Local Farmer
No.6	5-June-2010	Elelenwa	Local Farmer

Before commencing individual interviews, each participant was briefed on the purpose of the interview to secure their consent, and assured that information acquired through the interview would be used for the purpose of the PhD research alone and their anonymity is protected (Israel and Hay, 2006). This is important because the timing of the fieldwork not only coincided with the aftermath of the BP Deep Horizon incident in April 2010, but the UNEP was also conducting an investigation on oil-polluted sites in Ogoniland in River state where this study was eventually conducted.

The staff (operators and regulators) contacted were initially adamant that they would not grant the interview without official approval, which could take time and lobbying. However, after a series of persuasions and assurances that their expert knowledge would help me understand the true difficulties faced and efforts being made by both regulators and operators on oil spill management, they agreed. The two farmers were interviewed separately on different days and in different locations in the Port Harcourt metropolis; each of them was selected by the convenience encounter sampling method (Bernard, 2002) and willingness to participate in the interview session.

A preliminary site inspection was conducted on two oil spill sites located on the out skirts of Port Harcourt town using a framework designed (Appendix K) by the researcher. The aim was to:

i) investigate mitigation and management strategies used to prevent unnecessary exposure to the public on polluted sites;
ii) examine extent of contamination and potential exposure pathways;
iii) examine the remediation method used by contractors and evaluate their efficacy in line with the Niger Delta environment; and
iv) gain first-hand practical knowledge and experience in qualitative site assessment.

An initial attempt to visit a Shell site was turned down because Shell was not prepared to take responsibility for my security. As a consolation, I was introduced to a local clean-up contractor at SPDC, whom I accompanied to two of the sites he was contracted to remediate in the outskirts of Port Harcourt town, with the condition that I should not carry a camera or writing materials. His [the contractor] fear was that the materials would make me stand out and expose the nature of my visit, which may have consequences, e.g. harassment and extortion by youths in the area. This did not come as a surprise because, despite the tight security and official support given to the UNEP by both federal, state and local governments and MOCs, the UNEP was prevented from visiting some areas for their investigations (UNEP, 2011).

Questionnaire administration was necessary in order to generate a land use activity pattern that reflects the lifestyle of people in the area for the risk assessment. The questionnaire was designed (see Appendix A) to elicit information on duration, frequency, and type of land use activities performed by respondents. In addition, to ensure that the content of the questionnaire captures the essence of the topic, fellow PTDF/PhD scholars in UK universities were invited to review and offer suggestions on the wording and structural arrangement of the questionnaire. After this 300 copies of the questionnaire were sent to Nigeria for administration through designated research assistants recruited from the University of Port Harcourt.

The criterion for their [research assistants] selection was their localities (where they came from), which must be a community within the study area. Considering security warnings during my first visit in 2010, the use of research assistants became a viable option because, not only were they from the area, but also they know the people and can interact better with them than an outsider. After selection, an induction was conducted by phone between me and the point man, during which I explained what I wanted to achieve and the type of sampling strategy to adopt. After gaining knowledge of the unplanned nature of rural settlements in the area, and the farmers' willingness to participate, we agreed to use the convenience-sampling method, giving no preference to gender and land use occupation of respondents.

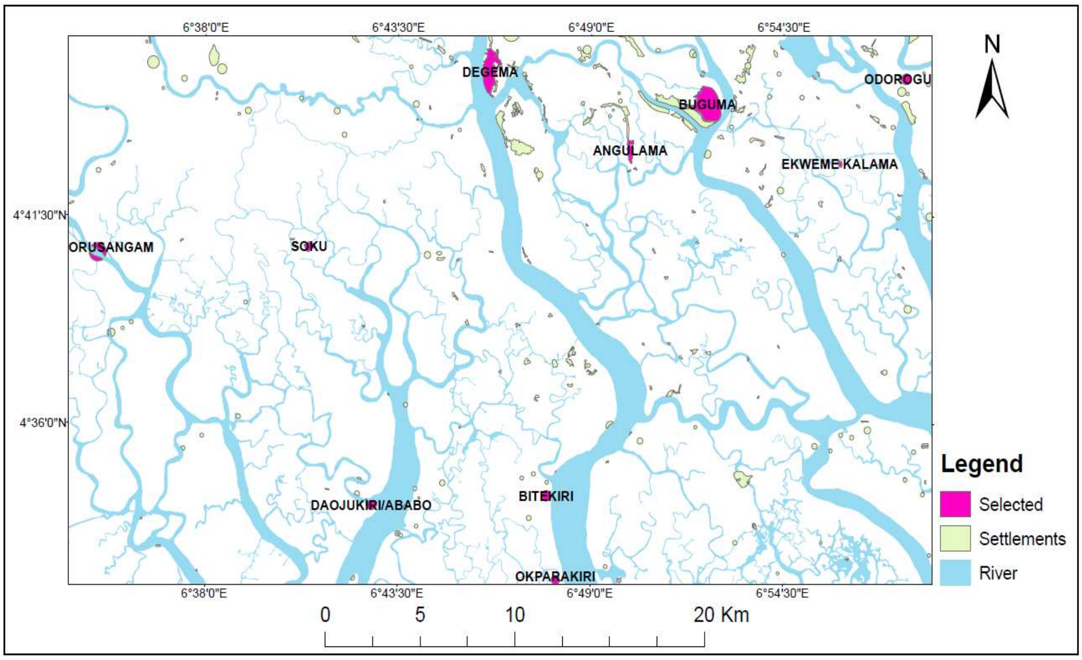


Figure 6-5: Location of selected communities where questionnaires were administered.

Table 6-4: List of communities where questionnaires were administered.

No.	**Community**	**Local Govt.**	**Response**		
			Returned	%Returned	Lost
1	Buguma	Asari-Toru	29	11.6	1
2	Degema	Degema	27	10.8	3
3	Angulama	Asari-Toru	22	8.8	8
4	Soku	Akuku-Toru	29	11.6	1
5	Odorogu	P/Harcourt	22	8.8	8
6	Ekweme Kalama	Degema	19	7.6	11
7	Bitekiri	Degema	20	8	10
8	Okparakiri	Degema	28	11.2	2
9	Orusangam	Brass	30	12	0
10	Daojukiri/Ababo	Brass	24	9.6	6
		Total	250	100	50

Although 300 questionnaires were sent out, only 250 were returned fully completed and 50 got lost through various reasons. This is often the case with questionnaire administration (Bryman, 2008). The exercise lasted for about three weeks in March 2013. Figure 6-5 shows names and the location of communities where questionnaires were administered, while Table 6-4 shows the number of questionnaires returned and lost in each community.

6.2 Materials and Methods

This and subsequent sections describe data analysis procedures and results achieved.

6.2.1 Analysis of Previous Oil Spills

The oil spill data were analysed to understand spatial distribution relative to pipeline network and communities. To do this, the join and relate command in ArcGIS was used to measure distances from community to: i) pipelines; ii) rivers and creeks; and iii) oil spill sites. The proximity to the hazard was determined by assessing communities within a distance of each of the variables listed above (Section 7.2).

A Thiessen polygon was constructed to determine the community with the most spill incidents using the Thiessen polygon to demarcate areas of influence for each community (Figure 7-24). The Thiessen polygon theory assumes that areas within a polygon are closer to the centroid than any other (Ratcliffe and Taniguchi, 2008); on this basis, oil spills found in a particular polygon were assigned to the respective community. By counting the number of spills in each polygon, the community with the highest record of spill is flagged as a potential risk area due to repeated occurrence of spills (Subsection 7.3.5). The use of the Thiessen polygon method ensured that all oil spills were accounted for.

The spatial distribution of oil spill was mapped in two ways: the first considered TPH concentration due to weathering, and the second reflected potential toxic units (Subsection 7.0.3) of fresh and weathered crude oil. The TPH concentration was derived from a linear equation (Figure 7-2) developed from a plot of eight sites selected from the UNEP (2011) field data using the year of spill as its criteria (Appendix G: Table G1). The second approach was based on the logic underpinning the relationship between weathering and toxicity, using a toxic unit (TU) (Subsection 7.0.3). For representation in ArcGIS, a two-staged unit-based normalisation procedure was followed to develop weightings between 0 to 10 for the spills, taking into account the difference in quantity and year of spill (Equation 7-4 and Equation 7-5).

In addition, analysis of frequency, quantity, and cause were calculated and results given in graphical representations (Section 7.1); since the spills occurred at different times and locations, a spatial-temporal analysis was done to evaluate spatial pattern over time (Section 7.3). Having determined these, the response time to spill incidents was calculated using time lapse between date of spill and date of survey (Subsection 7.1.1); according to the interview nothing is done on a spill site until joint investigation is concluded (Field Interview, 2010).

6.2.2 Analysis of Responses from Questionnaires

The questionnaires were administered to gather information on land use pattern, i.e. in farming, fishing, hunting, and wild gathering of fruits, insects etc. (Subsection 6.1.3). Information concerning work pattern, style, duration, and frequency is critical in land-use risk assessment. Thus, the questionnaires seek answers to:

i) frequency of work per week;

ii) duration of work in hours per day;

iii) whether work is considered intensive or not;

iv) part of the body usually exposed during work activity;

v) distance travelled to perform work activity; and

vi) whether or not protective clothing is worn.

The responses were analysed using simple frequency distribution, percentage, and Pearson correlation analysis (Section 7.4). Because people may perform multiple activities simultaneously, a nonparametric test was done with Pearson chi-square to determine whether respondents practise more than one activity (Appendix G2).

6.3 Derivation of Exposure Assessment Criteria

Exposure assessment measures exposure to chemical substances and describes source, pathway, and receptor (IPCS, 2004; Environment Agency, 2009). Results are then compared with national standards to determine whether Health Criteria Value (HCV) (e.g. tolerable daily intake) is exceeded or not (Environment Agency, 2009).

According to the UNEP (2011), EGASPIN classified petroleum hydrocarbons under mineral oil with target and intervention values of 50 and 5,000 mg/kg respectively (Table 3-9) without carbon range. Thus, because EGASPIN is based on a single parameter (mineral oil), the UNEP analysis reported in TPH (UNEP, 2011, p.83). In addition, the BTEX standards for both soil and groundwater are similar to the Dutch standard, which is not suitable due to lack of consideration for land use exposure. New sets of guideline values were derived (Section 8.4) for TPH (aliphatic and aromatic) in rural land use (Section 8.2):

i) rural agricultural land use;

ii) rural informal dwelling; and

iii) rural standard residential.

The GAC was derived using the Environment Agency's CLEA model v1.06 for the aforementioned land uses. Meanwhile, physico-chemical properties of aromatic and aliphatic EC number fractions in LQM/CIEH (Nathanail et al., 2009) were adopted, while some human exposure parameters reviewed in Chapter 4 and data gathered from questionnaires were used to modify default settings in the software. The new GACs are based on 1%, 2.5%, 5%, and 10% soil organic matter (Subsection 8.4.1).

6.4 MCE-AHP Modelling

Discussion on integration and application of MCE and AHP in spatial decision making was presented in Chapter 5. Using this technique and following the framework, a model was built with ArcGIS (Section 9.1 and Figure 9-4) to establish the potential pipeline impact radius (PPIR) and the HCA. This technique was deliberately chosen because it allows decision makers to make a judgement decision based on knowledge and experience (Ascough II et al., 2002), which is needed to navigate through the loopholes of data paucity. For instance, data on pipeline size, dimension, position in/on the ground, and network layout are sensitive information that the MOC is not willing to divulge; hence, the use of MCDM provided a means of demarcating the impact area (hazard zones) from interaction of subjectively selected criteria.

6.4.1 Potential Pipeline Impact Radius and High Consequence Area

The PPIR delineation is done by extracting specific hazard zones according to Equation 9-7. The selection by location command identifies communities within the PPIR and designates them as HCA. The same process is repeated for land cover, rivers, and creeks (Figure 9-9 and Figure 9-10).

6.4.2 Pipeline Classification

In doing this, two options (methods) were experimented. The first method considered distance to human settlements; pipeline segments within 201.2m of communities were classified as Class 1. The procedure was repeated for other distances until four classes of pipeline categories were produced (Table 9-10 and Figure 9-11). The second method uses pipeline and river intersections to classify pipeline segments (Figure 9-12). This method is an alternative to Subsection 5.5.3 because the requirements are not tenable in the Niger Delta, where pipeline ROWs are occupied due to increase in population and demand for land.

6.5 Constraints and Difficulties

Prior to the commencement of this research, constraints were envisaged but not expected to be as significant as manifested in the run-up to and during field data gathering. I was sure that the relevance of this research would give me the support I needed from stakeholders in the sector, but this was not so. Some challenges encountered are discussed here so that the reader may take into context the condition under which the study was undertaken.

6.5.1 Information Constraints

The intension was to collate oil spill data from variety of sources (MOCs) beyond what was given. The DPR gave me a letter of introduction to three MOCs requesting data on oil spill incidents in their areas of operation (see Appendix I), which I delivered personally to their offices in Lagos. The MOCs are listed in Table 6-5.

Table 6-5: MOCs introduced to and their response.

MOC	Designation	Date	Response
Shell Petroleum Development Company of Nigeria Limited	General Manager	18/05/2010	Yes
Chevron Nigeria Limited	General manager	18/05/2010	No
Nigeria Agip Oil Company	General Manager	18/05/2010	No

The willingness of SPDC to provide the data came with difficulties, because I was denied the opportunity to participate in the choice of location (Subsection 6.0.2). As a result, location, size, and characteristics of oil spill data provided were completely without my input (Appendix I-4). It is also important to remind the reader that the strictness of SPDC is understandable, because the fieldwork was conducted a few weeks after the BP Deep Horizon oil spill in the Gulf of Mexico in 2010 (explained in Subsection 6.1.3).

In addition, the fact that data requested are geo-referenced materials showing exact location of spill incidents on pipeline routes means divulging classified information. This information is confidential to the company (Appendix I-4) and cannot be released into the public domain in its raw form. However, after persuasion and assurance from my supervisor and myself that the information would be used for academic purposes only, they agreed but under the condition that the DPR is cited as the source (DPR is the custodian of such data and only the DPR has the mandate to release it).

6.5.2 Access Restrictions and Security Constraints

The desire to conduct a field assessment of oil spill sites was impossible because:

i) I did not have fore knowledge of the location to be given, and was not able to make private security arrangements within the short time limit;

ii) a request to visit oil installations or oil spill sites was denied for security and safety concerns (harassment, extortion, kidnap, and nature of the mangrove forest);

iii) in addition, Shell Nigeria would not be responsible for my Freedom to Operate (FTO) in the community, which by implication means my safety, and security could not be guaranteed.

There were serious issues of insecurity at the time of the fieldwork following reported cases of kidnap, extortion, and harassment of people, especially strangers in the Port Harcourt axis.

Conclusion

This chapter provided a description of procedures followed in data collection, and the preparation strategies employed to make the data fit for purpose. The issue of paucity of data, access to information and lack of current data forced me to develop new information with which to update available datasets for analysis. Different data gathering approaches such as physical observation, administration of questionnaires, interviews, literature, and documentary reviews were done with a view to achieve methodological triangulation and enhance confidence in my findings (Denzin, 1970; Bryman, 2008; Fielding, 2012).

The inability to obtain data from other MOCs introduced to, limits the study to one area under one MOC. Data from those MOCs could have broadened the study area and perhaps introduce new variables in terms of cause and frequency of pipeline failure peculiar to their respective areas of operation. However, by integrating qualitative and quantitative approach complements one another to offset weakness in data collection especially since issues of concern are intone with revelations from interviews and documentary reports by the international mass media (Appendix L).

The following Chapter provides data preparation and preliminary assessment of oil spills spatial distribution, proximity to settlements, frequency, cause, and quantity and toxicity.

CHAPTER 7

DATA GATHERING AND PREPROCESSING

7.0 Introduction

The use of secondary data is necessary where there is no primary data. Factors ranging from cost, time, and accessibility are some of the reasons researchers opt for secondary data. To do so, many secondary datasets require adjustments and modifications to make them suitable for present use. Thus, since some of the datasets collected were originally used in different projects, they need to be reformatted and modified so that relevant information can be extracted or embedded to make it suitable for present application. In addition, the proliferation of unregulated spatial data vendors in Nigeria has introduced different standards and data formats; therefore, users are made to prepare data in conformity with individual requirements. Consequently, this chapter presents some data pre-processing and preparation processes done to make the data suitable for analysis.

7.0.1 Data Preparation

In data preparation, shapefiles of land cover, river networks, community polygons, and local government boundaries extracted from spatial datasets acquired from vendors required updating, redevelopment and change of projection, i.e. from Decimal Degree to Universal Transverse Mercator, UTM_Zone 32N WGS84 Mina Datum. The researcher did these readjustments, realignments and other modifications.

To increase resolution of land cover and network of rivers and creeks for the study area, a supervised classification was done using a SPOT satellite image to generate 5-metres resolution shapefiles. Doing this was useful in generating additional creek and river systems not visible in the original datasets. In addition, more land cover distribution and floodable plains became visible due to increase in resolution.

7.0.2 Development of Community Polygon Shapefiles

Creating a polygon shapefile for communities in points, a projected population data (Subsection 6.1.2), was used to estimate and update the population of the communities. Population data are important for constructing polygon shapefiles because some communities are represented in points. The updated population and area attributes of communities with polygons were used as training sets in constructing a linear regression model (Figure 7-1) for calculating the area for communities in points.

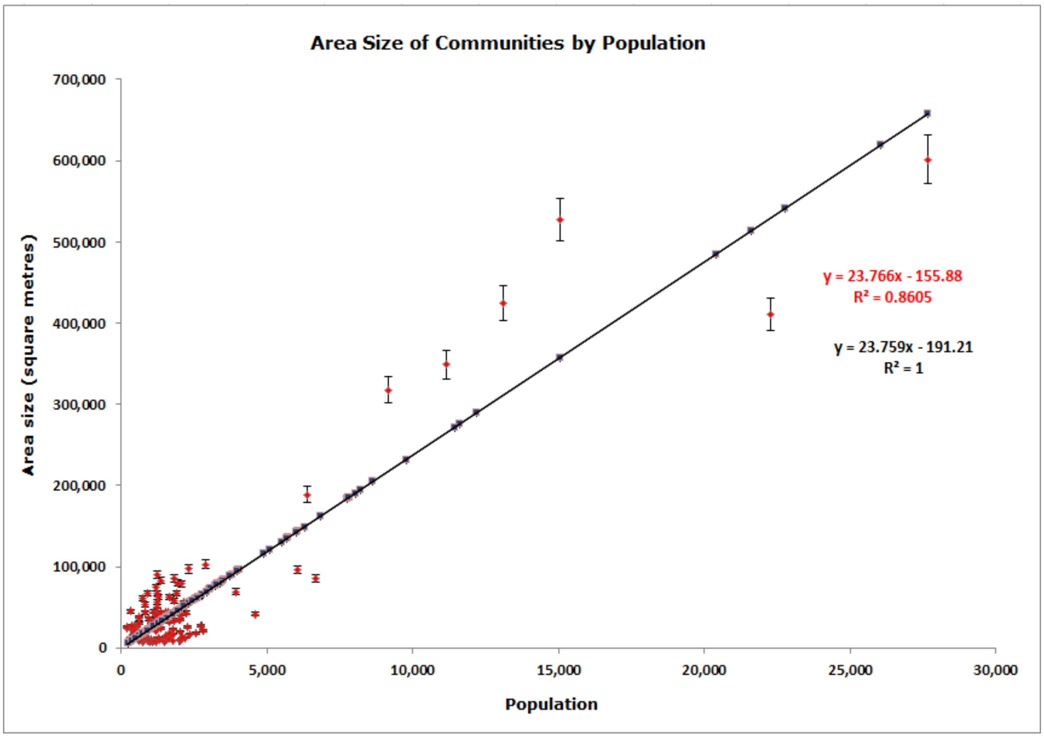


Figure 7-1: Model for predicting area size of a community based on population (± standard deviation error at 95% confidence limit) (Source: Field data).

By plotting the area against the population, a training equation was generated with which to estimate the area size for communities in points using simple variable circular buffers with a radius determined by Equation 7-1.

Equation 7-1

$$r = \sqrt{A/\pi}$$

Where:
r = radius; A= area; and π =3.14159.

After developing the polygon shapefiles, the two settlement shapefiles were merged together to produce 374 communities with polygon boundaries. The equation for the training set is y=23.766x–155.88 (R^2=0.8605[14]) shown in "Red" for the sampled data, and validation equation y=23.759x-191.21 (R^2=1) shown in "Black" was generated by ArcGIS for the newly created sets of community polygon shapefiles[15] used to validate the data.

7.0.3 Estimating TPH Toxicity Due to Weathering

When crude oil is release in the environment, weathering processes (Subsection 3.5.4) begin to remove some components, leaving behind the more resistant hydrocarbons (Howard et al., 2005; Zhibing et al., 2010; Jooa et al., 2013). Microorganisms function to disintegrate crude oil in the soil (Okereke et al., 2007; Onuoha et al., 2011), at a rate dependent on type of oil, environmental condition and capacity of native microorganisms to work effectively (Osuji and Onojake, 2006). Fingers (2000) in Table 3-14 estimated recovery time for various habitats according to intensity of clean-up work undertaken. To this effect, he suggected that a wetland

[14] The r-squared value of 0.8605 was achieved by discarding 21 outliers from 151 sampled communities.
[15] When shapefiles are converted to geodatabase, ArcGIS automatically measures their shape-areas.

would take 5-30 years to recover without clean-up. The present scenario did not provide information on concentration nor halflife of TPH in the Niger Delta. Although works by Salanitro et al. (2009), Howard et al. (2005), Coulon et al. (2010) and Onuoha et al. (2011) attempted to model petroleum hydrocarbon degradation in laboratory settings, none actually deveoped a model to estimate the rate of petroleum hydrocarbon degration over a long period of time in the field. In addition, most biodegradation investigations are focused on effectiveness of microorganisms on specific hydrocarbon compounds (Howard et al., 2005; Jooa et al., 2013) not usefull for the present purpose.

However, there are two options presently feasible: the first is to plot the concentration of TPH from sites investigated by the UNEP (2011) against the time of last oil spill, shown in Figure 7-2, to determine TPH degradation over time, in Figure 7-3, as a form of degradation over time.

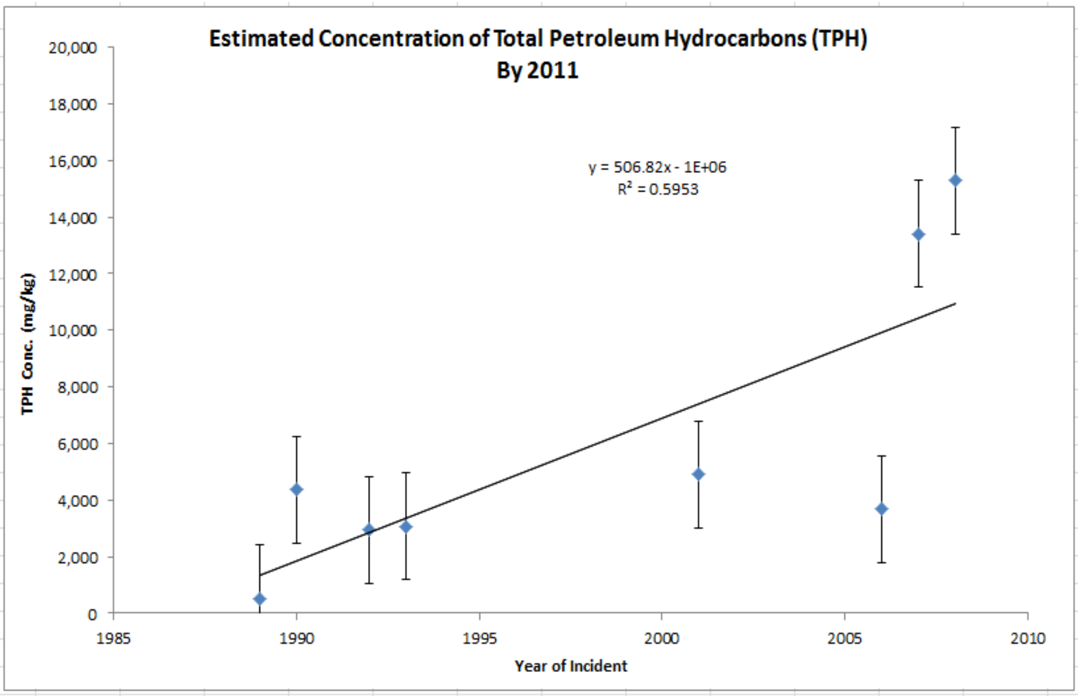


Figure 7-2: Estimating TPH degradation and loss of concentration (± standard deviation error at 95% confidence limit).

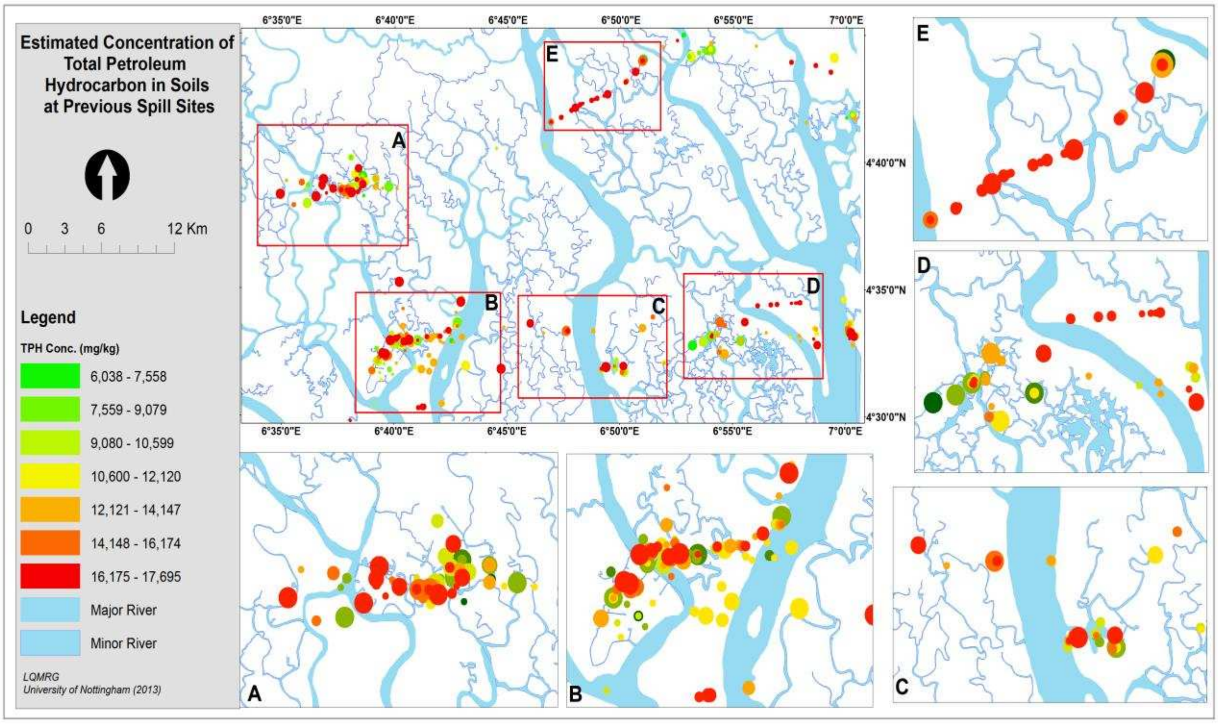


Figure 7-3: Oil spill sites showing estimated TPH concentrations in soil.

To achieve this, the last recorded year of spill incidents and current maximum TPH concentrations in soil (as at 2011) reported on sites (Appendix G: Table G1) was used. The linear equation was used to generate TPH concentration for the oil spills in Figure 7-3 above.

Alternatively, a toxic potentials of hydrocarbon mixture (Subsection 4.3.2) that is based on the ratio of water-column concentration C_w and critical concentration C_w^* which is used to determine TU can be adapted from Di Toro et al. (2007). Although changes in toxicity are determined by several factors such as physicochemical characteriatics of the petroleum and the dominant weathering process (Bellas et al., 2013), in this procedure all factors are considered uniform.

Assumming the toxicity of a mixture is the sum of the toxic potential of each hydrocarbon compound weighted by its mole fraction in the oil mixture, then, for a three compound mixture, the mole fraction must be equal to one, e.g. $a_1 + a_2 + a_3 = 1$. The weathering of a neat oil and weathered oil would then have a TU = 7.5 and 3.3 respectively according to the following illustration (Di Toro et al., 2007).

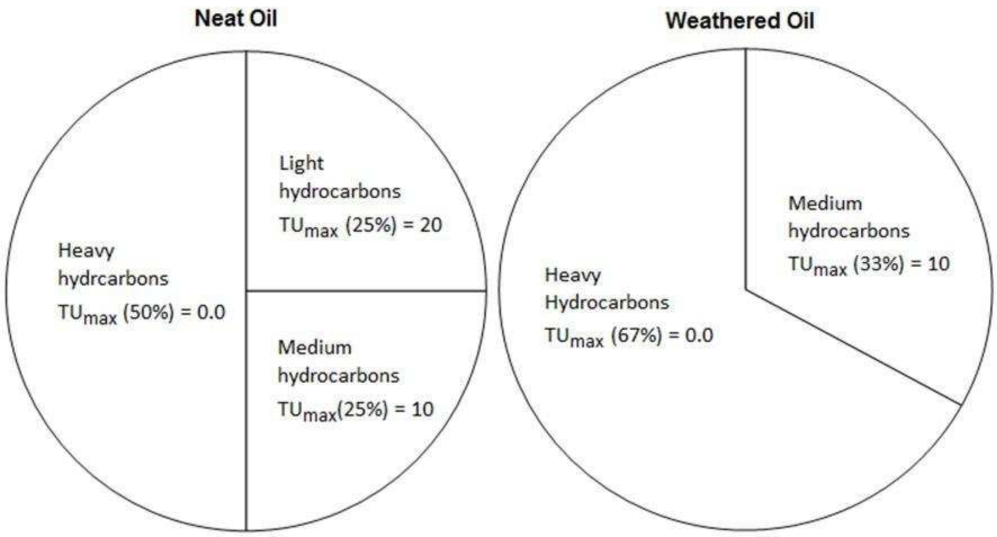


Figure 7-4: Illustrates change in composition of fresh and weathered oils based on light, medium, and heavy hydrocarbon fractions in Di Toro et al, (2007).

Equation 7-2: Fresh oil

$$TU = 20(0.25) + 10(0.25) + 0(.50) = 7.5.$$

Equation 7-3: Weathered oil

$$TU = 10(0.33) + 0(0.67) = 3.3.$$

Based on their assumption (Di Toro et al., 2007), a fresh crude oil would be composed in mole fractions 25% light hydrocarbons (low log-$_{KOW}$), 25% medium hydrocarbons (intermediate log-$_{KOW}$), and 50% heavy hydrocarbons (high molecular-weight log-$_{KOW}$) mixture with a toxic potentials maximum (TU_{max}) of 20, 10, and 0 for the three components. Thus, TU for the fresh (neat) and weathered oil would be equal to 7.5 and 3.3 (Equation 7-1 and Equation 7-3) respectively. Because of the removal of the lighter fractions by weathering, the crude mole fractions change proportionately in response to this loss and increase the medium components from 0.25 to 0.33 mole fraction (Figure 7-4). In effect, the loss of the lighter and more toxic components caused the TU to reduce from the initial 7.5 to the final 3.3, which inevitably is a decrease in toxicity.

Thus, following the illustration by Di Toro et al. (2007), a weighting between 1 and 10 is allocated to oil spills greater than 100bbl (Figure 7-5) to demonstrate loss of toxicity due to weathering.

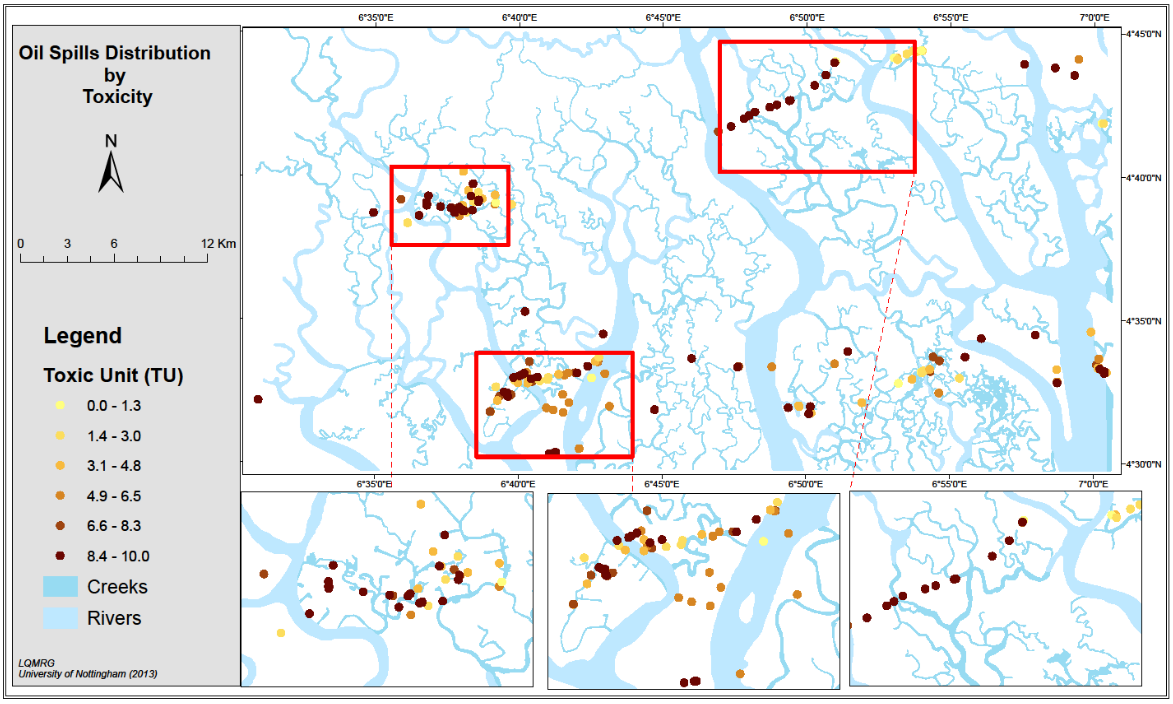


Figure 7-5: Oil spill sites indicating toxic levels.

A two-staged normalisation procedure was adopted to assign TU to individual spills. Stage 1 accounts for the difference in quantity of individual spills by multiplying a normalised year with Q_y according to Equation 7-4, while Stage 2 uses Equation 7-5 to derive the TU by normalising the results from Stage 1. Multiplying TU by 10 converts the TU to $TU_{(0\text{-}10)}$, i.e. range 0-10. See Appendix D-2 for the feature attribute table and weighting value. The general toxic potentials of spills greater than

100bbl indicates a massive loss of toxic potentials due to weathering, about 68% having lost their light and medium component leaving behind the less toxic heavy hydrocarbons.

There is a relatively strong correlation between TU and quantity of oil spilt at r=0.823, n=202, p<0.01, while there is a weak correlation between TU and year of spills, i.e. r=0.366, n=202, p<0.01 (2-tailed Pearson correlation) Appendix G: Table G2. This shows the significance of quantity in oil toxicity as reflected in the weighting computation, i.e. since the loss of lighter more toxic components of oil causes reduction in toxic unit (Di Toro et al., 2007), the quantity of oil discharged can influence the proportion of lighter hydrocarbons to be removed. In essence, it would take longer to remove the lighter proportion of hydrocarbons in 100 barrels of crude than it would 10 barrels under similar conditions.

Stage 1: the spill year (S_y) was normalised from 0 to 1 to bring the years into proportion, then multiplied with the quantity (Q_y) of individual spill events using the following equation:

Equation 7-4

$$S_{y_{(0-1)}} = \frac{S_y - S_{\min(y)}}{S_{\max(y)} - S_{\min(y)}} \; X \; Q_y$$

Where:

$S_{(0-1)}$ = the spill year normalised between 0 and 1

S_{min} = the minimum year

S_{max} = the maximum year

S_y = individual spill incident year

Q_y = the quantity spilt by incident

Stage 2: normalise results from Equation 7-4 to generate potential TUs (0-10) by the following normalisation equation, which is multiplied by 10:

Equation 7-5

$$TU_{(0-10)} = \frac{TU_{sy} - TU_{\min(sy)}}{TU_{\max(sy)} - TU_{\min(sy)}} X\ 10$$

Where

$TU_{(0-10)}$ = the oil spill incident toxic unit from 0-10

TU_{sy} = individual spill incident

$TU_{min(sy)}$= minimum of normalised spills in Stage 1

$TU_{max(sy)}$ = maximum of normalised spills in Stage 1

10 = standardisation TU assigned to spills

7.1 Analysis of Cause, Quantity, and Frequency of Oil Spills

There are different causes of oil spills discussed in Subsection 3.1.1. However, according to data at hand, the main causes here are: "corrosion" resulting from chemical reaction, "production error" during the production process, "interdiction" from a deliberate act of sabotage, bunkering and theft, and finally "unknown causes" which are unresolved oil spill cases.

Assessment of frequency of oil spills and quantity discharge by cause showed that interdiction discharged the largest quantity of about 32% of crude (Figure 7-6). Oil spills due to production error occurred 154 times and discharged about three times less than interdiction. Lack of a leak detection system, poor oil spill contingency plan, and accessibility according to Steiner (2010) contribute to large quantities of oil discharged.

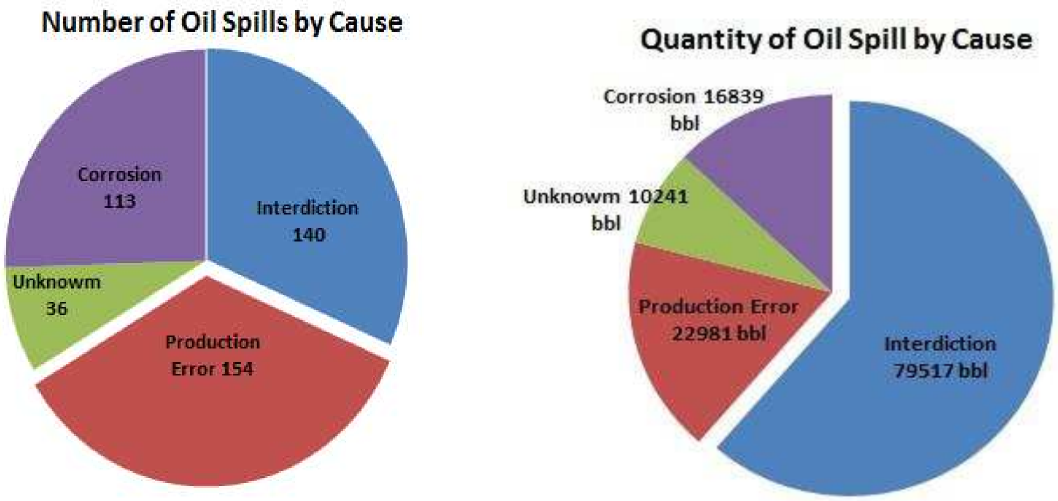


Figure 7-6: Comparison of spill frequency and quantity by cause.

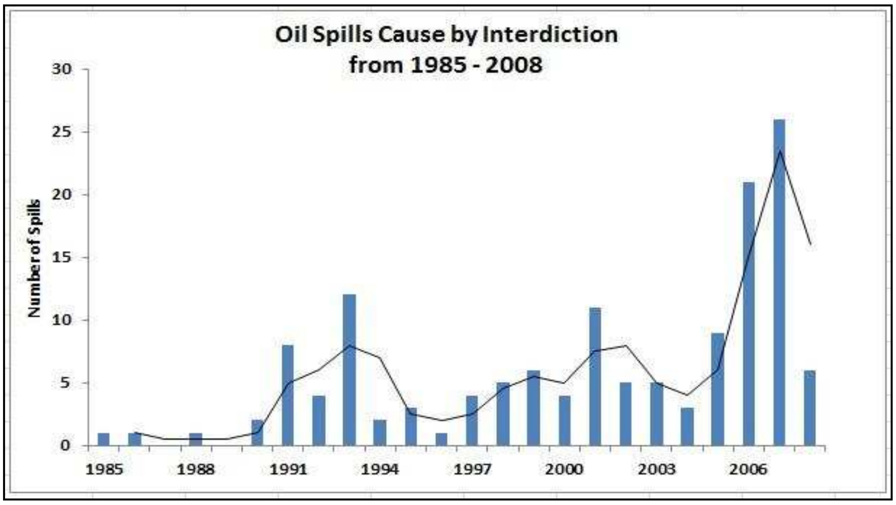


Figure 7-7: Frequency of spills caused by interdiction.

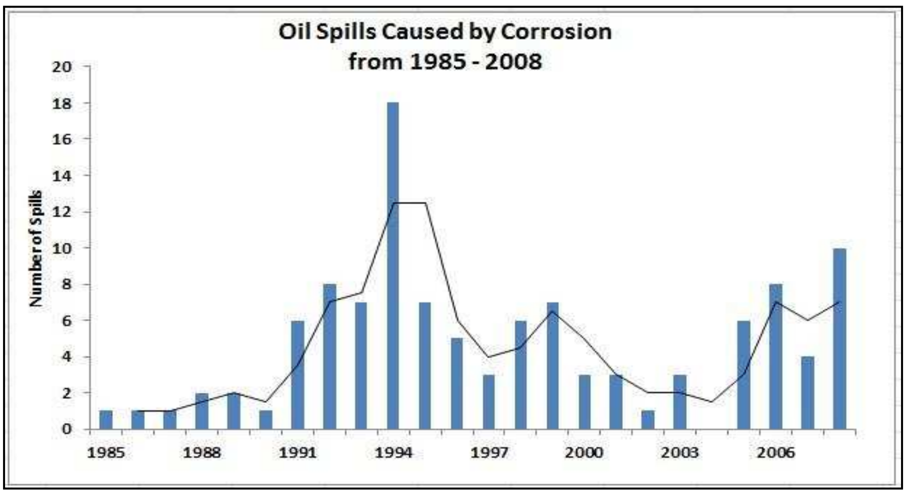


Figure 7-8: Frequency of spills caused by corrosion.

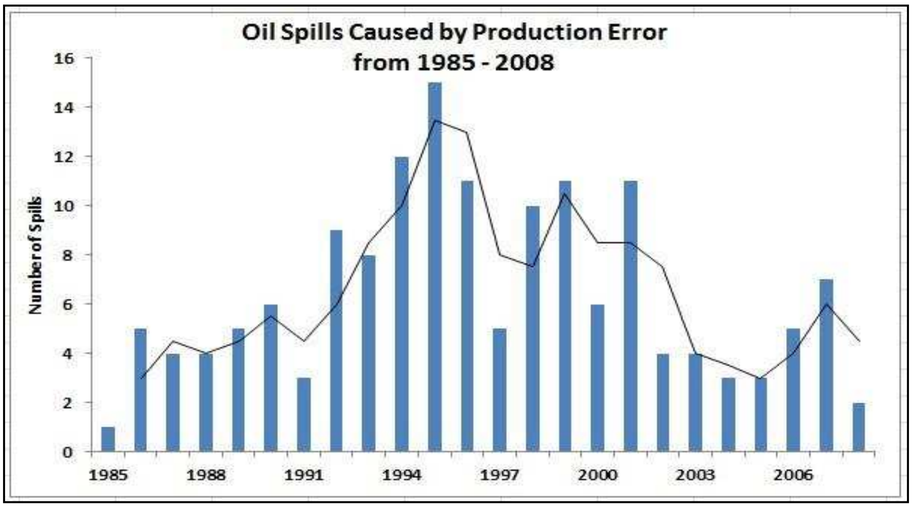


Figure 7-9: Frequency of spills caused by production error.

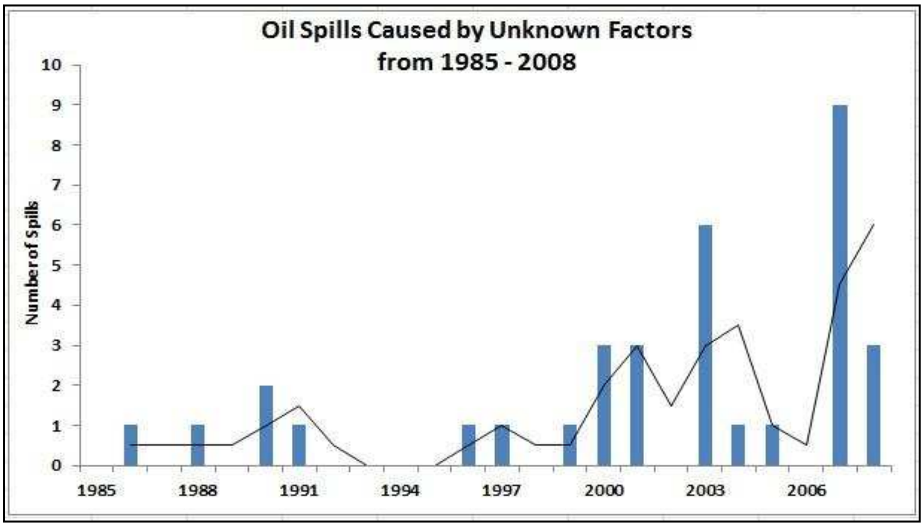


Figure 7-10: Frequency of spills caused by unknown factors.

Figure 7-7, Figure 7-8, Figure 7-9 and Figure 7-10 show oil spill frequencies by cause. However, there is a weak correlation between cause of oil spills and quantity discharged, r=.14, n=201, $p<0.05$ (2-tailed Pearson correlation, see Appendix G: Table G2), while there is a relatively strong correlation between frequency and quantity, i.e. r=.70, n=24, $p<0.01$ (2-tailed Pearson correlation, see Appendix G: Table G3).

Because perpetrators of interdiction operate different levels of skills and sophistication, the volumes of oil released often correspond to the skills they possess. Field interviews (2012) revealed that amateurs and saboteurs are usually responsible for discharging large quantities of oil, mainly because their intention is to impair oil production. Although there is a general lack of prompt response to spills, recurring cases of interdiction and bunkering can also aggravate the size of oil discharge (Mohammed, 2012; John, 2013).

7.1.1 Response Time to Oil Spill Incidents

Timely response to oil spills plays a significant role in the volume of oil discharged. Sources at SPDC claimed the company is able to respond to spills within 24 hours, provided the information is received during working days and hours.

To test this claim, a response time was derived from difference in date of spill incident and date of site survey, assuming that nothing is done until a joint venture inspection is conducted (Subsection 3.2.2). A joint inspection team must be mobilised before visiting oil spill sites greater than 100kg.

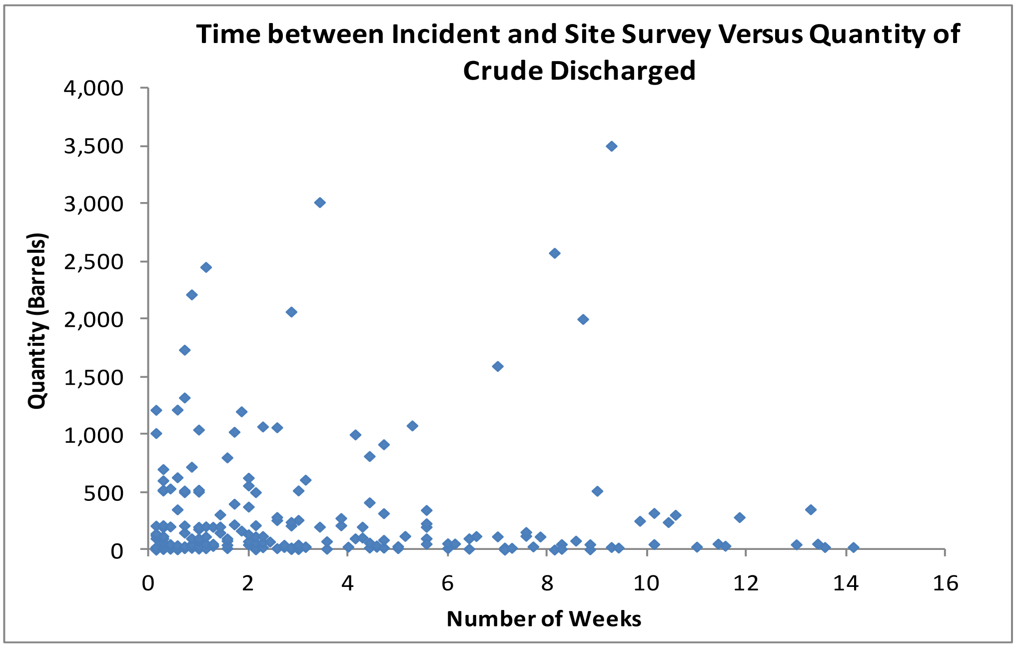


Figure 7-11: Time lapse from incident to survey indicating response time.

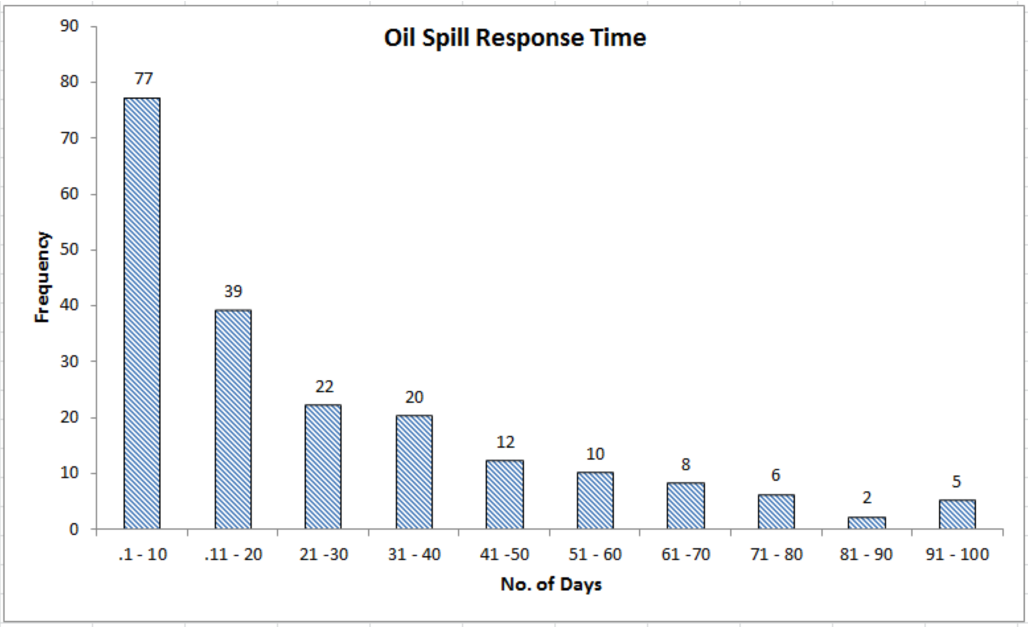


Figure 7-12: Number of oil spills attended to in days.

The average response time according to Figure 7-11 is about three weeks, contradicting the official claim of responding within 24 hours. Figure 7-12 also shows that only about 57.7% of oil spills were responded to within 20days.

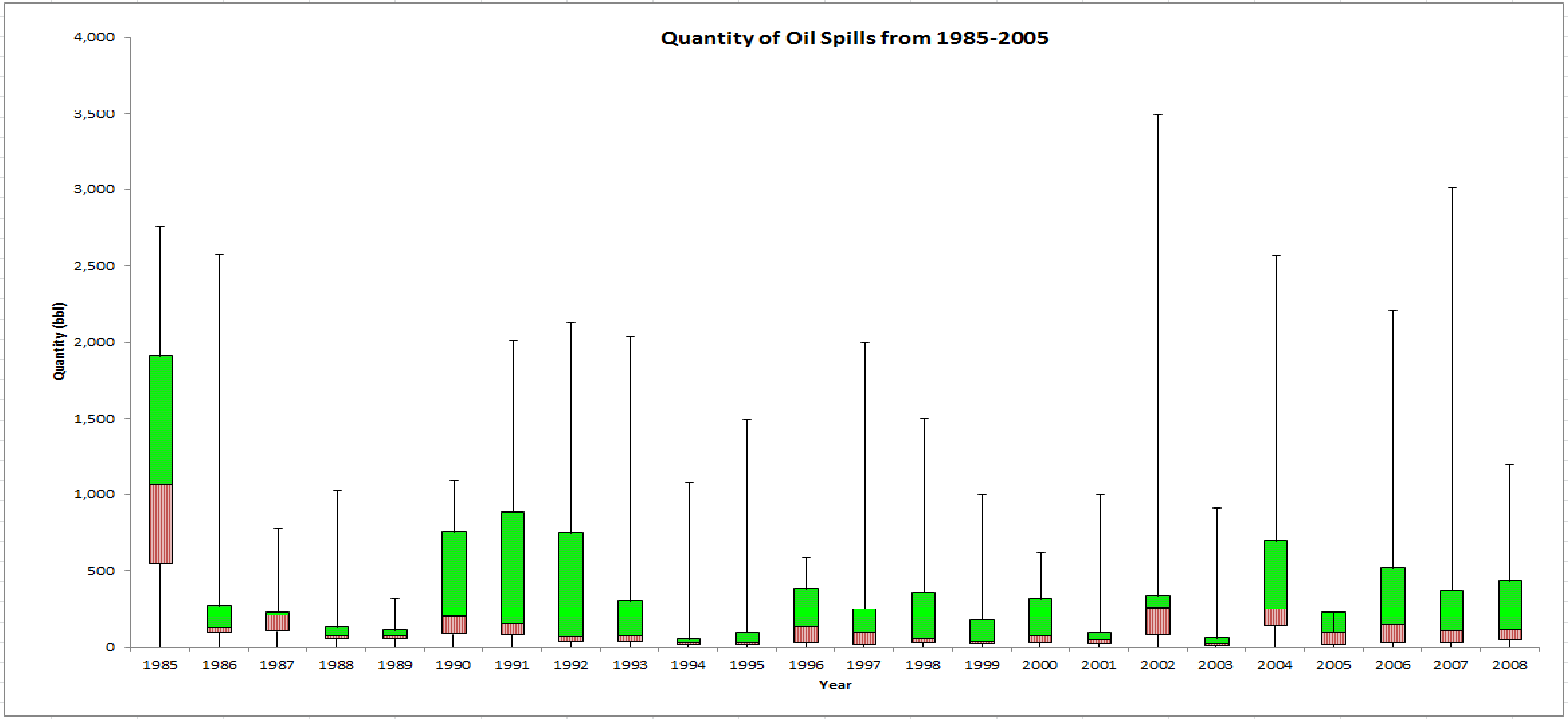


Figure 7-13: Quantity of oil spilt from 1985-2008 in barrels (Fieldwork, 2010).

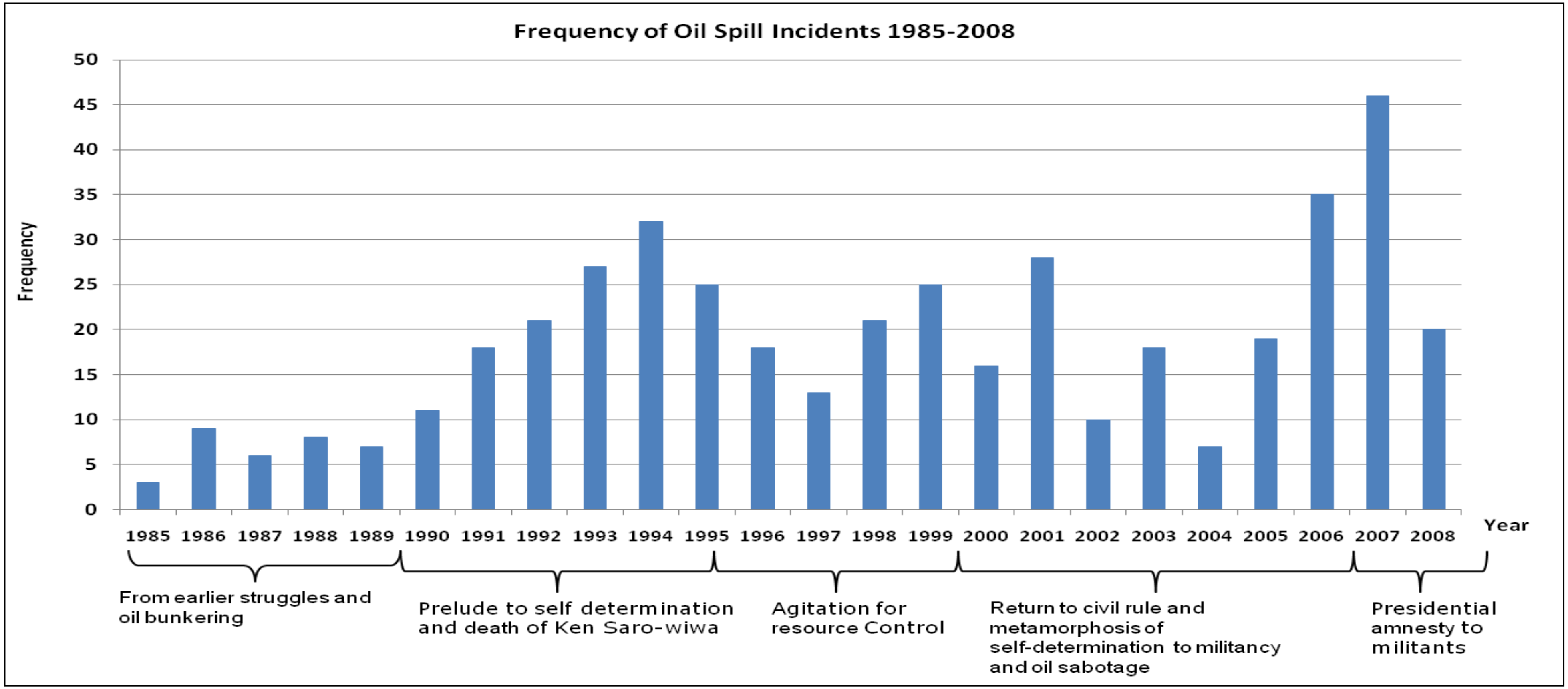


Figure 7-14: A chronological link of oil spill incidents to socio-political trends discussed in Section 3.4 likely to be responsible for frequency of oil spill incidents in the period under review (Fieldwork data, 2010).

7.1.2 Socio-Political Influence on Oil Spills

The severity and frequency of oil spill incidents in the period under study does not follow a particular pattern and quantity discharged is by no means proportional to the frequency of spill (Section 7.1). There is no logical explanation for the fluctuations in yearly quantity discharged indicated in Figure 7-13.

However, this can be linked to socio-political factors affecting oil operations in the area. The issue of socio-economic and political deprivation has undoubtedly been a driving force behind oil bunkering and vandalism, just as it has supported insurgence and militancy in the Niger Delta. Ken Saro-Wiwa (Subsection 2.33) brought resource control and the environmental movement to international limelight in the mid-1990s. Another relevant trend with direct bearing on oil interdiction is the presidential amnesty for militants announced in 2007 by the late President Yar'adua. The amnesty initiation was to allow them surrender their weapons in exchange for vocational training and employment (perhaps this was why there was a drop in 2008 Figure 7-14).

7.1.3 Seasonal Variation and Flow Direction of Surface Spills

The climatic characteristic of the Niger Delta gives rise to seasonal inundation during rainy seasons, which leads to an increase in surface water levels (UNEP, 2011); at such times footpaths, roads, farms and homes become inundated (Gay et al., 2010). Therefore, oil spill incidents during rainy sessions can cause wide spread damage due to the ability to migrate with the flow of surface and subsurface water. However, Figure 7-15 did not display a distinct pattern to suggest direct influence of seasons on oil spill incidents.

The direction of surface and underground water plays an important factor in the direction of oil spill migration. In the rainy season, rivers, surface water and tributaries flow towards the Atlantic Ocean in the south just as the water table tilts towards the same direction. In the dry season, however, the direction changes with a significant drop in groundwater level (UNEP, 2011).

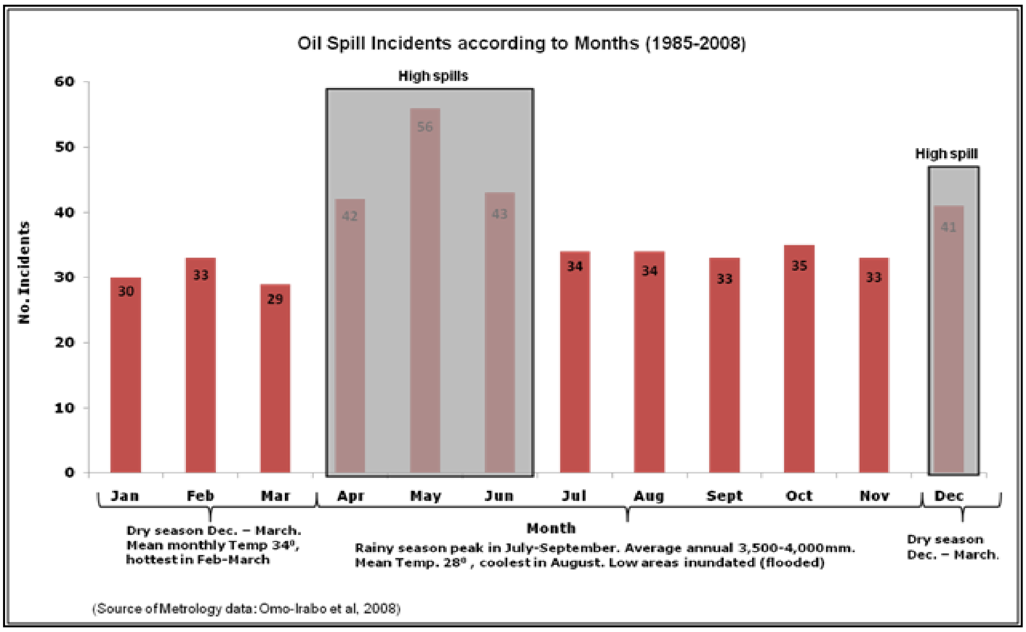


Figure 7-15: Spill incidents in different seasons (Fieldwork data, 2010).

This scenario can provide many opportunities for trapped oil to migrate freely along the southward flow direction without major restriction from inundated surfaces (Figure 7-16), more so in that seasonal inundation submerges shorter vegetation that would have impeded smooth movement of hydrocarbons flowing on the surface. Figure 7-16 and Figure 7-17 show different migration scenarios under the influence of seasonal characteristics. Here the influence of topography is minimal because the area is relatively flat with occasional minor rise and fall of high grounds created by alluvium deposits (Akpokodje, 1987; Abam, 1999, 2001).

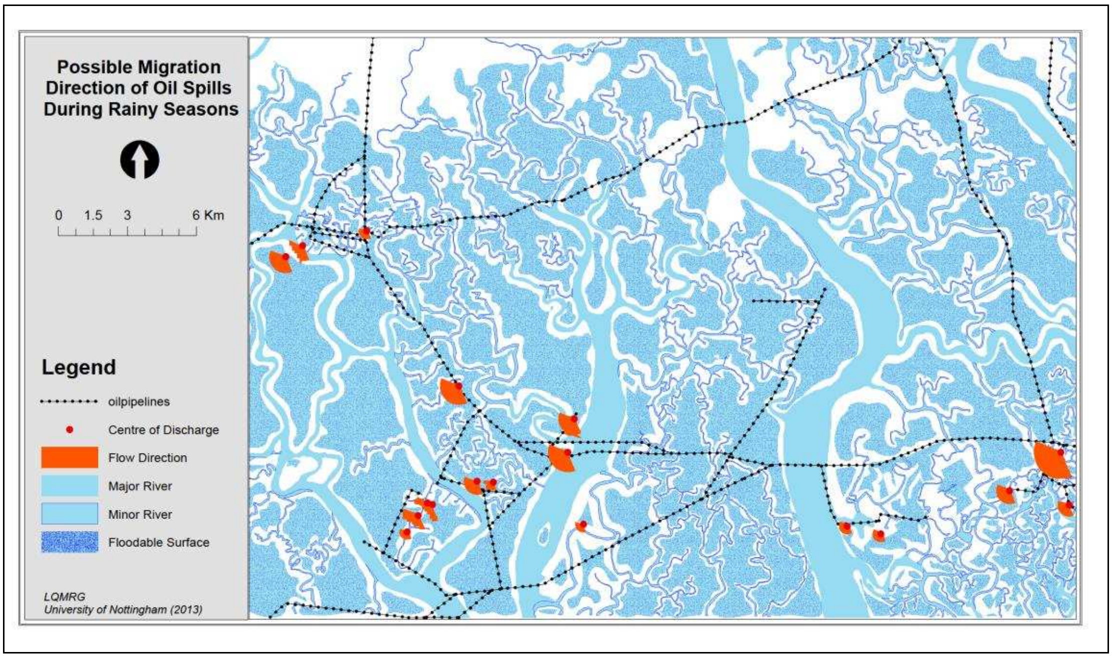


Figure 7-16: Surface oil spills flow southwards in the rainy season.

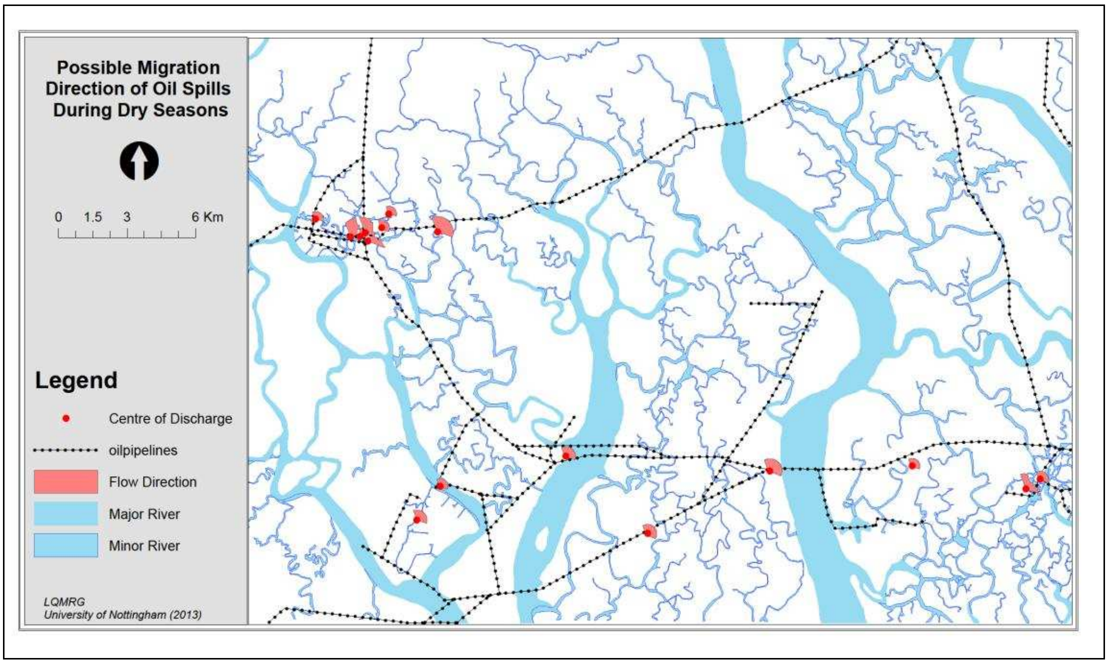


Figure 7-17: Surface oil spills flow northwards in the dry season.

7.2 Assessing Proximity of Communities to Hazards

Given that closeness to pipelines presents a potential hazard by itself, so also is closeness to the river that serves as a vector for hydrocarbon migration. Places where oil spills had occurred can also present current danger to people living nearby. Thus, the proximity of settlements to these possible sources of petroleum contaminants is critical in exposure assessment, hence the need to determine communities likely to be within distance of pipelines, rivers and creeks, and previous oil spill sites.

Plate 7-1 shows the closeness of homesteads to oil installations. Note the control valves and discoloured sections of the pipe, which is caused by corrosion and intermittent submergence in water during the rise and fall of water levels. The water can rise as high as one metre during the rainy season (UNEP, 2011).

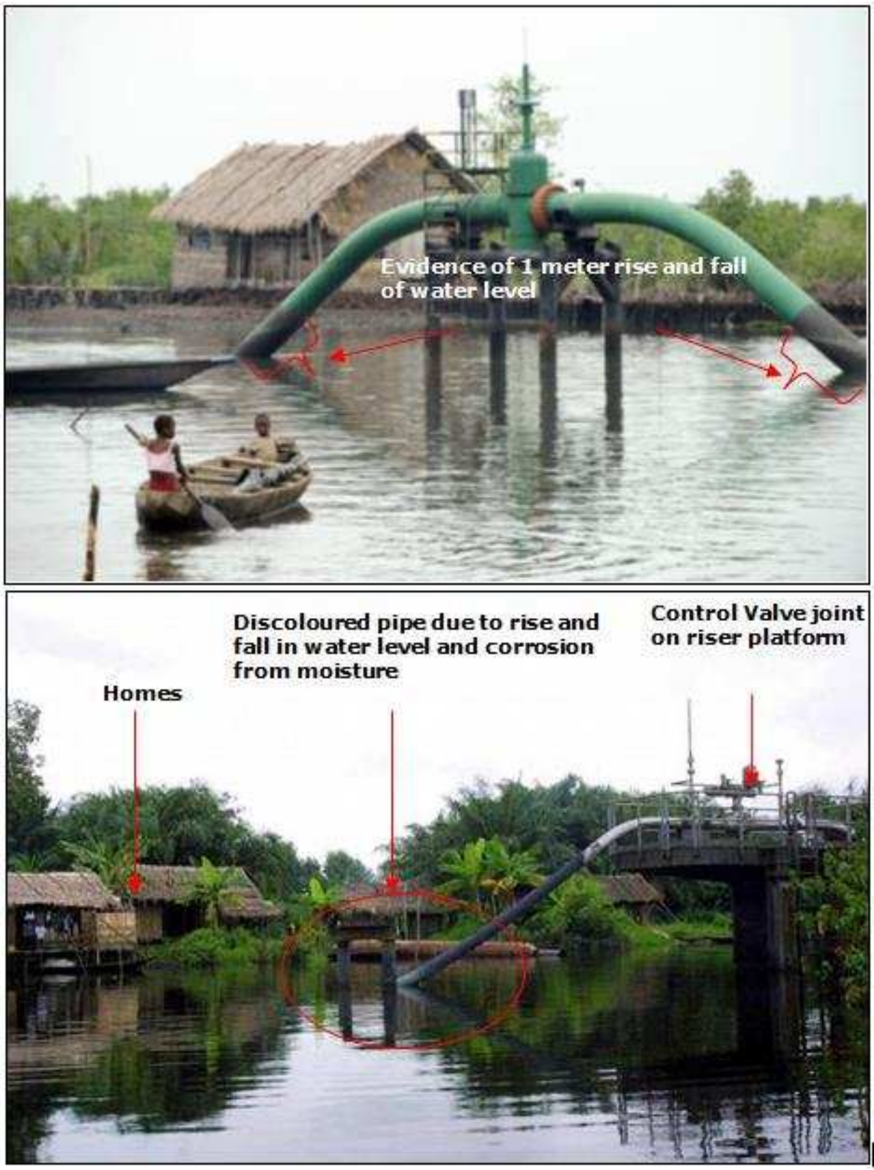


Plate 7-1: A riser platform on the river (NAPIMS, 2010).

7.2.1 Proximity to Historic Oil Spill Sites

This refers to closeness of human dwellings to historic oil spill sites. Although some hydrocarbon compounds escape immediately after a spill, the more persistent remain under a protective crust for a long time. Hence, some hydrocarbon components would remain despite prevailing weathering processes (Subsection 3.5.4) even though toxicity would decrease with weathering (Subsection 4.3.2). However, repeated oil spill incidents could encourage accumulation and regular supply of fresh hydrocarbons to replace escaped toxic lighter hydrocarbons. Figure 7-18 shows that about 47% of 347 communities are located within 3.0 kilometres of oil spill sites.

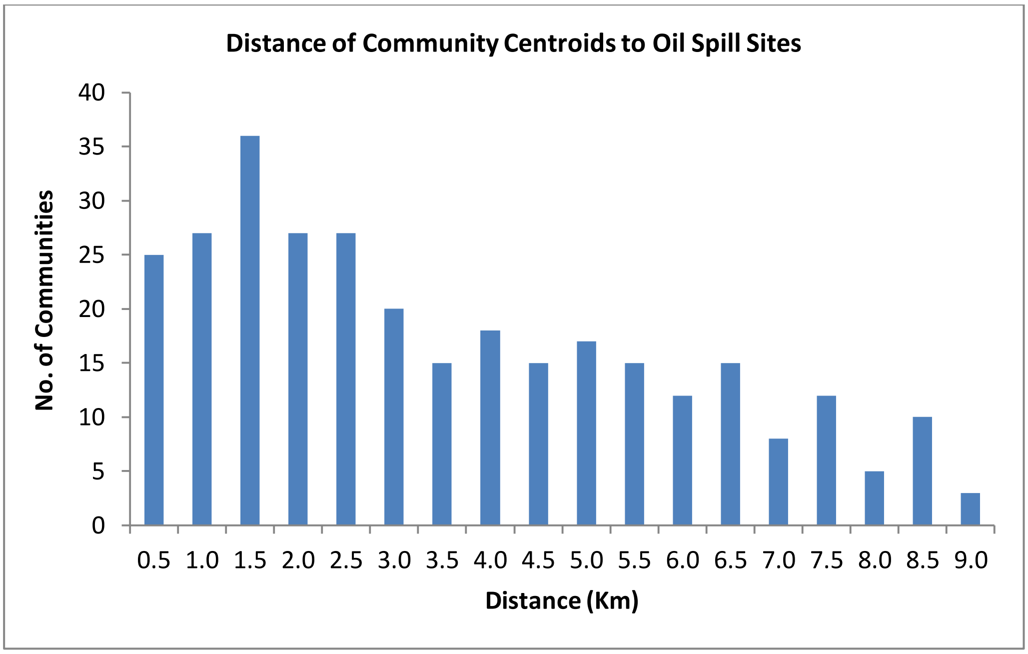


Figure 7-18: Distance of communities to historic oil spill sites.

7.2.2 Proximity to Pipeline System

Pipeline interdiction and accidental discharge can happen on any segment of a pipeline system. Therefore, it is sensible to assume a worst-case scenario wherein an entire pipeline system is treated as a potential source of hazard. There is a 30-metres official buffer for pipelines in the country (EGASPIN, 2002), but observations during the field investigation identified farms and homesteads on several locations along pipeline ROWs. Figure 7-19 indicates the proximity of communities to pipelines.

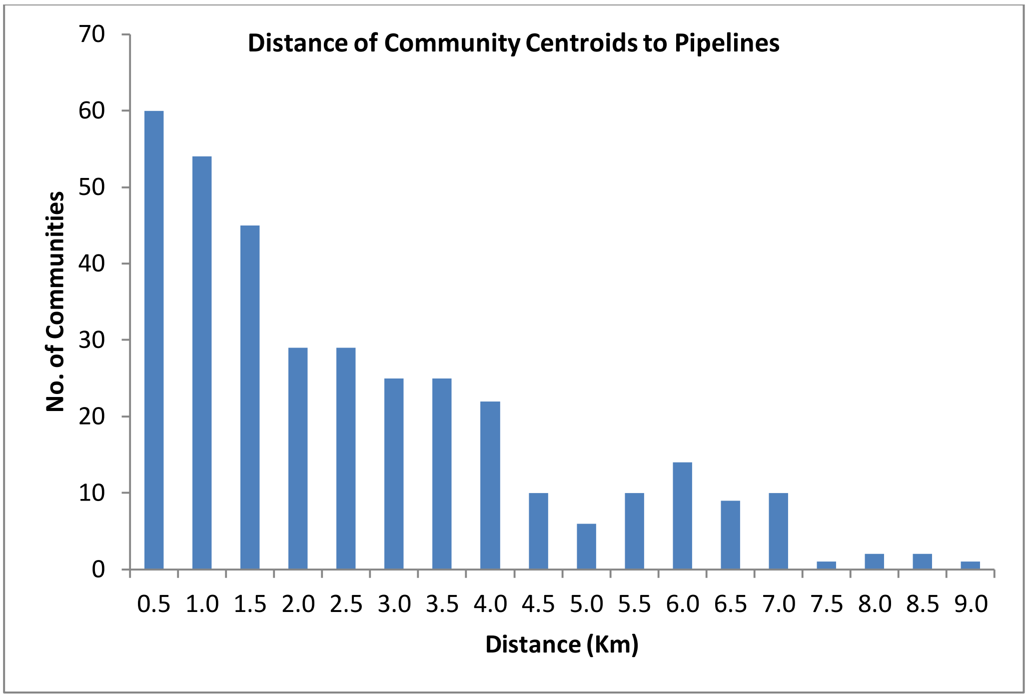


Figure 7-19: Communities distance to pipeline network.

7.2.3 Proximity to Rivers and Creeks

Oil discharge on rivers at pipeline-river intersections, or flushed from land to rivers would migrate and redistribute along the river network. The fact that there is only one aquifer system in the area means wells and boreholes can easily be contaminated due to the shallow water table (UNEP, 2011). Also, riser platforms (Plate 7-1) which are constructed along river intersections to i) avoid running pipes under water, and ii) provide access to control valves, are constantly attacked by vandals and oil thieves (Field interview, 2010).

The distance of communities to spill sites, pipelines, and rivers (Subsections 7.2.1, Subsection 7.2.2, and Subsection 7.2.3) showed that about 25%, 46%, and 93% of communities with around 319,085, 658,958, and 1,249,238 people live within 1.5km of previous spill sites, pipeline network, and rivers respectively. The role of rivers in settlement location is well-known to human geographers and, being a riverine area, it is only logical that settlements are located close to rivers and creeks (Subsection 6.0.1).

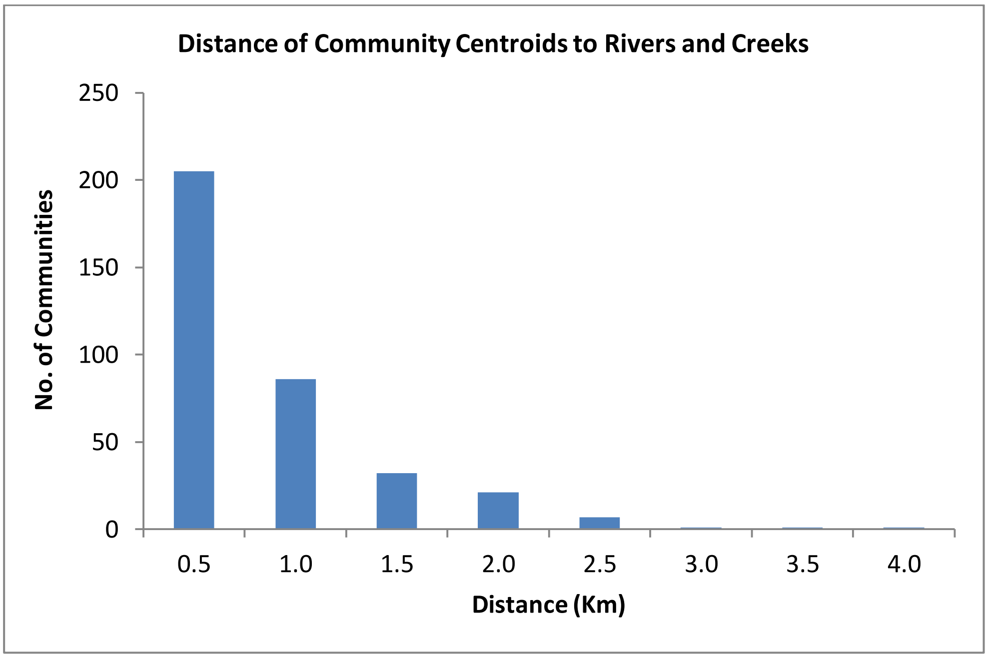


Figure 7-20: Distance of communities to river.

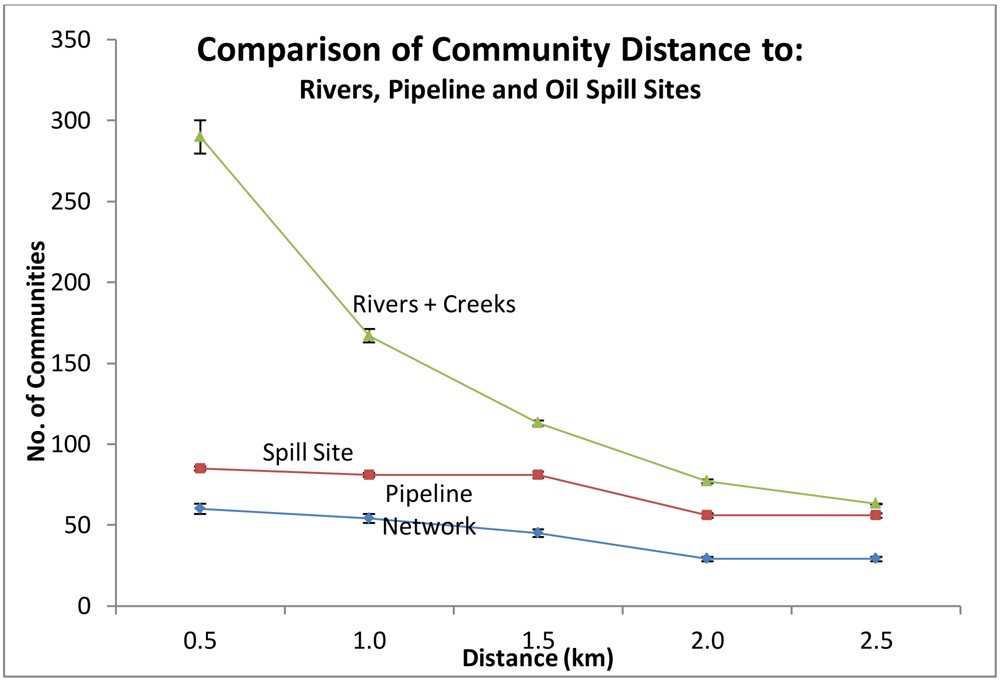


Figure 7-21: Communities within direct and indirect impact radius.

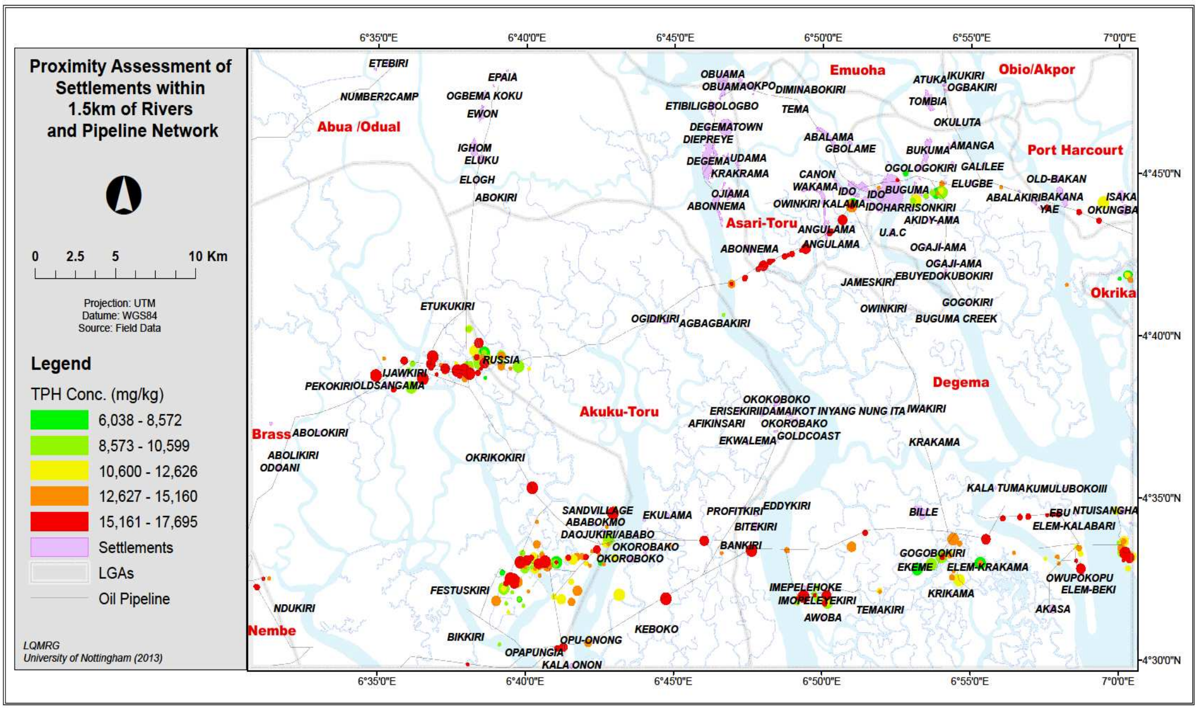


Figure 7-22: Identification of communities within 1.5km of spill sites, pipeline network, and rivers (communities identified by name).

Pipelines seem to influence settlement locations in the Niger Delta even though pipelines do not add any direct economic, social, and political value to their lives. In fact, pipelines not only restrict access to farms and waterways, they prevent free movement and present greater danger to lives and properties close to them (Ogwu, 2011). The following pipeline role in a settlement location was cited (Field Interview, 2010):

i) That local people recruited by pipeline construction companies stay behind to colonise areas around campsites after construction work has finished and the camps dismantled. Those that stayed behind convert the cleared land space to makeshift settlements for fishing and farming purposes, and then gradually evolve into formal settlements with increase in population of relations and friends joining them. Thus, smaller settlements in remote areas were established this way (Field Interview, 2010).

ii) Easement[16] for pipeline ROW is another reason for settlement location. Some landowners give their land for ROW easement, and then occupy part of it. Most low populated communities were established through this means.

According to Figuer 7-23, there is no correlation between distances of communities to pipeline network using population. Perhaps the pattern could be clearer if information on date of community establishment were available. Therefore, with lack of information to determine which came first, pipeline or settlement, it is difficult to validate the above suggestion.

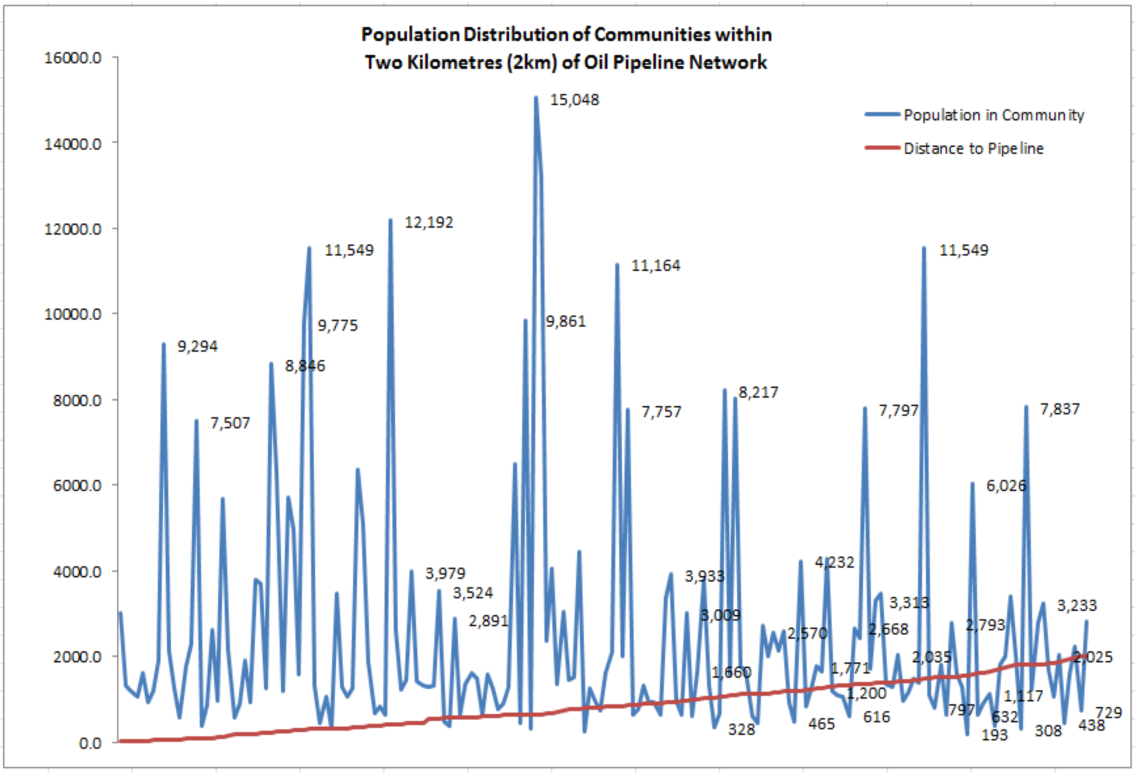


Figure 7-23: Trend of populations in communities within 2km distance of oil pipelines.

[16] Pipeline ROW agreement between MOCs and property owner or landowner.

7.3 Assessment of Oil Spills in Time and Space

The frequency and severity of environmental hazards vary over time and space and, naturally, very severe hazards happen less frequently (Eckle et al., 2012). Thus, in order to determine the severity or otherwise of these spills, the quantity discharged by each spill is considered as its severity. Therefore, following the above logic the severe oil spills should occur less frequently. This is important in risk assessment for determining probability and severity of occurrence in terms of hydrocarbon accumulation in specific areas due to repeated occurrence.

The spatio-temporal analysis examines risk potentials among communities due to repeated spills. To achieve this, the Thiessen polygon method was adopted because of its suitability for this purpose, which is to divide and allocate areas of influence around community centroids (Figure 7-24).

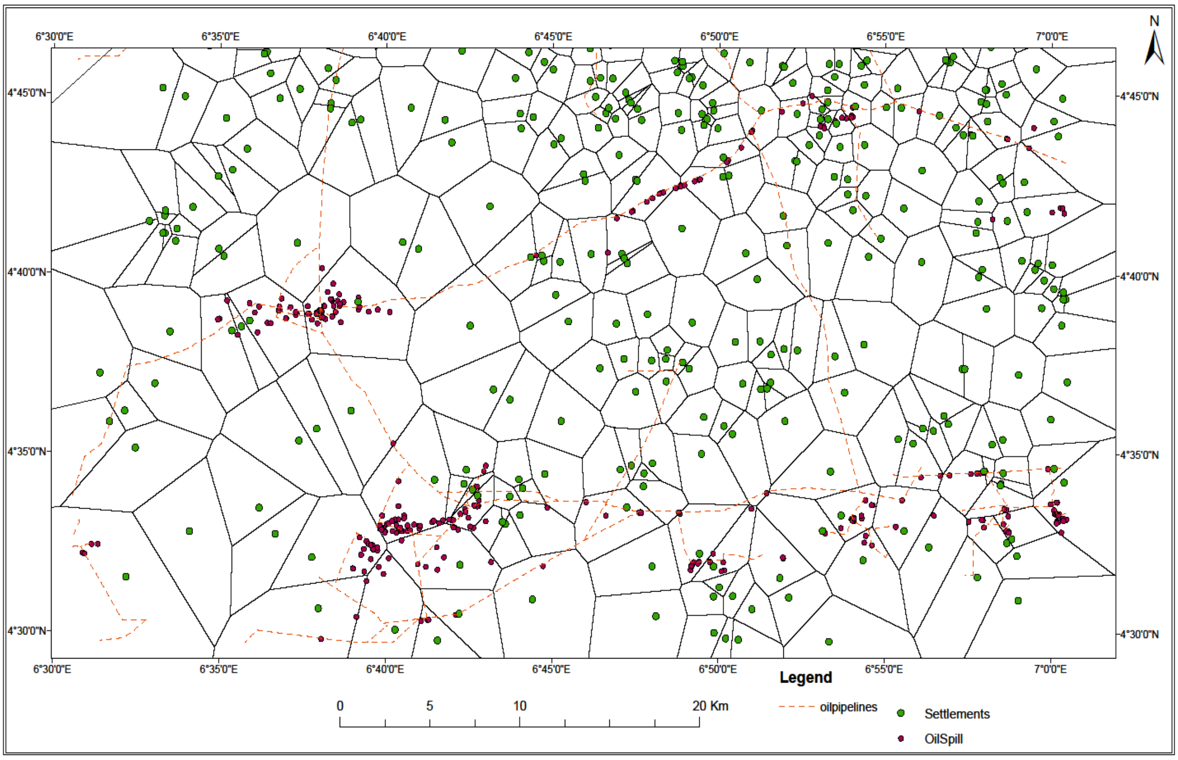


Figure 7-24: Allocation of area of influence to communities by Thiessen polygon.

The Thiessen polygon:

i) ensures that no spill site is on no man's land;

ii) areas enclosed in a polygon are closer to only that polygon; and

iii) communities with the highest count of spills can be identified.

The Thiessen polygon method is preferable to simple buffer or natural boundaries, which would create overlaps or violate the first condition by allowing spills to fall on no man's land. The Thiessen polygon helps to eliminate this bias because spills are allocated to the closest polygon centroid (Subsection 5.5.1).

There are 443 oil spills that occurred over 24 years (Subsection 6.1.1). These spills were divided into four groups of six according to years of occurrence: i.e. 1985-1990 (first period): 1991-1996 (second period): 1997-2002 (third period): and 2003-2008 (fourth period) for the analysis. Although preliminary analyses (Section 7.1) indicate that interdiction was responsible for about 31% of the spills and, because people cause interdiction, it is logical to assume that communities with the highest record of spills caused by interdiction encourage it. Benedict (2011) reported that mobile gangs go about from one community to another to vandalise oil pipelines.

7.3.1 Oil Spills Spatio-Temporal Analysis

A total of 129,778 barrels (bbl.) of crude oil was discharged in 443 incidents around 58 communities in the period under review. Several communities had multiple consecutive incidents (see Appendix D) within their areas of influence. The notable ones are Russia (59), Onongisuo (45), Ijawkiri (24), Gogobokiri (27), Aderikiri (32), Egorobiti (23), Festuskiri (27) etc (Figure 7-25 and Appendix D). Meanwhile Russia, Ekulama, and Festukiri, had 26, 16 and 12 case of interdiction respectively

(Figure 7-25); thus, going by Benedict (2011), this suggests a high tendency for interdiction activities in these communities.

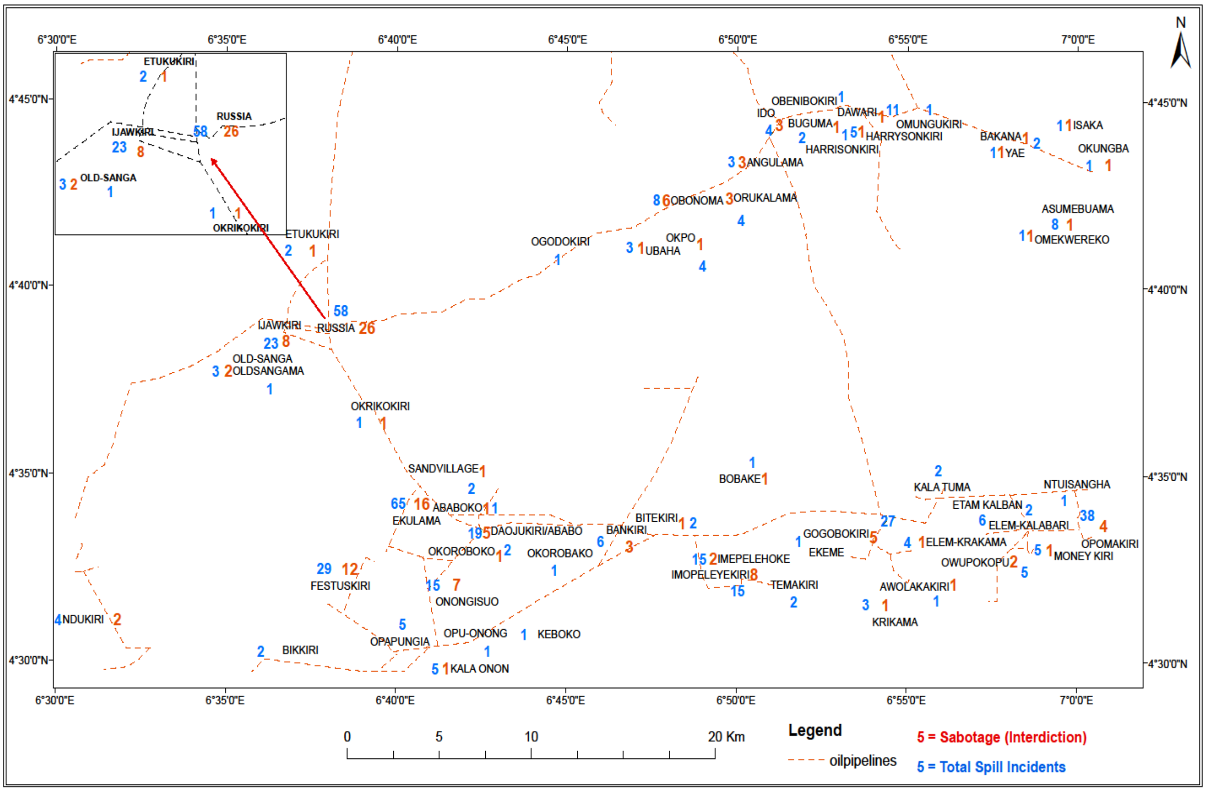
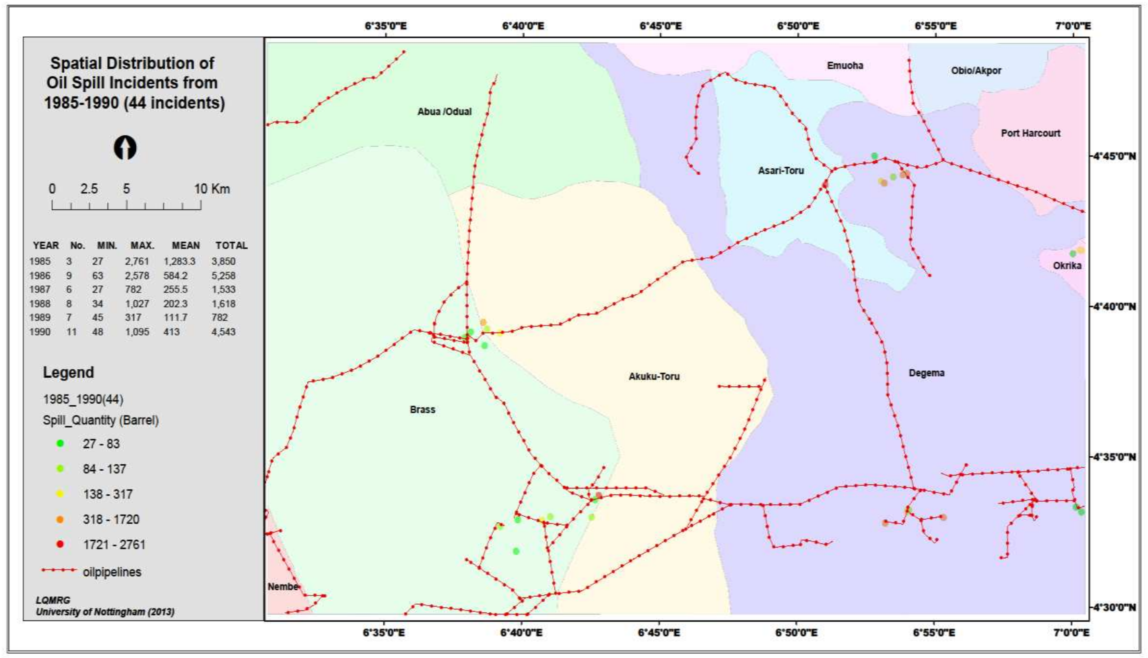
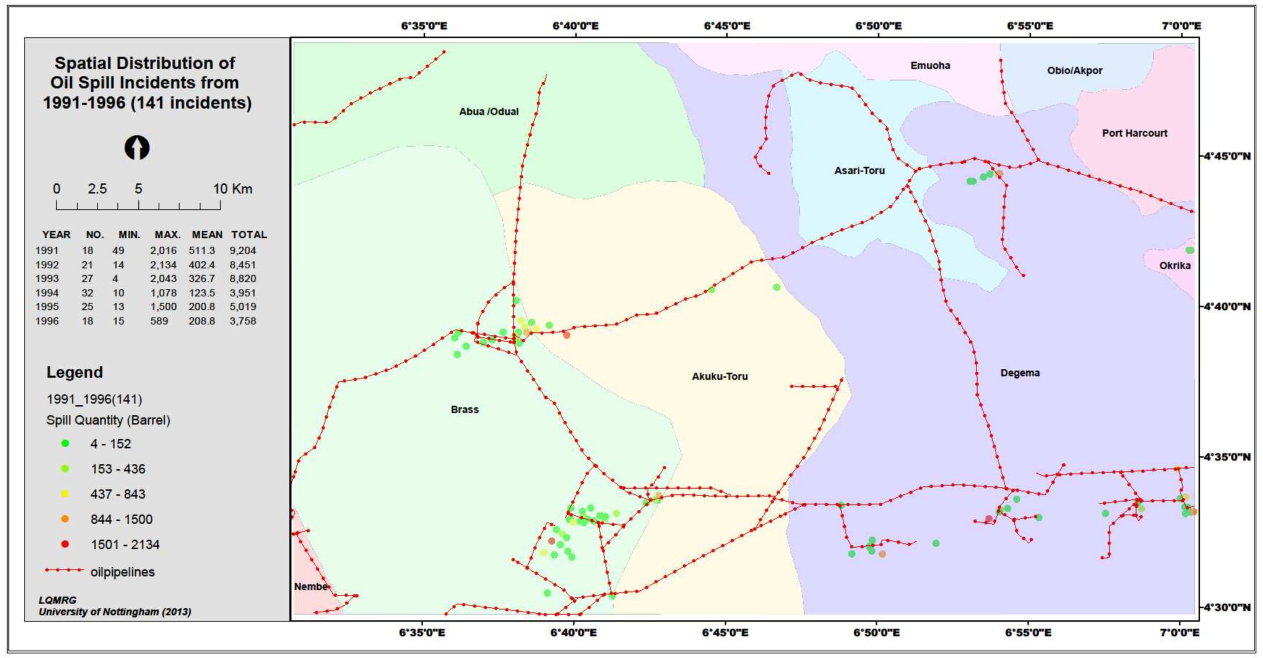


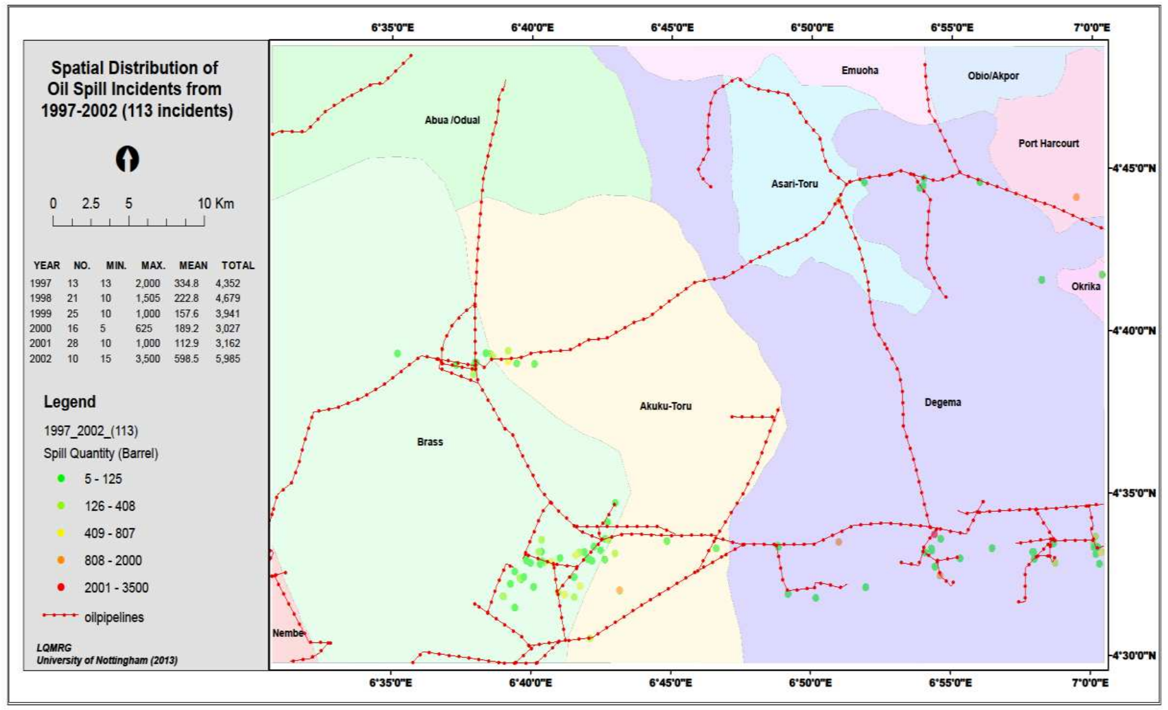
Figure 7-25: Oil spill incident count by communities showing total spills and spills caused by interdiction (insert Russia, with the highest number of interdictions).

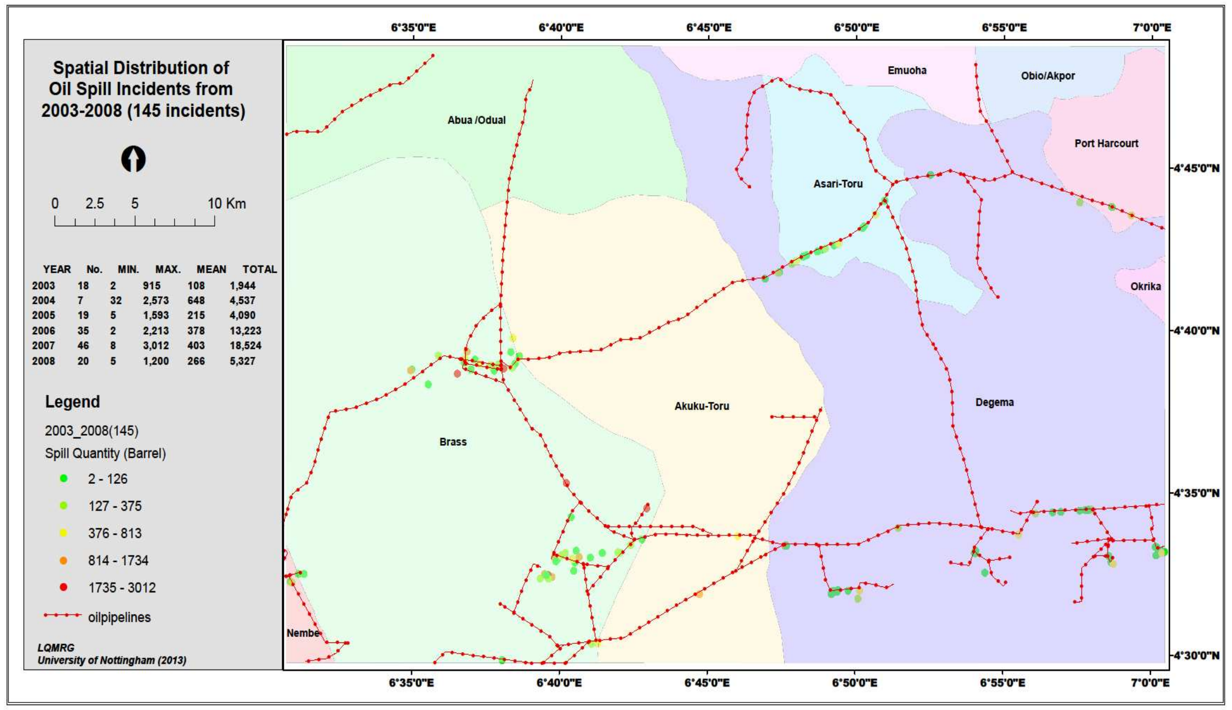


1) 44 incidents, 17,584 barrels (mean=400, SD=632, 95th=1,443).



2) 141 incidents, 39,203 barrels (mean=405, SD=607, 95th=1,407).





3) 113 incidents, 25,146 barrels (mean=214, SD=406, 95th=884).

4) 145 incidents, 47,645 barrels (mean=240, SD=481, 95th=1,034).

Figure 7-26: Spatial distribution of oil spill incidents and quantities discharged (Fieldwork data, 2011).

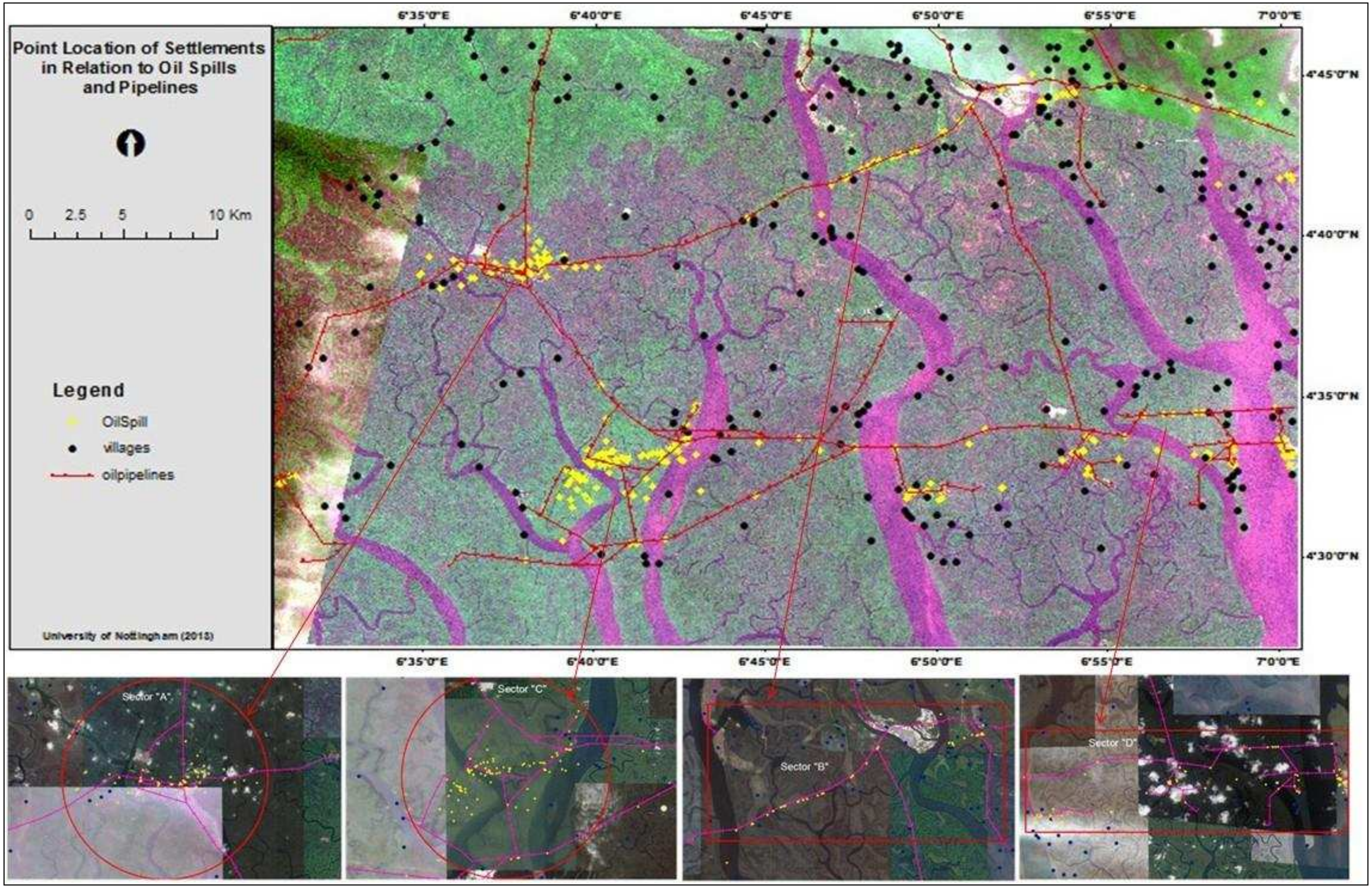


Figure 7-27: Location of areas with highest spill - see Figure 7-28 for identified oil facilities (Google Earth, 2011).

Figure 7-28: Sector "A" oil facility around Old Sangama and Ijawkiri area, Sector "B" south of Degema and Obonoma communities, Sector "C" oil facility around Festuskiri and Egorobiti area and Sector "D" oil facility around Okikiri, Imepelehoke and Imopeleyekiri area (prepared courtesy of Google Earth).

7.3.2 Communities with High Cumulative Exposure Risk

Subsections 7.3.1 revealed that 59 communities had multiple spill incidents. The top 20 communities are presented in Table 7-1 showing number of spills in each year category; communities with a score of four against them means they had spills in each category.

Table 7-1: Top ten communities with repeated spill incidents.

S/N	Name	No of Incidence					Freq.	Sabotage
		85-90	*91-96*	*97-02*	*03-08*	Score		
1	RUSSIA	7	21	13	18	4	59	26
2	ONONGISUO	2	13	21	9	4	45	7
3	IJAWKIRI	x	11	1	12	3	24	8
4	GOGOBOKIRI	5	12	6	4	4	27	5
5	ADERIKIRI	2	9	10	11	4	32	8
6	EGOROBITI	1	10	9	3	4	23	8
7	FESTUSKIRI	2	12	5	8	4	27	12
8	IMEPELEHOKE	x	x	1	3	2	4	2
9	DAOJUKIRI/ ABABO	3	4	5	2	4	14	5
10	DAWARI	4	2	2	x	3	8	1
11	ABABOKMO	x	4	5	3	3	12	4
12	IDO	1	x	1	2	3	4	3
13	BANKIRI	x	1	1	5	3	7	3
14	OKPO	x	x	x	7	1	7	2
15	KILLYKIRI	3	2	1	x	3	6	1
16	OPOMAKIRI	1	4	3	x	3	8	4
17	OMEKWE-TARI-AMA	x	x	x	6	1	6	1
18	ASUMEBUAMA	5	2	1	x	3	8	1
19	ELEM-KRAKAMA	1	1	1	1	3	4	1
20	OBENIBOKIRI	1	2	x	x	2	3	1

G1=1985-1990, G2=1991-1996, G3=1997-2002, G4=2003-2008. x =no incident1

A community with multiple spill incidents is at risk of becoming susceptible to hydrocarbon exposure due to accumulation of hydrocarbon contaminants. Consequently, if risk can be defined as the probability of occurrence (frequency of spill) and consequences (quantity) of spill events (Eckle et al., 2012), then communities in the Top 20 are suceptible to risk of hydrocarbon contamination.

7.4 Land Use Questionnaires Analysis

Two hundred and fifty questionnaires were administered to 199 males and 51 females, aged from 16 to 43 years (Figure 7-29).

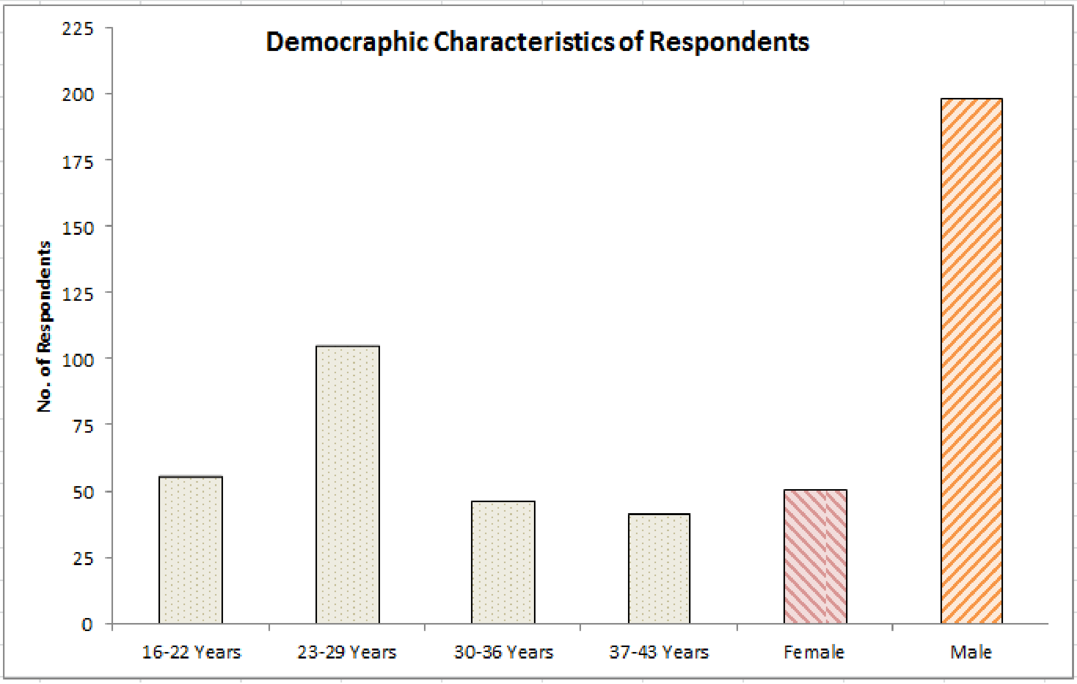


Figure 7-29: Demography of respondents.

About 198 undertake farming, 151 Fishing, 174 hunting, and 197 wild gathering. The result showed that about 13.2% perform all four activities, 9.2% combine three, 12.4% combine two, while 65.2% do just one activity. A non-parametric test using Pearson chi-square was conducted to determine the proportion of respondents who combine more than one land use activity. The chi-square test result (with Yates Continuity Correction) indicated significant association between the following land use activities: hunting and wild gathering X^2 *(1, n=250) =72.9, p=.000, phi =.55*;

hunting and fishing X^2 *(1, n=250) =51.0, p=.000, phi =.46*; wild gathering and fishing X^2 *(1, n=250) =13.3, p=.000, phi =.24;* and farming and wild gathering X^2 *(1, n=250) =10.4, p=.001, phi =-.22* (Appendix G2). There is no association between farming and other activities except wild gathering; it means farmers do not perform serious fishing or hunting. This is true because fishing and hunting require skills and are full time occupations; therefore, farmers are not likely to use periods of the dry season to fish but would rather gather from the wild in preparation for the rainy season.

7.4.1. Land-Use Frequency and Duration

Farming begins in the onset of the rainy season when farmers clear their farms in preparation for planting; during this time much is done; however, work rate reduces after weeding and then intensifies again for the harvest.

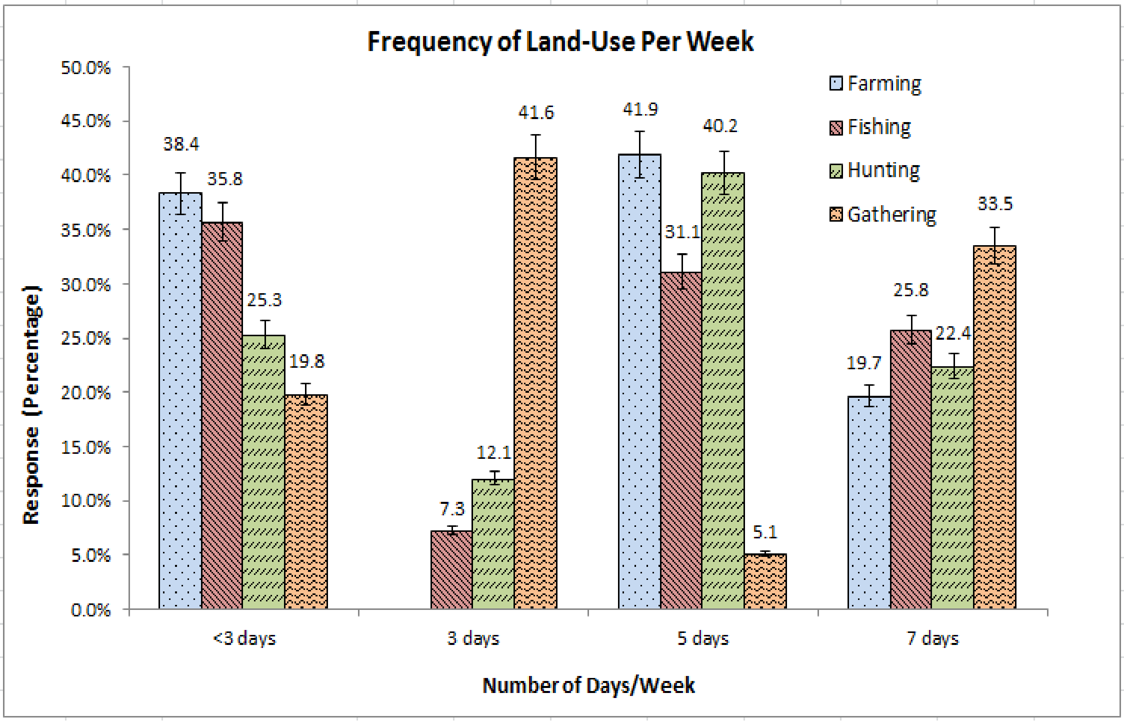


Figure 7-30: Frequency of land use activities.

It is customary in many villages for people to stay at home on Sundays (Christian communities) and, on market days, rural markets take place periodically rotating among neighbouring communities on a weekly cycle

(Ataguba, 2013; Oguntade, 2013; Yusuf, 2013). From Figure 7-30 it is evident that respondents work from 5 to 7 days per week, with the majority working five days a week. The exception is wild gathering where 33.5% claim to gather for seven days; it is usual because gathering involves a lot of things, i.e. gathering wild vegetables, fruits and other edibles for family consumption.

On hours spent working in a day, about 88% across all activities spend more than four hours daily (Figure 7-31). Also, asked about distance covered every day to where they conduct land use activities, 70% claimed they travel more than 3km daily (Appendix G10).

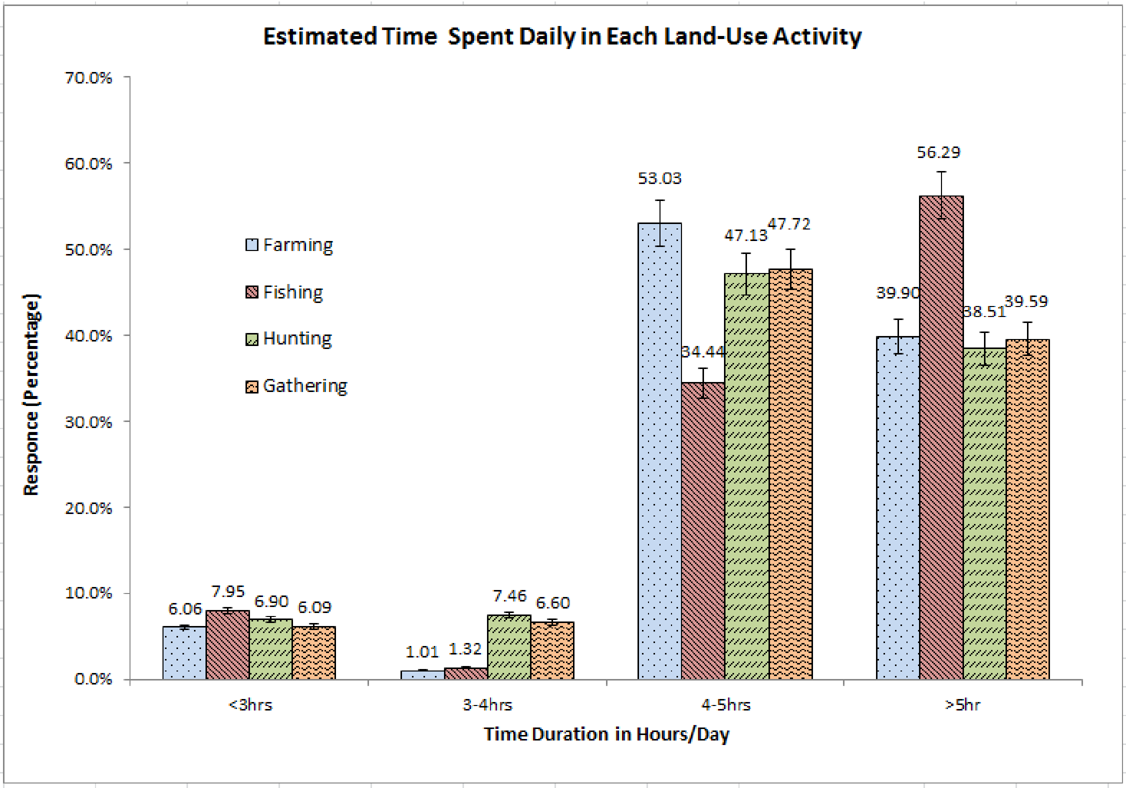


Figure 7-31: Time spent performing land use.

7.4.2. Work Intensity and Protective Clothing

When asked if the work they do is energy intensive, 60.5% (151) responded in the affirmative (very intensive) while 27% (67) opined their work is less intensive and 12.8% (32) claimed their work is not energy intensive. On the type of labour they use, about 65% (162) confirmed they use menial labour provided by family members.

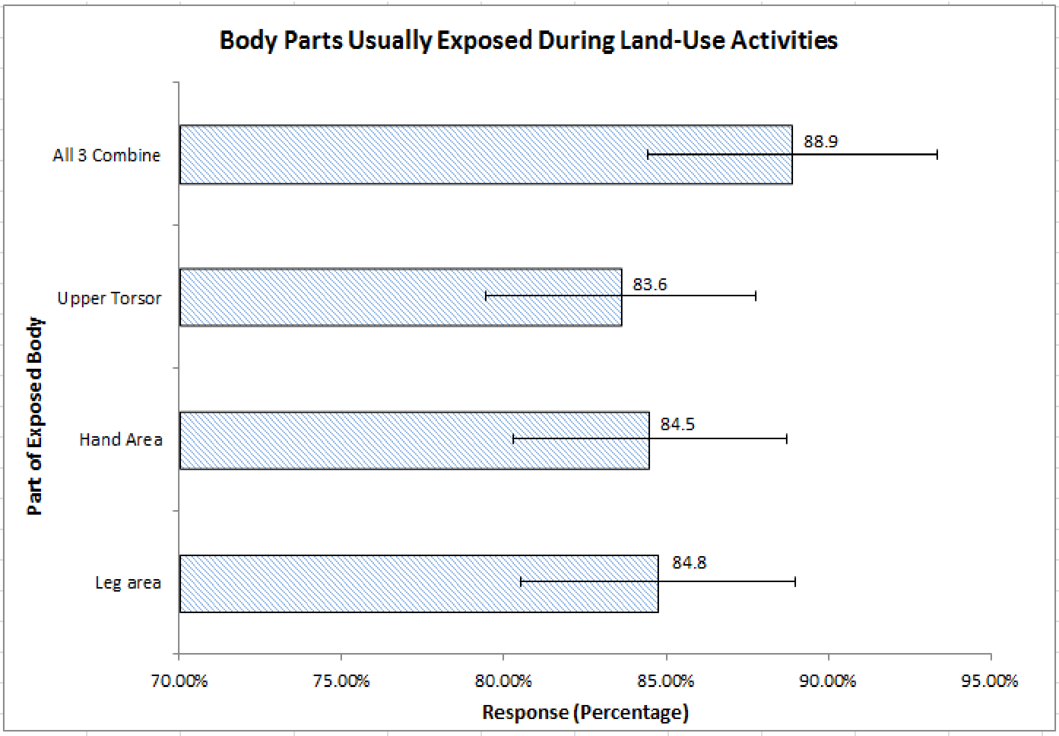


Figure 7-32: Parts of body left uncovered during land use.

Asked whether they use protective clothing during work (protective clothing in this regards refers to any form of clothing material or layer worn to cover the body), about 83% said they do not use protective clothing during land use activities; in fact 94% leave their leg area (85%), hand (85%), torso (94%) and 89% uncovered (Appendix G13-17).

The relationship between age and protective clothing was investigated to determine whether age has any influence on working with parts of the body exposed during land use. The results showed no direct correlation between age and protective clothing, i.e. *r= 0.02, n-250, p>0.05 (2-tailed Pearson Correlation)*. Therefore, non-use of protective clothing could be due to lack of it or a customary trend. However, there was strong correlation between age and working with exposed body, i.e. *r=0.16, n=250, p<0.01 (2-tailed Pearson Correlation)*, just as there is correlation between protective clothing and exposed body, i.e. *r= 0.26, n=250, p<0.05 (2-tailed Pearson Correlation*) (Appendix G: Table 2a). What this means is that age has no influence on non-use of protective clothing; children and adults work under high temperatures using highly-intensive forms of menial labour, which would require them to remove their tops or roll up sleeves and trousers to allow ventilation and prevent excessive perspiration when working. The use of protective clothing on the other hand is a function of availability and comfort; it may be difficult to work for a long period under high temperatures with full clothing (protective layer) on the body.

Conclusion

Data is an important ingredient in any research; both primary and secondary data are developed to derive a reasonable conclusion on a subject matter. Consequently, this chapter is built on secondary datasets acquired from different sources to generate information on spatial distribution of oil spills relative to human settlements in the study area. This was possible through the harmonisation of datasets collated from different sources into one coherent meaningful resource for analysis.

Consequently, it was possible to identify communities potentially susceptible to petroleum hydrocarbon hazards due to: i) proximity and ii) repeated occurrence of oil pipeline spills in their areas of influence. As a result, communities like Russia, Onongisuo, Ijawkiri among others were identified as having a high record of oil spill incidents and pipeline interdiction (Figure 7-25). Although these communities may not be directly responsible, it is however logical to conclude that they are complacent with interdiction activities, according to assertions from Benedict, (2011). Having information (high incident communities) like this is important for implementing some of UNEP's recommendations, specifically on a community’s proactive stance against vandalism (Table 3-8) and in strategic planning of a sensitisation campaign for public trust and cooperation.

The distribution of oil spill incidents is not random and seems clustered around particular areas, i.e. communities, oil infrastructure and pipeline network (Figure 7-26, Figure 7-27, and Figure 7-28). Results from the analysis also revealed the lack of a direct relationship between frequency and quantity or cause of oil spills (Section 7.1). As a result, no specific reason could be deduced for lack of a clear pattern in oil spill incidents; however, there is no doubt that the socio-political crisis in the Niger Delta (discussed in Chapter 2) provided basis for oil theft and interdiction (Mohammed, 2012; John, 2013). It is vital to conclude that quantities of crude oil have been released into the environment and it is probable that impacted sites are yet to fully recover based on evidence from toxicity mapping of oil spill sites (Figure 7-4 and Figure 7-5). From the correlation, it is safe to conclude that the quantity of oil spill plays a significant role in weathering-based toxicity reduction.

The important point is that these communities may be exposed to hydrocarbon-contaminated environmental media in land use or during routine daily life activities. Subsection 7.0.3 showed that toxicity of crude oil does not dissipate completely with weathering: other resistant hydrocarbon fractions (high molecular weight) remain (Bellas et al., 2013). The replenishment of hydrocarbons through repeated spill incidents is an indication that (Appendix D) portends danger to people living in such areas. This chapter has established the existence of oil spills and identified communities around the impacted sites. Considering dangers posed by hydrocarbons to humans’ health, a generic risk assessment criteria is developed in the following chapter for rural land use assessment in the Niger Delta.

CHAPTER 8

LAND-USE CHARACTERISATION AND EXPOSURE EVALUATION

8.0. Introduction

This chapter investigates outdoor land-use activities performed by indigenes of the study area in their day-to-day livelihood in order to gather information on how, whom, what and when it is being performed, and the scale and duration of land use. Based on this information, a potential land-use pattern and exposure scenarios are developed to assess outdoor land-use risk exclusively for communities within designated HCAs. Lack of human health risk assessment criteria in Nigeria necessitates the development of screening values for rural land use related to human health risk, using established parameters from the United Kingdom, United States of America and others.

8.1 Land-Use Exposure

Exposure occurs where pollutant linkages exist. This can be a simple unconscious hand-to-mouth contact, from cloth to skin, from home-grown food cultivated on contaminated land, to tracking of contaminants back into homes, etc. (Kimbrough et al., 2010). Guideline values have been derived based on generic assumptions of the behaviour and characteristics of contaminants in land-use exposure scenarios (Cheng and Nathanail, 2009; Canadian Council of Ministers of the Environment, 2010; CLAIRE, 2010). Consequently, contaminants in land use such as residential, allotment, commercial, industrial, recreation etc. have been assigned screening levels beyond which they are assumed to have deleterious impact on human health. As a result, different countries have their respective GAC, some of which may be very stringent or conservative.

But, despite ample exposure opportunities in rural areas, no work has so far incorporated rural human receptors, whose lifestyles and occupations predispose them to substantial exposure tendencies, e.g. farming, fishing, gathering, hunting, animal herding etc. (Doyle et al., 2010) in human health risk assessment criteria. Extensive work has been done on land-use exposure in developed countries such as the United States, United Kingdom, Canada etc. (Environment Agency, 2009; Canadian Council of Ministers of the Environment, 2010; US Environmental Protection Agency, 2011) leading to the development of land-use assessment frameworks. However, there is as yet no framework specifically designed to address rural land-use exposure. Presently there are no assessment criteria for petroleum hydrocarbons in Nigeria, nor is there regulatory framework for contaminated land management.

8.1.1 Exposure Duration, Frequency and Averaging Time

Two exposure scenarios are envisaged. Firstly, exposure due to presence of polluted media around a homestead and, secondly, exposure due to contamination of farmland and land-use sites. The first depicts long-term continuous indoor and outdoor exposure as people spend time at home; the second, on the other hand, is not continuous because outdoor activities are time specific. This work is focused on outdoor land use because activities are performed at a specific time and season (indoor exposure is outside the scope of this research), hence the duration and frequency of an activity can be used to determine exposure. A questionnaire survey (Subsection 6.1.3) showed that the majority of the respondents spend more than four hours a day in their respective land-use activities (Figure 7-31) and four to five days a week (Figure 7-30). Using this information, duration and frequency per day per week for each activity is determined in

Table 8-1, and used to estimate exposure (IPCS, 2000; Environment Agency, 2009).

The Environment Agency (2009, p.15) developed a very simple approach for estimating AT. For example, the AT of a six-year-old child is 2,190 days, being the number of days in a year (365 days) multiplied by the child's age (6 years). By adopting this approach, a non-carcinogenic averaging time is estimated for each land-use activity selected (Table 8-1). Thus, while exposure duration is the time spent conducting a particular activity, AT is the number of days in a year multiplied by the years of a receptor. For non-threshold (carcinogenic) exposure assessment on the other hand, 75 years is used in the United States (USEPA, 1997, 2009a). In the case of non-threshold (carcinogenic) assessment for Nigeria where life expectancy at birth is 52 and 54 years for men and women respectively (World Bank, 2011; WHO, 2013), 75 years is used with caution for benzene in the soil-screening values (see Subsection 8.3.1).

8.1.2 Outdoor Rural Land Use

This comprises all land-use activities undertaken to meet the daily sustenance and economic requirement of a household, which may be performed on allotments (gardens) near homes or on marginal fields far away from settlements. Availability of land and household size determines the scale and size of land put under use, although land ownership (including dry land, pond, swamp and forest) in the small communities of the Niger Delta is owned by clan, inheritance, conquest, donation, rent and purchase (UNEP, 2011). Most rural people practise small-scale agriculture with intensive physical labour, and often their choice of cultivation is reliant on seasons (Okoli, 2006; Kassali et al., 2009; Ismaila et al., 2010).

The outdoor land uses under consideration are guided from the responses of 250 questionnaires, the result being used to estimate duration and frequency, and calculate averaging time for individual land use as presented in Table 8-1. Since about 85% of the respondents work for five days or less (Appendix G: Table G11) in a week, five days was used to calculate the weekly duration and frequency. This is logical because an average farmer goes to the market on market days to sell produce and buy essential supplies. Market days in rural areas alternate between communities so that each community has a specific market day in a week. Sundays are always for worship; hence the author used Sundays and market days to account for the remaining two days of the week.

8.2 Land-Use Classification

The types of land-use activities performed by people reflect their socio-economic level and lifestyles. Although the purpose of land use may differ from place to place, land is used to meet man's needs in one way or another (Efiong, 2011). Unfortunately, there is no documented information on rural land-use regimes in Nigeria, even though about 50% of the country's population live in rural areas (UNdata, 2013). The environment where people live shapes their culture, and culture influences land-use participation and allocation. Consequently, it is common in traditional African rural communities to find specific tasks reserved for particular age groups or genders; it is also unlikely for another group to be seen performing tasks not traditionally allocated to them, e.g. fetching water, and firewood collection are reserved for women (Dalton, 1962).

Table 8-1: Land-use potential receptors, estimated exposure duration and averaging time.

No.	Activities	Possible Exposure Route	Potential Receptor	Est. Exposure Duration and Frequency per Year	Est. Averaging Time for 30yrs adult and 6yrs child
1	**Farming**	i) Inhalation of contaminated dust particles during soil tilling. ii) Ingestion of contaminated farm produce or soil ingestion by means of substance-to-hand-to-mouth (IPCS, 2005). iii) Dermal contact through deposition of suspended particles on parts of the body.	Members of the family who provide farm labour, i.e. children and adults.	ED=5hrs/day, 5days/week for 8months (240days) being the length of the farming season. $EF = \frac{5}{7} \times (8 \times 30) = 171\ days\ per\ year$ *8 months duration of cultivation*	Adults' AT *171days x 30yrs* *= 5,130days* Children's At *171days x 6yrs* *= 1,026days*
2	**Fishing**	i) Dermal contact: direct and indirect skin contact with contaminated water during fishing. Indirect contact transfers contaminants from soaked cloth to skin. ii) Inhalation of volatile hydrocarbons from a freshly-spilled surface can be significant. Inhalation during fish smoking (a preservation technique with heat and smoke). Release trapped hydrocarbons in fish tissue into the ambient air for inhalation. iii) Ingestion can occur by ingesting contaminated water and fish. Consumption of contaminated fish is a potential source of exposure.	Children and adults involved in fishing, fish preparation, and fish consumption.	ED=6hrs/day, 5days/week for a year. $EF = \frac{5}{7} \times 365 = 261\ days\ per\ year$.	Adults' AT *= 261 x 30* *= 7,830* Children's AT *= 261 x 6* *= 1,566*
3	**Hunting**	i) Dermal contact may occur when a hunter's trap site becomes polluted. Direct and indirect contact via deposition of suspended hydrocarbons on skin or from cloth to skin, as he travels through different layers of polluted surfaces. ii) Ingestion from surface-to-hand-to-mouth or ingesting contaminated wild fruits. iii) Inhalation during movement from one trap site to another is possible since it involves travelling within and between changing layers of polluted air.	The receptors are children and adults performing this activity.	ED=5hrs/day, 5days/week for a year. $EF = \frac{5}{7} \times 365 = 261\ days\ per\ year$	Adults' AT *= 261 x 30* *= 7,830* Children's AT *= 260 x 6* *= 1,566*
4	**Gathering**	i) Inhalation when gathering on or near a polluted site; inhalation of contaminated air or dust particles within a polluted microenvironment is possible. Also, burning of wood can release trapped hydrocarbons in plant tissue. ii) Dermal contact can occur while walking through polluted sites or being in contact with contaminated surfaces. Suspended hydrocarbons can deposit on leaves and be transferred while walking past. iii) Ingestion is not common in this activity except if wild contaminated fruits are consumed or surface-to-hand-to-mouth contact occurs.	Women and children are the critical receptors in this activity because they are more involved with cooking and gathering.	ED=5hrs/day, 5days/week for a year. $EF = \frac{5}{7} \times 365 = 261\ days\ per\ year$	Adults' AT *= 261 x 30* *= 7,830* Children's AT *= 261 x 6* *= 1,566*

Note: For duration and frequency per day per week per activity, see Figure 7-30 and Figure 7-31

For a man to do that in some cultures, he may be scorned by other villagers; hence, traditional allocation makes it easy to fit particular land-use activities to a specific gender and age group (Table 8-1) to derive exposure parameters. Land use, under the concept of contaminated land management and risk assessment, uses a conceptual model to assess risk using information on historic and current land use, nature of contaminant on site, its fate and transport, as well as its toxicity and extent (Cheng and Nathanail, 2009). The outcome is compared with established national standards to evaluate the magnitude of risk. Previous oil spill sites (Chapter 7) can satisfy the condition of a contaminated site and, since Nigeria does not have a coherent contaminated land regime, the UK definition may suffice. Contaminated land under Part 2A of the Environmental Protection Act 1990 is:

> "*any land … by reason of substances in, on or under the land, that a) significant harm is being caused or there is a significant possibility of such harm being caused or b) pollution of controlled waters is being, or is likely to be caused*" (Department for Environment Food and Rural Affairs, 2012).

Thus, human activity patterns on land considered contaminated can provide data for exposure assessment (Dept. of Environmental Affairs, 2010). In this regard, land-use activities are categorised broadly into rural agricultural land use, rural informal dwelling, and rural standard residential. While the last two may have indoor exposure attributes, this research is primarily concerned with outdoor land-use exposure. Therefore, the outdoor land uses discussed herein are agricultural land use (consisting of farming, fishing, wild gathering, and hunting in Table 8-1), rural informal residential, and rural standard residential. Table 8-2 indicates potential exposure pathways inherent in the three land uses.

Table 8-2: Possible exposure pathways in rural land use.

Exposure pathways	Rural Land Use		
	Agriculture	Informal Dwelling	Standard Residential
Inhalation of vapour (outdoor)	✓	✓	✓
Inhalation of soil-derived dust (outdoor)	✓	✓	✓
Ingestion of soil attached to vegetables	✓		
Ingestion of soil and dust	✓	✓	✓
Ingestion of contaminated water	✓	✓	✓
Dermal contact with soil and dust	✓	✓	✓
Consumption of home - grown vegetables	✓	✓	✓

8.2.1 Rural Agricultural Land Use

Seasonal pattern is crucial in agricultural land use; decisions on what type and duration of production must conform to the season. For instance, farming takes about six months from cultivation to harvest (depending on crop). Fishing on the other hand is favourable in the dry season (Tamuno et al., 2009; Abowei et al., 2010) when the river level is low. Wild gathering is done throughout the year because produce is freely available both in the rainy season, e.g. snails, palm kernels, periwinkles, edible insects, fruits, vegetables etc., and in the dry season, e.g. materials like dry wood, herbs, tree fruits etc. Since most rural production is on the subsistence level (International Food Policy Research Institute, 2004; Baiphethi and Jacobs, 2009), households take advantage of seasonal patterns to partake in different land uses to sustain their family through the year.

For this land use, an area with a repeated history of oil spill incidents and polluted fields is envisaged, because people are unable to relocate due to land scarcity in the Niger Delta (Gay et al., 2010). Possible exposure pathways are in agricultural land use (see Table 8-2), and the hypothetical receptor is a household with children who provide labour during the rainy season for cultivation (Adeoti et al., 2013), and fish or gather during the dry season. The critical receptor is a child age 16 years who, due to his bodyweight, is more sensitive to exposure (Cheng and Nathanail, 2009; Environmental Agency, 2009). A typical rain-fed farmland is similar to a cultivated patch of land in Plate 8-1.

Plate 8-1: Farms located along an oil-polluted river (UNEP, 2011).

8.2.2 Rural Informal Dwelling

This scenario represents a small and less-populated rural dwelling in its early formative stage. These sorts of dwellings are constructed with combustible materials like palm leaves, wooden sticks and grasses; there are no concrete floors, slabs, roads, or pavements. The homesteads are sparsely distributed with space in-between for small-scale gardening.

Dwellings in this category are less organised; there are no markets, the main source of domestic water is local streams, ponds, and hand-dug wells. Less than 45% of rural communities in Nigeria have an improved source of drinking water (World Bank, 2008); as such, many rural communities depend on natural sources. The inhabitants depend solely on materials obtained from the local ecosystem. A typical rural dwelling is shown in Plate 8-2 and the possible exposure pathways for this land use are indicated in Table 8-2.

Plate 8-2: A typical informal rural homestead (UNEP, 2011).

The assessment considered that an adult female is assumed to spend the greater part of her time at home close to the pipeline rights of way or an area with a repeated history of oil spills such as in Plate 8-2 above.

8.2.3 Rural Standard Residential

This form of settlement is relatively organised with a market square, and the homesteads being close together with a larger population than the informal dwellings (Plate 8-2). Houses are constructed with concrete materials, pavements and paved roads. There is limited land available for any form of cultivation; people would normally travel outside the community to farm or gather. The small patches of land available are used for small gardens or allotments; the source of domestic water is from community boreholes and open streams. The common exposure pathways associated with this land use are indicated in Table 8-2, and children aged 0-6 years playing around previous oil spill site are considered.

Plate 8-3: Rural residential settlements (UNEP, 2011).

8.3 Land-Use Risk Assessment Criteria for Human Health

Health Criteria Values (HCV) represent a tolerable risk to human health from chronic exposure to contaminants (Environment Agency, 2009). This is a baseline value specified in Soil Guideline Values (SGV) for the protection of human health or to minimise the risk of significant harm (Environment Agency, 2009; CLAIRE, 2010). SGVs are expressed in terms of mass of contaminant per mass of soil (Department of Environmental Affairs, 2010). However, what may seem a significant possibility of significant harm (SPOSH) may not be significant, as it is a matter of a judgement decision for the enforcing agency (DEFRA, 2008, 2012); therefore, the values must be used with caution. This is because GAC represent a "cautious estimation" of the contaminant level in soil at which there is no risk to human health; they are used to indicate that land poses no SPOSH to human health (DEFRA, 2012).

GAC provide a basis for site-specific assessment criteria in specific land-use scenarios where there are no SGVs. Consequently, this section developed similar SGVs for rural land use described in Section 8.2 and Generic Land Use Human Health Risk Assessment Criteria using CLEA v1.06 for the following critical receptors (Table 8-3), bearing in mind the significance of height and weight in exposure assessment.

Table 8-3: Critical receptors evaluated using the CLEA software.

Land use	Critical Receptor	Age Class
Rural Agriculture	0 to 16 year male child	1 to 16
Rural Informal Dwelling	0 to 30 year female	1 to 17
Rural Standard Residential	0 to 6 year male child	1 to 16

8.3.1 Soil Guideline Values (SGVs)

An SGV is a standard with which individual chemical concentration is compared to determine the possibility of risk to human health and the environment. Soil quality value is derived for different land uses, for different receptors and exposure scenarios inherent in a land use (Canadian Council of Ministers of the Environment, 2010). In Canada it is called "soil quality guideline", in the United Kingdom it is "soil guideline value", in New Zealand it is "soil contaminant standard", the USA "soil screening guidance", the Netherlands "soil and water target and intervention value", and South Africa "soil screening value". Irrespective of nomenclature, the standards perform the same purpose, which is to define allowable or tolerable concentration of individual chemical contaminants in soil or groundwater for respective land uses.

The soil and water standard in Nigeria's EGASPIN is a direct copy from the Dutch's "target and intervention value" for soil and groundwater remediation. Table 8-4 and Table 8-5 showed BTEX values adopted in EGASPIN from the Dutch (Netherlands) standard. This standard does not take cognisance of land-use exposure scenarios; therefore, it is not appropriate for use.

Table 8-4: EGASPIN target and intervention values for soil and groundwater (EGASPIN, 2002).

Substance	**Soil/Sediment** (mg/kg dry material)		**Groundwater** (µg/l)	
Aromatic	Target value	Intervention value	Target value	Intervention value
Benzene	0.05	1	0.2	30
Ethylbenzene	0.05	50	0.2	150
Toluene	0.05	130	0.2	1000
Xylene	0.05	25	0.2	70

Table 8-5: BTEX screening levels in soil in selected countries (Source: UNEP, 2011).

Substance *(mg/kg)*	**Country**				
	Canada	China	Netherlands	Thailand	UK
Benzene	0.0068	0.2	1	6.5	0.33
Toluene	0.08	26	130	520	610
Ethylbenzene	0.018	10	50	230	350
Xylenes	2.4	5	25	210	230

Consequently, a new "soil screening value" (SSV) is derived for BTEX compounds for land uses described in Section 8.2; this was derived with recognition of rural activity pattern and environmental conditions prevalent in a tropical climate using Equation 8-1 for threshold and Equation 8-2 for non-threshold assessment. The equation is a product of consultations between government, consultants and the public sector to develop a land-use-based contaminated land assessment framework (Department of Environmental Affairs, 2010).

The description of informal residential and the physico-chemical and toxicological parameters used in the South African setting is similar to rural areas in Nigeria; hence they were adopted. However, the human related parameters were based on expert elucidation and literature (Table 8-6). The parameters were used to derive SSVs for benzene, a carcinogen (Table 8-7), toluene (Table 8-8), ethyl benzene (Table 8-9), and xylene (Table 8-10), while Table 8-11 summarises SSV for BTEX compounds.

Table 8-6: Source of parameters substituted in the equation

Parameter	**Source**
Body weight	Ayoola et al. (2010)
Soil ingestion	Expert elucidation and US-EPA (2009)
Inhalation	Expert and US-EPA (2009a)
Exposure frequency	From questionnaire response
Exposure duration	From questionnaire response
Exposed skin area	US-EPA, (2009) recommended body parts surface
Averaging time	From questionnaire response

Equation 8-1: For threshold (non-carcinogenic)

$$SSV\ (mg/kg) = \frac{THI \times BW \times AT}{EF \times ED\left(\left(\frac{1}{RfD_i} \times 10^{-6} \times IR_s \times GI\right) + \left(\left(\frac{1}{RfD_i}\right) \times \left(\left(IR_a \times \frac{1}{PEF}\right) + \left(\frac{IR_a}{2} \times \left(\frac{1}{VF_1} + \frac{1}{VF_0}\right)\right)\right)\right) + \left(\left(\frac{1}{RfD_d}\right) \times SA \times AF \times ABS \times 10^{-6}\right)\right)}$$

Equation 8-2: For non-threshold (carcinogenic)

$$SSV\ (mg/kg) = \frac{TR \times BW \times AT}{EF \times ED\left((SF_O \times 10^{-6} \times IR_s \times GI) + \left(SF_O \times \left(\left(IR_a \times \frac{1}{PEF}\right) + \left(\frac{IR_a}{2} \times \left(\frac{1}{VF_1} + \frac{1}{VF_0}\right)\right)\right)\right) + (SF_d \times SA \times AF \times ABS \times 10^{-6})\right)}$$

Where:

SSV = soil screening value (mg/kg)

TR = target risk

AT = averaging time (days)

ED = exposure duration (yrs.)

IRa= inhalation rate–air (m^3/day)

RfDo = reference dose-oral

RfDd = reference dose-dermal

SFa = slope factor-air

GI = GI absorption factor

VF = volatilisation factor (m^3/kg)

ABS = dermal absorption factor

THI = target hazard index

BW = body weight (kg)

EF = exposure frequency (day/yr)

IRs = ingestion rate-soil (Mg/day)

SA = surface area of exposed skin (Cm^2)

RfDi = reference dose-inhalation

SFo = slope factor-oral

SFd = slope factor-dermal

PEF = particulate emission factor (m^3/kg)

AF = skin adherence factor (mg/cm^2/day)

Table 8-7: Parameters for deriving soil-screening value for Benzene.

Benzene Carcinogenic (Non-Threshold)

Parameter / Land Use activity Description	Symbol	Unit	AGRIC	DWELLING	RESIDENTIAL
Body Weight	BW	kg	75.1	75.1	75.1
Averaging Time	AT	days	12825	27375	27375
Exposure Frequency	EF	days/yr	171	365	365
Exposure Duration	ED	yrs	75	75	75
Ingestion Rate (soil)	IR_S	mg/day	400	400	200
GI absorption factor	GI		1	1	1
Surface Area Exposed Skin	SA	cm^2	27920	16920	15380
Soil to Skin Adherence Factor	AF	mg/cm^2/day	0.07	0.07	0.07
Dermal Absorption Factor	ABS		0.1	0.1	0.1
Inhalation Rate (air)	IR_a	m^3/day	25	25	25
Particulate Emission Factor	PEF	m^3/kg	7.24E+08	7.24E+08	7.24E+08
Volatilisation Factor	VFi	m^3/kg	585	585	585
Volatilisation Factor	VFo	m^3/kg	55866	55866	55866
Target Hazard Index	THI		1	1	1
Target Risk	TR		1.00E-05	1.00E-05	1.00E-05
Toxicological Data for Benzene					
Slope Factor (Oral)	SFo		0.029	0.029	0.029
Slope Factor (Inhalation)	SFi		0.029	0.029	0.029
Slope Factor (Dermal)	SFd		0.029	0.029	0.029
SSV Benzene (mg/kg)			**1.46**	**1.17**	**1.18**

Table 8-8: Parameters for deriving soil-screening value for Toluene.

Toluene Non-Carcinogenic (Threshold)

Parameter / Land Use Activity Description	**Symbol**	**Unit**	**AGRIC**	**DWELLING**	**RESIDENTIAL**
Body Weight	BW	kg	53	75.1	25.1
Averaging Time	AT	days	2880	10950	2190
Exposure Frequency	EF	days/yr	180	365	365
Exposure Duration	ED	yrs	16	30	6
Ingestion Rate (soil)	IR_S	mg/day	400	400	200
GI absorption factor	GI		1	1	1
Surface Area Exposed Skin	SA	cm^2	20630	14030	4400
Soil to Skin Adherence Factor	AF	$mg/cm^2/day$	0.2	0.2	0.2
Dermal Absorption Factor	ABS		0.1	0.1	0.1
Inhalation Rate (air)	IR_a	m^3/day	22	25	17
Particulate Emission Factor	PEF	m^3/kg	7.24E+08	7.24E+08	7.24E+08
Volatilisation Factor	VFi	m^3/kg	375	375	375
Volatilisation Factor	VFo	m^3/kg	13072	13072	13072
Target Hazard Index	THI		1	1	1
Target Risk	TR		1.00E-05	1.00E-05	1.00E-05
Toxicological Data for Toluene					
Reference Dosage (Oral)	RfDo		0.2	0.2	0.2
Reference Dosage (Inhalation)	RfDi		0.11	0.11	0.11
Reference Dosage (Dermal)	RfDd		0.2	0.2	0.2
SSV (mg/kg) Toluene			**191.81**	**239.38**	**117.86**

Table 8-9: Parameters for deriving soil-screening value for Ethyl benzene.

Ethyl benzene Non-Carcinogenic (Threshold)

Parameter / Land Use Activity Description	**Symbol**	**Unit**	**AGRIC.**	**DWELLING**	**RESIDENTIAL**
Body Weight	BW	kg	53	75.1	25.1
Averaging Time	AT	days	2880	10950	2190
Exposure Frequency	EF	days/yr.	180	365	365
Exposure Duration	ED	Yrs.	16	30	6
Ingestion Rate (soil)	IR_S	mg/day	400	400	200
GI absorption factor	GI		1	1	1
Surface Area Exposed Skin	SA	cm^2	20630	14030	4400
Soil to Skin Adherence Factor	AF	$mg/cm^2/day$	0.2	0.2	0.2
Dermal Absorption Factor	ABS		0.1	0.1	0.1
Inhalation Rate (air)	IR_a	m^3/day	22	25	17
Particulate Emission Factor	PEF	m^3/kg	7.24E+08	7.24E+08	7.24E+08
Volatilisation Factor	VFi	m^3/kg	709	709	709
Volatilisation Factor	VFo	m^3/kg	13072	13072	13072
Target Hazard Index	THI		1	1	1
Target Risk	TR		1.00E-05	1.00E-05	1.00E-05
Toxicological Data for Ethyl benzene					
Reference Dosage (Oral)	RfDo		0.1	0.1	0.1
Reference Dosage (Inhalation)	RfDi		0.029	0.029	0.029
Reference Dosage (Dermal)	RfDd		0.1	0.1	0.1
SSV (mg/kg) ethyl benzene			**93.31**	**116.45**	**57.33**

Table 8-10: Parameters for deriving soil-screening value for Xylenes.

Xylenes Non-Carcinogenic (Threshold)

Parameter / Land Use Activity Description	Symbol	Unit	AGRIC	DWELLING	RESIDENTIAL
Body Weight	BW	kg	53	75.1	25.1
Averaging Time	AT	days	2880	10950	2190
Exposure Frequency	EF	days/yr	180	365	365
Exposure Duration	ED	yrs	16	30	6
Ingestion Rate (soil)	IR_S	mg/day	400	400	200
GI absorption factor	GI		1	1	1
Surface Area Exposed Skin	SA	cm^2	20630	14030	4400
Soil to Skin Adherence Factor	AF	$mg/cm^2/day$	0.2	0.2	0.2
Dermal Absorption Factor	ABS		0.1	0.1	0.1
Inhalation Rate (air)	IR_a	m^3/day	22	25	17
Particulate Emission Factor	PEF	m^3/kg	7.24E+08	7.24E+08	7.24E+08
Volatilisation Factor	VFi	m^3/kg	348	348	348
Volatilisation Factor	VFo	m^3/kg	13072	13072	13072
Target Hazard Index	THI		1	1	1
Target Risk	TR		1.00E-05	1.00E-05	1.00E-05
Toxicological Data for Benzene					
Reference Dosage (Oral)	RfDo		2	2	2
Reference Dosage (Inhalation)	RfDi		0.09	0.09	0.09
Reference Dosage (Dermal)	RfDd		2	2	2
SSV (mg/kg) Xylenes			**146.91**	**183.20**	**90.06**

Table 8-11: Summary of land use soil-screening values.

Compound	**Agriculture Land-Use**	**Rural Informal Dwelling**	**Rural Standard Residential**
	Child-16yrs	Adult -Female	Child-6yrs
	(mg/kg)		
Benzene *	1.46	1.17	1.18
Toluene	191.81	239.38	117.86
Ethyl benzene	93.31	116.45	57.33
Xylenes	146.91	183.20	90.06

*Evaluated as carcinogen, i.e. 75 years.

8.4 Developing Generic Assessment Criteria (GAC)

The GAC for aliphatic and aromatic TPH fractions' parameters in LQM/CIEH were adopted to derive TPH EC fractions for use in rural land-use human health risk assessment using CLEA v1.06. The land uses described in Section 8.2 were defined in accordance with the risk-based contaminated land management framework in which historic and current land use, contaminants' fate, transport, and toxicity form the basis for conceptual modelling (Cheng and Nathanail, 2009). Consequently, exposure scenarios were developed in isolation, assuming time is spent on a single land use at a time. Due to the lack of published work in this area in Nigeria, physico-chemical parameters in LQM/CIEH for related TPH EC fractions (Nathanail et al., 2009) were adopted.

8.4.1 Petroleum Hydrocarbon Fractions GAC

The GAC for individual land use is derived as the concentration of hydrocarbon fractions in soil at which the Average Daily Exposure (ADE) calculated by CLEA v1.06 represents the HCV. The GAC for four Soil Organic Matters (SOMs), i.e. 1%, 2.5%, 5% and 10%, is based on a sandy clay laom soil described by the United Nations Environment Programme (2011).

Although the LQM/CIEH reported GAC at 1%, 2.5% and 6%, which is in conformity to the Environment Agency preferred 6% SOM (Nathanail et al., 2009), the author's choice of SOM percentage intervals for the Niger Delta followed a wide consultation and expert elicitation. The GAC values for the petroleum hydrocarbon EC numbers for the defined rural land use are presented in Table 8-12, Table 8-13, Table 8-14 and Table 8-15 according to SOM of 1%, 2.5%, 5% and 10% respectively.

The CLEA v1.06 calculated the ADE:HCV ratio and percentage contibution of exposure pathways, as presented in Table 1c, Table 2c and Table 3c in Appendix C. GAC values in shaded cells are those that exceeds solubility and vapour saturation limits indicated in brackets under the soil saturation concentration column.

Table 8-12: Land use GAC at 1% Soil Organic Matter (mg/kg).

GAC for Rural Land Use at 1% SOM (mg/kg)				
TPH Fraction	Rural Agricultural Land Use	Rural Informal Dwelling	Rural Standard Residential	Soil Saturation Conc.
Aliphatic				
EC5-6	264.00	109.00	178.00	340.00
EC>6-8	283.00	142.00	275.00	144(vap)
EC>8-10	7.87	4.45	9.57	55.80
EC>10-12	7.90	4.64	9.96	47.50
EC>12-16	7.91	5.04	10.50	23.70
EC>16-35	43.80	31.50	58.20	8.48(sol)
EC>35-44	43.80	31.50	58.20	8.48(sol)
Aromatic				
EC5-7	22.50	5.31	6.99	1220.00
EC>7-8	25.90	7.55	10.60	869.00
EC>8-10	7.87	4.54	9.57	55.80
EC>10-12	7.90	4.64	9.96	47.50
EC>12-16	7.91	5.04	10.50	23.70
EC>16-21	2.29	1.60	2.78	0.0154(sol)
EC>21-35	2.31	1.71	3.04	4.83
EC>35-44	43.80	31.50	58.20	8.48(sol)
Aliphatic and Aromatic				
EC>44-70	2.31	1.72	3.07	0.29(sol)

Table 8-13: Land use GAC at 2.5% Soil Organic Matter (mg/kg).

GAC for Rural Land Use at 2.5% SOM (mg/kg)				
TPH Fraction	Rural Agricultural Land Use	Rural Informal Dwelling	Rural Standard Residential	Soil Saturation Conc. (mg/kg)
Aliphatic				
EC5-6	280.00	138.00	254.00	558.00
EC>6-8	289.00	160.00	325.00	322.00(sol)
EC>8-10	7.89	4.61	9.83	136.00
EC>10-12	7.90	4.65	10.50	118.00
EC>12-16	7.91	5.33	10.50	59.10
EC>16-35	43.80	31.90	58.20	21.20(sol)
EC>35-44	43.80	31.90	58.50	21.20(sol)
Aromatic				
EC5-7	27.00	8.49	12.20	2260.00
EC>7-8	29.80	11.60	18.40	1920.00
EC>8-10	7.89	4.61	9.83	136.00
EC>10-12	7.90	4.65	10.50	118.00
EC>12-16	7.91	5.33	10.50	59.10
EC>16-21	2.30	1.67	2.95	0.04(vap)
EC>21-35	2.31	1.72	3.06	12.10
EC>35-44	43.80	31.90	58.20	21.20(sol)
Aliphatic and Aromatic				
EC>44-70	2.31	1.73	3.07	0.73(sol)

Table 8-14: Land use GAC at 5% Soil Organic Matter (mg/kg).

GAC for Rural Land Use at 5% SOM (mg/kg)				
TPH Fraction	Rural Agricultural Land Use	Rural Informal Dwelling	Rural Standard Residential	Soil Saturation Conc. (mg/kg)
Aliphatic				
EC5-6	286.00	153.00	300.00	981.00
EC>6-8	291.00	166.00	347.00	618.00
EC>8-10	7.90	4.63	9.92	270.00
EC>10-12	7.91	4.83	10.50	236.00
EC>12-16	7.91	5.49	10.50	118.00
EC>16-35	43.80	32.10	58.20	42.40(sol)
EC>35-44	43.80	32.10	58.20	42.40(sol)
Aromatic				
EC5-7	29.70	11.50	18.10	4010.00
EC>7-8	31.60	14.50	26.10	3660.00
EC>8-10	7.90	4.63	9.92	270.00
EC>10-12	7.91	4.83	10.50	236.00
EC>12-16	7.91	5.49	10.50	118.00
EC>16-21	2.31	1.70	3.01	0.08(sol)
EC>21-35	2.31	17.30	3.07	24.10
EC>35-44	43.80	32.10	58.20	42.40(sol)
Aliphatic and Aromatic				
EC>44-70	2.31	1.73	3.08	1.45(sol)

Table 8-15: Land use GAC at 10% Soil Organic Matter (mg/kg).

GAC for Rural Land Use at 10% SOM (mg/kg)				
TPH Fraction	Rural Agricultural Land Use	Rural Informal Dwelling	Rural Standard Residential	Soil Saturation Conc. (mg/kg)
Aliphatic				
EC5-6	289.00	162.00	331.00	1830.00
EC>6-8	292.00	169.00	359.00	1210.00
EC>8-10	7.90	4.64	10.40	539.00
EC>10-12	7.91	5.11	10.50	472.00
EC>12-16	7.91	5.61	10.50	236.00
EC>16-35	43.80	32.30	58.20	84.80
EC>35-44	43.80	32.30	58.20	84.80
Aromatic				
EC5-7	31.50	14.40	24.90	7500.00
EC>7-8	32.70	17.60	32.90	7150.00
EC>8-10	7.90	4.64	10.40	539.00
EC>10-12	7.91	5.11	10.50	472.00
EC>12-16	7.91	5.61	10.50	236.00
EC>16-21	2.31	1.71	3.04	0.15(vap)
EC>21-35	2.31	1.73	3.07	48.30
EC>35-44	43.80	32.30	58.20	84.80
Aliphatic and Aromatic				
EC>44-70	2.31	1.73	3.08	2.91(sol)

8.4.2 Exposure Pathway Contributions

The contributions of each exposure pathway calculated by the software can be found in Appendix C for respective land use. Two exposure contribution pathways were calculated at 1% and 5% SOM to compare variations; the result indicates no significant difference (see Appendix C).

The most significant exposure pathways in rural agricultural land use include direct soil ingestion of aliphatic EC>16-35, EC>35-44, aromatic EC>5-7, EC>7-8, EC>16-21, EC>21-35, EC>35-44 and aliphatic and aromatic EC>44-70. Background oral is significant in the total exposure of all fractions, while background inhalation is higher in aliphatic EC>16-35, EC>35-44 and aromatic EC>16-21 to EC>35-44. Dermal contact with soil has 0.01% contribution for some fractions, while dust and consumption of home-grown produce and attached soil is significant for the lighter aliphatic and aromatic.

All the exposure pathways in CLEA v1.06 contributed in rural informal dwelling land use. However, the most significant pathways are direct soil ingestion, consumption of home-grown produce and attached soil, inhalation of indoor and outdoor vapour, and background oral and inhalation. There is no remarkable difference in exposure pathway contribution for 1% and 5% SOM.

For the rural standard residential, all exposure pathways were involved with the exception of inhalation of dust. The less significant is direct soil ingestion of EC5-6 (Aliphatic) and EC>5-7 and EC>7-8 (Aromatic), while higher EC fractions are the most significant for both aliphatic and aromatic in this pathway.

In Chapter 4, the procedure for assessing human health risk and exposure was discussed, also tables with estimated values for inhalation, ingestion and dermal derived by the USEPA were presented. Paucity of data in Nigeria demands new values be derived for use in Nigeria. This was done through interview response, expert elicitation and, where appropriate, direct adaptation of the USEPA data. Consequently, exposure frequency for soil ingestion, dermal and inhalation used for the GAC can be found in Appendix C.

8.4.3 Determining Critical Human Receptor

This aspect was analysed using reported concentration of benzene in air to assess long-term average daily exposure through inhalation. Since there are no officially-documented estimates for inhalation rates for either adults or children in Nigeria, the 95th percentile of the long-term inhalation rate according to age recommended by the US-EPA in Table 4-4 was used for this illustration.

Noting the influence of climate and labour intensity in the Niger Delta, inhalation rates would be considerably different. Hence, the USEPA recommended inhalation rates for each age group be increased incrementally by 10%, i.e. at 20%, 30%, 40% and 50%, to investigate the implication of higher inhalation rates on average daily exposure. By using UNEP's (2011) reported concentration 48.20µg/m^3 (0.0482mg/m^3) of benzene in air in Ogoniland, variation in intake via air inhalation between adults and children was demonstrated with the CLEA Average Daily Exposure (ADE) formula.

To do this, the CLEA equation (Equation 4-1) was segregated to a specific exposure route for inhalation. Also, the 95th percentile body weights for rural communities in Nigeria were derived for 5-30 years from Ayoola et al.

(2009), and the GAC averaging time for rural agricultural land use was substituted in the equation. Firstly, the intake rate was obtained with Equation 8-3 for Table 8-16.

Equation 8-3

$$Intake = Concentration\,(mg/m^3) \times Inhalation\,Rate\,(m^3/day)$$

Table 8-16: Benzene intake via inhalation.

Age	Inhalation Rate (m3/day)					Intake (mg/day)				
	USEPA*	+20%	+30%	+40%	+50%	USEPA	20%	30%	40%	50%
< 6	14	16.8	18.2	19.6	21	0.67	0.81	0.88	0.94	1.01
7-8	15	18	19.5	21	22.5	0.72	0.87	0.94	1.01	1.08
9-10	17	20.4	22.1	23.8	25.5	0.82	0.98	1.07	1.15	1.23
11-12	22	26.4	28.6	30.8	33	1.06	1.27	1.38	1.48	1.59
13-14	22	26.4	28.6	30.8	33	1.06	1.27	1.38	1.48	1.59
15-16	22	26.4	28.6	30.8	33	1.06	1.27	1.38	1.48	1.59
17-18	25	30	32.5	35	37.5	1.21	1.45	1.57	1.69	1.81
19-20	25	30	32.5	35	37.5	1.21	1.45	1.57	1.69	1.81
21-30	21	25.2	27.3	29.4	31.5	1.01	1.21	1.32	1.42	1.52

*USEPA (2009a).

Secondly, the average daily exposure (ADE_{Inh}) was calculated with Equation 8-4 by substituting with parameters in Table 8-17 to obtain results in Table 8-18 and Figure 8-1.

Equation 8-4

$$ADE_{Inh} = \frac{IR_{Inh} \times EF_{Inh} \times ED_{Inh}}{BW \times AT}$$

Where

ADE = average daily exposure to chemical from soil (mg/kg/bw/day),
IR = chemical intake (mg/day),
EF = the exposure frequency (days $year^{-1}$),
ED = the exposure duration (year),
BW = the human body weight (kg)
AT = the averaging time (days),
NB: inh= inhalation.

Table 8-17: Parameters substituted into Equation 8-4.

Age Year	*BW (kg)	AT (days)	EF (days)	ED (year)	Chemical Intake (IR) mg/day				
					USEPA	20%	30%	40%	50%
<6	25.1	2190	240	6	0.67	0.81	0.88	0.94	1.01
7-8	26.6	2920	240	8	0.72	0.87	0.94	1.01	1.08
9-10	28	3650	240	10	0.82	0.98	1.07	1.15	1.23
11-12	34.8	4380	240	12	1.06	1.27	1.38	1.48	1.59
13-14	40.1	5110	240	14	1.06	1.27	1.38	1.48	1.59
15-16	53	5840	240	16	1.06	1.27	1.38	1.48	1.59
17-18	62	6570	240	18	1.21	1.45	1.57	1.69	1.81
19-20	66.4	7300	240	20	1.21	1.45	1.57	1.69	1.81
21-30	75.1	10950	240	30	1.01	1.21	1.32	1.42	1.52

*Ayoola et al. (2012).

Table 8-18: Average Daily Exposure according to percentage increment.

Age	**ADE** (mg/kg/bw/day)				
	USEPA	20%	30%	40%	50%
<6 yr	1.77E-02	2.12E-02	2.30E-02	2.47E-02	2.65E-02
7-8yr	1.79E-02	2.14E-02	2.32E-02	2.50E-02	2.68E-02
9-10yr	1.92E-02	2.31E-02	2.50E-02	2.69E-02	2.89E-02
11-12yr	2.00E-02	2.40E-02	2.60E-02	2.81E-02	3.01E-02
13-14yr	1.74E-02	2.09E-02	2.26E-02	2.43E-02	2.61E-02
15-16yr	1.32E-02	1.58E-02	1.71E-02	1.84E-02	1.97E-02
17-18yr	1.28E-02	1.53E-02	1.66E-02	1.79E-02	1.92E-02
19-20yr	1.19E-02	1.43E-02	1.55E-02	1.67E-02	1.79E-02
20-30yr	8.86E-03	1.06E-02	1.15E-02	1.24E-02	1.33E-02
R^2	0.7493	0.7493	0.7493	0.7493	0.7493
Y	-0.0012x	-0.0015x	-0.0016x	-0.0017x	-0.0018x

From Figure 8-1, the following deductions can be made on the influence of different inhalation rate on ADE.

i) That from 6 years to 30 years the increase in inhalation rates results in a proportional increase in critical threshold based on mg/kg/bw/day.

ii) Children aged 12 and lower have a higher average daily exposure in terms of concentration on an mg/kg/bw/day basis.

iii) Therefore, if exposed to the same concentration of contaminants, children are more susceptible than adults due to their lower body weight and attenuation time.

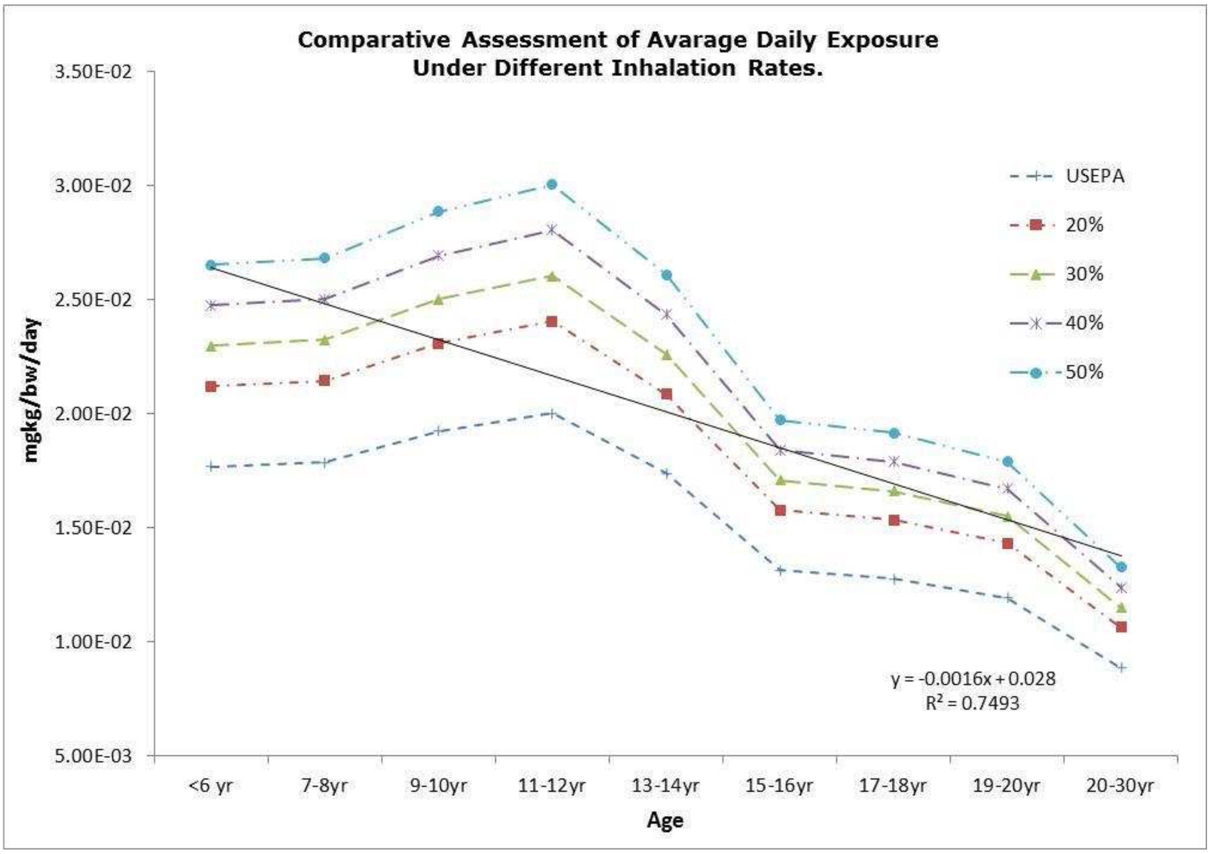


Figure 8-1: Average daily intake (inhalation) of benzene by age group.

Conclusion

Generic land-use assessment criteria for total hydrocarbons based on EC number has been developed for aromatic and aliphatic fractions using CLEA v1.06 (Subsection 8.4.1), in addition to SSV derived for BTEX compounds for the same land use (Subsection 8.3.1). By adopting values from the USEPA, LQM/CIEH and South Africa, the gap created by lack of risk assessment criteria in Nigeria was overcome. The new GAC provide the basis for conducting petroleum hydrocarbon-related human health risk assessment for land use in the Niger Delta in place of the EGASPIN's target and intervention values (Table 3-9) originally developed for soil and ground water remediation by the Dutch (Subsection 3.3.1). Henceforth, a basis for advancing the human health screening standard is being developed for rural land use in the Niger Delta. The CLEA software can be a framework for this purpose; hence, as new assessment parameters are developed from laboratory and field experiments in Nigeria, these can be introduced into the software since it allows the introduction of new parameters like land use, physico-chemical properties, exposure values etc. (Environment Agency, 2009).

It was also determined that children are critical receptors in comparison with adults, as their lower body weights and AT predispose them to higher doses than adults whose body weight and longer AT help neutralise the magnitude of exposure.

The assumption throughout this chapter has been on land uses close to and around oil-polluted areas, and since exposure occurs when a pollutant linkage is established, the essence of proximity becomes a relevant variable. Therefore, considering the proximity of settlements in the study area to pipeline networks (Subsection 7.2.2) and previous oil spill sites (Subsection 7.2.1), a method for delineating hazard zones from pipeline networks is developed in the following chapter using an MCDA and AHP framework.

CHAPTER 9

MODELLING LAND-USE HAZARD AREAS

9.0 Introduction

Potential Impact Radius (PIR) is a method developed for demarcating possible areas of impact following pipeline failure (Subsection 5.5.2). In this chapter, a similar method is developed using Multi-Criteria Decision Analysis in the context of Analytical Hierarchy Process (MCDA-AHP) to map hazard areas for rural land use using population density, land cover, river systems, and pipeline proximity as alternatives (criteria). Developed as a model, users can extract or store data relating to settlements considered susceptible to pipeline impact for landuse human health risk assessment in HCAs.

9.1 MCE-AHP Modelling Procedure

The initial step in MCDA is to identify criteria alternatives relevant to the defined goal(s), i.e. identify possible land-use areas potentially susceptible to pipeline hazard. The main objectives are categorised into i) establishment of source of impact and ii) identification of land-use criteria and derivation of alternatives, e.g. proximity to pipeline, proximity to river, land cover and population density. The criteria layers here are selected based on available spatial data and their significance to rural land use as well as capacity to allow exposure scenarios.

i) *The Land cover layer* represents the natural vegetation and land resources available for land-use benefits. The land covers (Figure 9-1a) consists of mangrove forest, forested fresh water swamp, rain-fed agriculture land, grazing field etc. The map shapefiles were developed by supervised classification (Subsection 7.0.1).

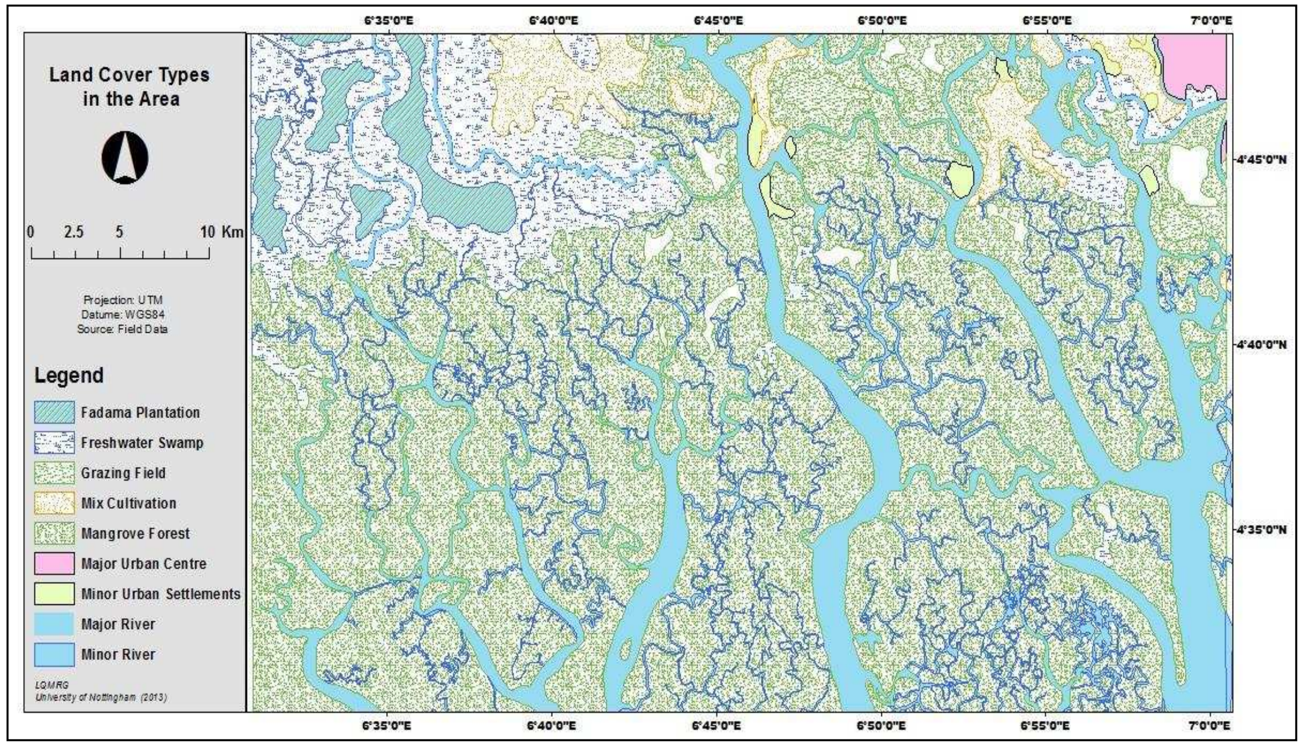
ii) *The pipeline network* consists of a series of connected pipelines (Figure 9-1b) used for conveying crude oil to various destinations. It represents the main source of petroleum hydrocarbon discharge in the area. This also was developed by on-screen digitisation (Subsection 7.0.1).

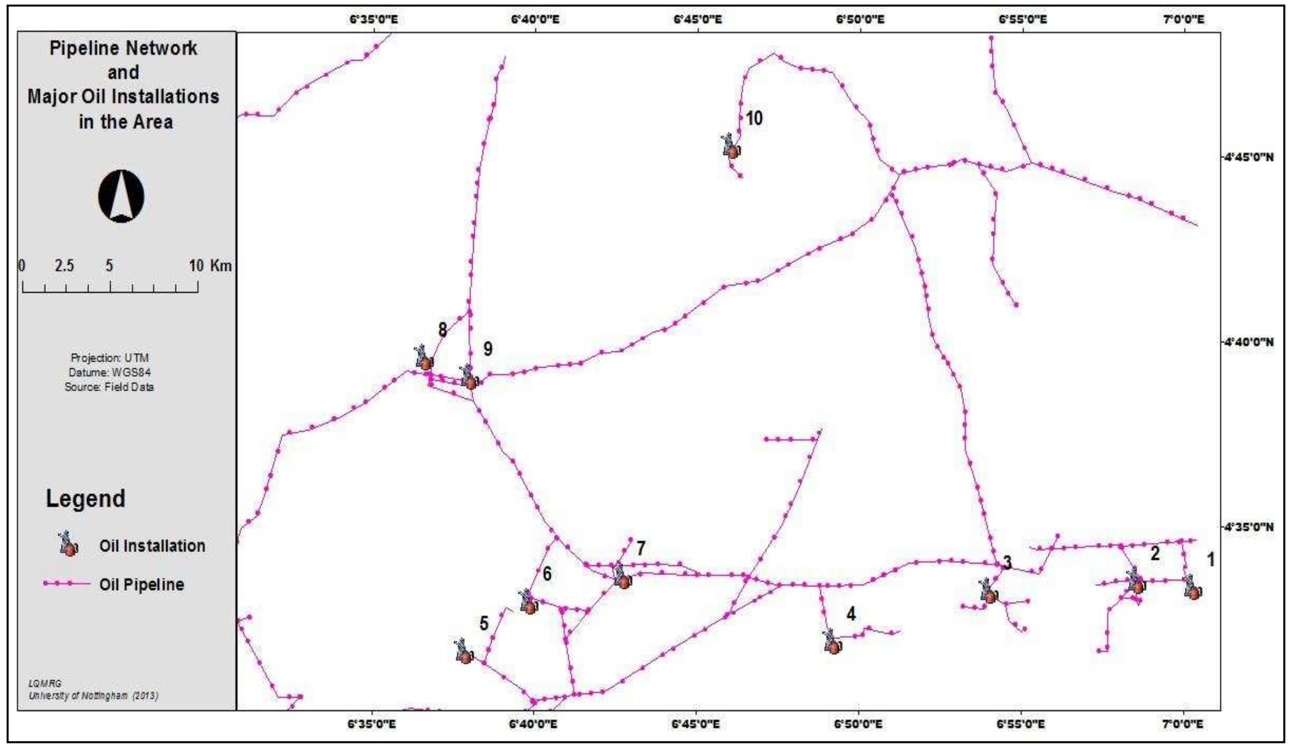
iii) *The settlement layer* is used as a surrogate for population distribution in the area; here, population density is marked by point density to describe the population distribution per square kilometre (Figure 9-1c) (Subsection 7.0.1).

iv) *Rivers and creeks*: this represents major rivers and interconnecting minor rivers (creeks) (Figure 9-1d). River (water) transport is the most common means of transportation and source of domestic water supply, as well as a fishing ground. This layer is an important variable in the socio-economic life of the rural Niger Delta and yet it influences the migratory capacity of oil spills. This layer was also developed by supervised classification (Subsection 7.0.1).

9.1.1 Factors and Constraints Specification

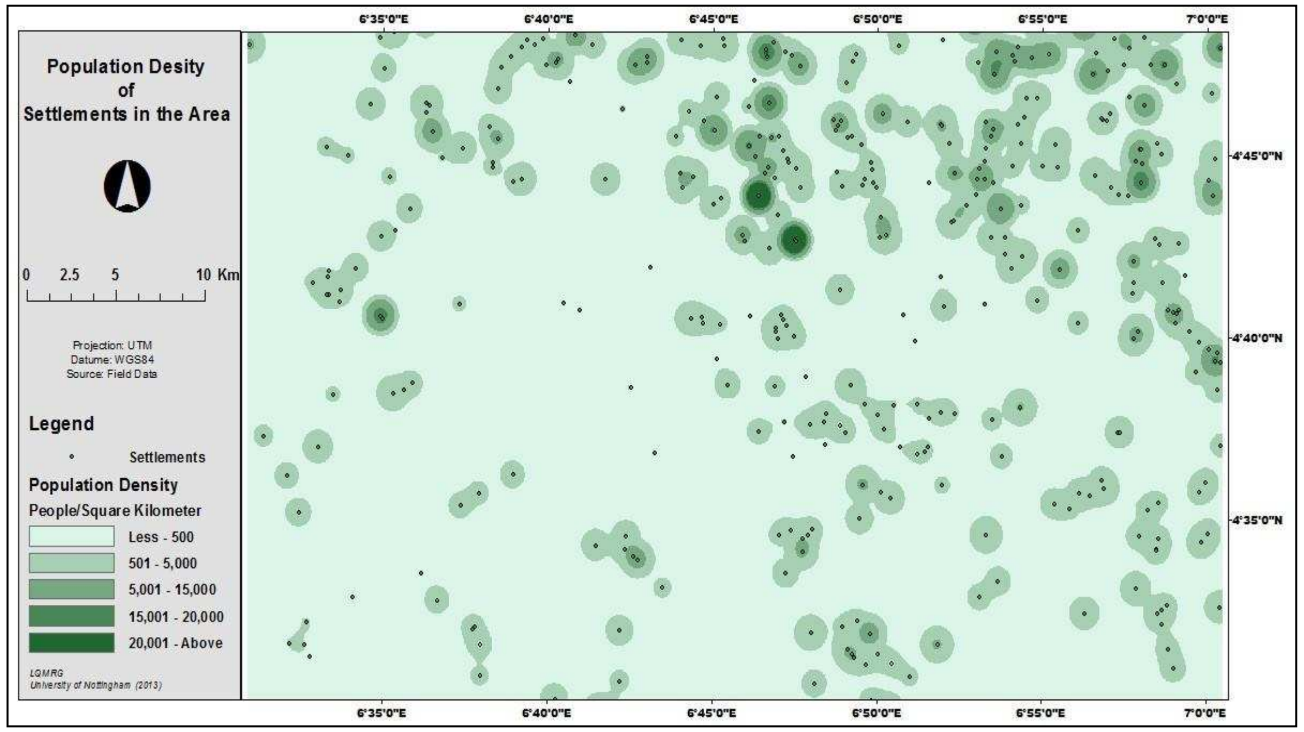
A factor is a condition imposed on a variable to facilitate the requirement of achieving a set of objectives or goals, while constraint is a condition imposed on a variable to prevent or limit its chances to meet the same objective or goal (Mwasi, 2001). For example, conditions excluding an area are based on distance, absence, or availability of a feature. The constraint and factor conditions (Table 9-1) prioritised the proximity to pipelines: river, human population (settlements), and land cover to primary source of hydrocarbons (pipeline).

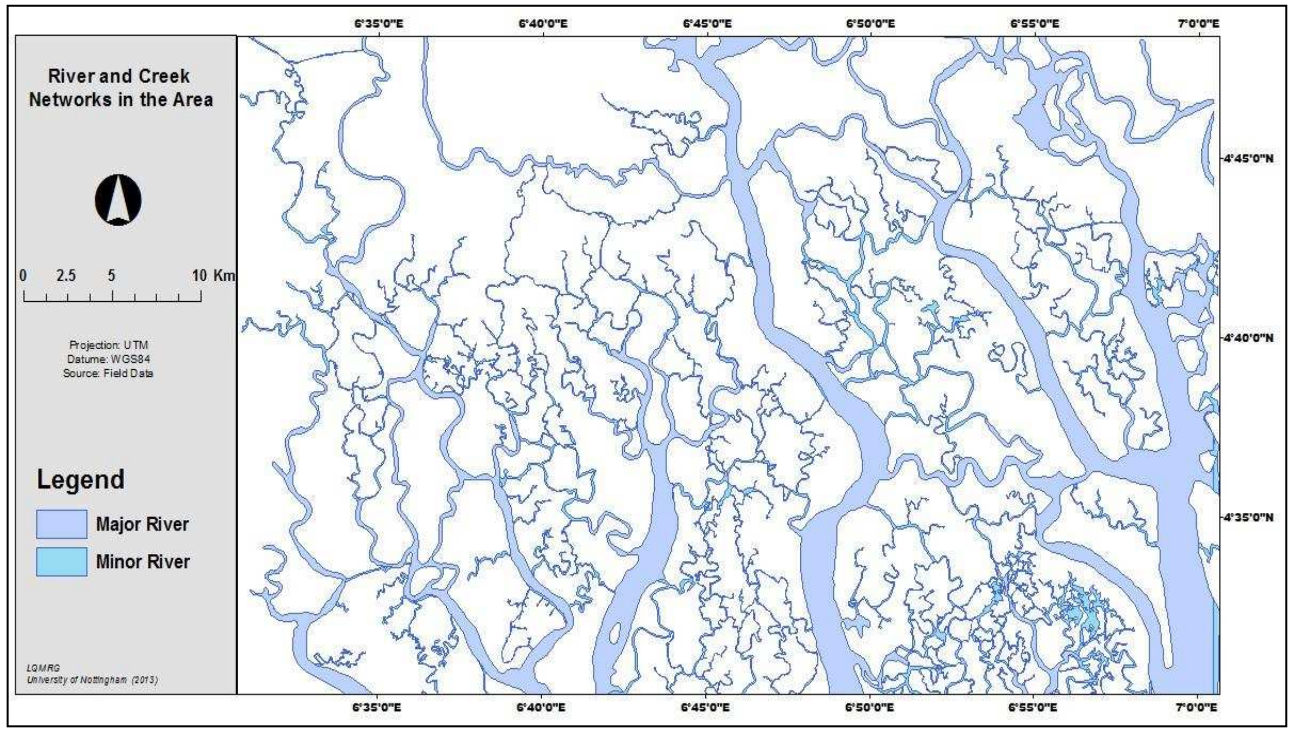




A) Vegetation and land cover (Source: Field data, 2010).

B) Pipeline network (Source: Field data, 2010).





C) Population of the area (Source: Field data, 2010).

D) River Network (Source: Field data, 2010).

Figure 9-1: Thematic layers used for the MCE-AHP modelling (Source: Field data, 2010).

The logic behind the 4km buffer represents the distance farmers travel daily for outdoor land use (Subsection 8.1.2) in rural areas of Nigeria (Kassali et al., 2009), validated by questionnaire response (Subsection 7.4.1). This logic was extended to other land uses in which it is assumed that people may travel within the said distance to perform specific land use. Since pipeline failure can occur on any segment of the pipeline system, the entire pipeline network is considered a potential source of hazard.

Table 9-1: Factor and constraint parameters.

Criterion	Factor (in)	Constraint (out)	Procedure
Proximity to pipeline	≤4km	>4km	Buffer 0.5km interval
Proximity to river	≤4km	>4km	Buffer 0.5km interval
Land cover	N/A	N/A	All land cover
Population	N/A	N/A	Point density

9.1.2 Criteria Weighting

Weights were assigned by pairwise comparison matrix (Table 9-2), comparing relative significance of individual criterion to determine which is more significant to the objective. The less significant criterion is rated 1 and the most significant rated 9 according to Saaty's scale of decision preference (Dawotola et al., 2010; Abenan et al., 2012).

Although there are other techniques for assigning weights, the pairwise matrix developed in the context of AHP was chosen because of ease and its wide applications in MCE decision studies. Application of weighted linear combination in GIS spatial decision and MCE requires criterion weights to be normalised to the same unit so the variables can be compared on a similar scale (Eastman et al., 1995; Malczewski, 1999). In this study, criterion layers were ranked from 1 to 9 according to their contribution to land-use exposure opportunities using experience and expert elicitation from colleagues.

9.1.3 Multi-Criteria Evaluation and Analysis

Table 9-2 shows the procedure for allocating weights in a pairwise matrix based on the 1 to 9 scale preference by Saaty. The first stage allocates and sums scores of every criterion in the column according to Equation 9-1:

Equation 9-1:

$$\sum \mathbf{wc}$$

Where wc is the score of a cell in each column, for example:

1 + 1/3 + 1/5 + 1/9 = 1.64

Table 9-2: Pairwise comparison matrix.

Criterion	Stage 1:				Stage 2: Standardisation				
	PP	PR	AL	PC		PP	PR	AL	PC
Proximity to pipeline (PP)	1	3	5	9		0.608	0.661	0.535	0.5
Proximity to river (PR)	1/3	1	3	5		0.202	0.221	0.321	0.228
Land cover	1/5	1/3	1	3		0.122	0.074	0.107	0.167
Population	1/9	1/5	1/3	1		0.068	0.044	0.036	0.056
Total	1.64	4.53	9.33	18		1.00	1.00	1.00	1.00

The second stage normalises the scores of each criterion by dividing with the sum total of its column.

Equation 9-2:

$$\sum \frac{wc}{\sum wc}$$

Where *wc* is the score in a cell and Equation 9-2 is the sum total of the column. For example:

1/1.64 = 0.608.

Table 9-3: Weights allocation.

Stage 3: Eigenvector/Weight Calculation		Weight
Proximity to pipeline (PP)	[0.608+0.661+0.535+0.5]/4	0.576
Proximity to river (PR)	[0.202+0.221+0.321+0.228]/4	0.243
Land cover	[0.122+0.074+0.107+0.167]/4	0.117
Population	[0.068+0.044+0.036+0.056]/4	0.051

The third and last stage determines weights by calculating the eigenvectors.

Equation 9-3:

$$\sum \frac{\boldsymbol{wc}}{\sum \boldsymbol{wc}} \times \frac{\mathbf{1}}{\mathbf{4}}$$

Here, the standardised score for each criterion is added and divided with the number of criteria. For example;

[0.608+0.661+0.535+0.5]/4=0.576.

The last operation measures consistency in weight allocation. Consistency ratio (CR) is determined by summing criterion weights and dividing each by the initial score allocated in stage 1, i.e.

Table 9-4: Consistency ratio determination.

Consistency ratio determination Step I		
Criterion		
Proximity to pipeline (PP)	[0.576*1]+[0.243*3]+[0.117*5]+[0.051*9]	2.349
Proximity to river (PR)	[0.576*0.333]+[0.243*1]+[0.117*3]+[0.051*5]	1.041
Land cover	[0.576*0.2]+[0.243*0.333]+[0.117*1]+[0.051*3]	0.465
Population	[0.576*0.111]+[0.243*0.2]+[0.117*0.333]+[0.051*1]	0.203
Consistency ratio determination Step II		
Criterion		
Proximity to pipeline (PP)	[2.386/0.576]	4.078
Proximity to river (PR)	[1.041/0.243]	4.284
Land cover	[0.465/0.117]	3.974
Population	[0.203/0.051]	3.980

Equation 9-4:

$$\sum \frac{\boldsymbol{wc}}{\sum \boldsymbol{wc}} \times \frac{\mathbf{1}}{\mathbf{4}} \times \boldsymbol{tc}$$

Where tc is the total column. For example:

(0.576x1) + (0.243x3) + (0.117x5) + (0.051x9) = [2.349/0.576] = 4.078

Lambda (λ) = *[4.078+4.284+3.974+3.980]/4*

=4.079

Equation 9-5:

$$\text{Consistency Index (CI)} = \frac{\boldsymbol{\lambda - n}}{\boldsymbol{n - 1}}$$

$$\text{For-example} \quad \frac{4.079-4}{4-1} = 0.026$$

Equation 9-6:

$$\text{Consistency Ratio (CR)} = \frac{\boldsymbol{CI}}{\boldsymbol{RI}}$$

$$\text{Such that } \frac{\mathbf{0.026}}{\mathbf{0.90}} = \mathbf{0.029}$$

RI is a consistency indices used to determine CR in weight allocation; the CR is defined by the number of criteria (Table 9-5). If the RI value is greater than the RI allocated to a particular number of criteria, then weight allocation is inconsistent. A good CR for four criteria according to Malczewski (1999) is less than 0.9. Therefore, with the 0.029 CR, the weight distribution is consistent.

Table 9-5: Random inconsistency index table for n=1, 2…, 9 and 15.

n	1	2	3	4	5	6	7	8	9	15
RI	0.00	0.00	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.59

The weights derived from the comparison showed that proximity to pipeline has the highest score of 0.576, proximity to river 0.243, land cover 0.117, and population 0.051 in Figure 9-2.

It is obvious from the weight distributions that proximity to pipeline is very significant (important criterion) being the main means of crude oil transportation and major source of hydrocarbon discharge. Proximity to rivers scored second; this is important considering the behaviour of crude oil on water and land (Subsection 3.5.2). The rise and fall in water levels due to inundation promotes the flushing of hydrocarbons into the creeks and rivers as well as vertical spreading and surface run-off (Gay et al., 2010; UNEP, 2011).

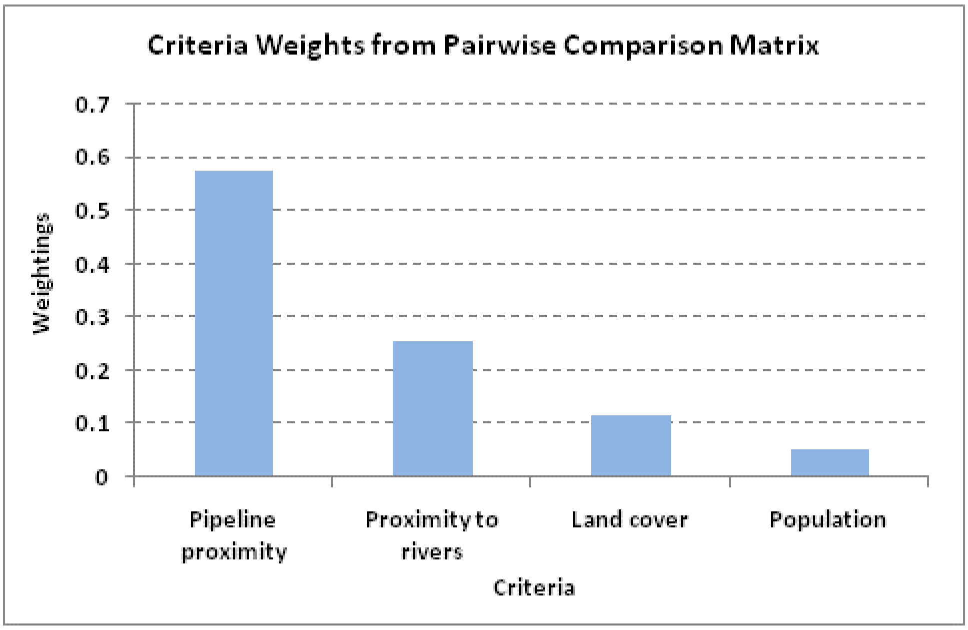


Figure 9-2: Criteria weights derived from pairwise comparison.

Land cover on the other hand can be a retardant against free movement of crude oil on ground surfaces. Although only part of land cover maybe directly affected, the chances of hydrocarbons migrating in both horizontal and vertical directions through a soil vadose zone should not be ignored. Last but not least is population density, which is per square kilometre (km^2) in Figure 9-1c.

9.2 Modelling and Weighted Linear Combination

The weighted overlay for the map layers (Table 9-6) was done based on the Weighted Linear Combination (WLC) methodology (Subsection 5.2.2) to produce a hazard map (Figure 9-3). The assigned scores reflect the distance from the centre of each criterion that is closer to the source of hazard. Thus, the closer a criterion is to the source, the higher its score. Land cover on the other hand reflects the economic factor, while population is treated the same because every human population has equal importance irrespective of size or distribution.

Table 9-6: Criteria score and weights.

Criterion	Score	Weight	Consideration
Proximity to pipeline			
0.0 - 0.5km	9		
0.5 - 1.0km	8		
1.0 - 1.5km	7		
1.5 - 2.0km	6	0.576	Physical
2.0 - 2.5km	5		Distance
2.5 - 3.0km	4		
3.0 - 3.5km	3		
3.5 - 4.0km	1		
Proximity to river			
0.0 - 0.5km	9		
0.5 - 1.0km	8		
1.0 - 1.5km	7		
1.5 - 2.0km	6	0.256	Economic
2.0 - 2.5km	5		Distance
2.5 - 3.0km	4		Physical
3.0 - 3.5km	3		
3.5 - 4.0km	2		
Land cover			
Agric-Cultivation	8		
Fadama Plantation	6		
Minor River	3		
Major River	2		
Rain-fed agriculture	7		
Forested freshwater swamp	6	0.117	Economic
Minor urban	4		
Mangrove forest	8		
Major urban	4		
Population density			
Less - 500	9		
501 – 5,000	9		
5,001 – 15,000	9	0.051	Economic
15,001 – 20,000	9		
25,001 – Over	9		

Scale: 9=Extremely high, 8=Very very high, 7=Very high, 6=Moderately high, 5=Moderate, 4=Moderately low, 3=Very low, 2=Very very low, 1=Extremely low.

The Pipeline Potential Impact Radius (PPIR) is a combination of three major hazard zones defined by Equation 9-7.

Equation 9-7

$$PPIR\ = ehh + vhh + hh$$

Where: ehh = extremely high; vhh = very high; and hh = high hazard zones (Figure 9-3), these are extracted to establish the PPIR buffer.

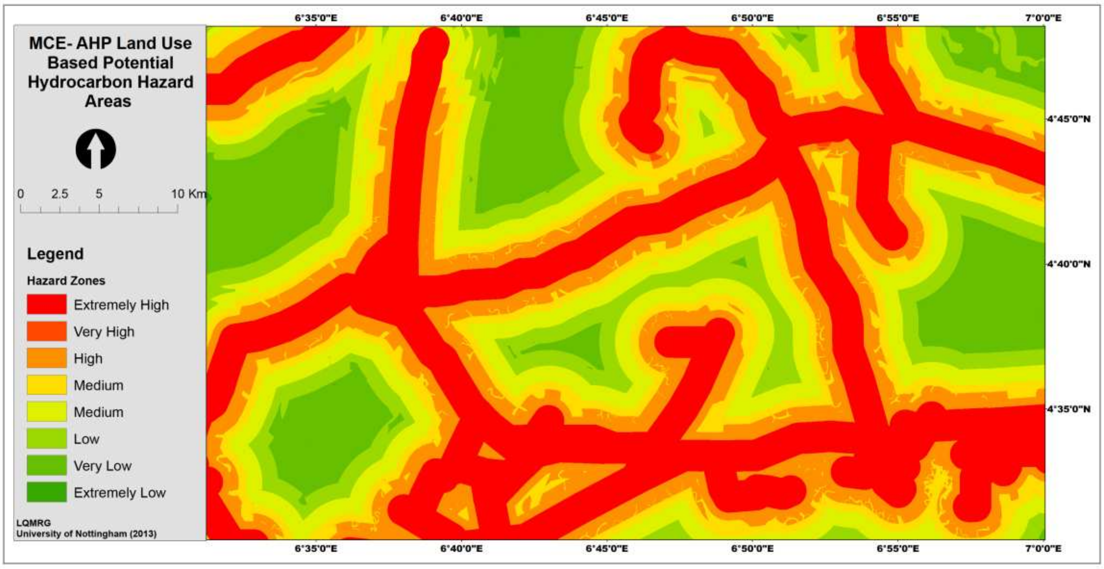


Figure 9-3: MCE model of land-use hazard based on proximity to source

9.2.1 Model Builder Structure and Documentation

Figure 9-4 shows the flow diagram of the MCDM-AHP model structure (see Appendix J-1 for python script). A model is a mapping technique in ArcGIS used to link different tools to perform specific tasks (Allan, 2011). The model can run repeatedly in automated mode to find the solution to spatial problems (ESRI, 2006; Longley et al., 2011, p.406). GIS-based models developed in this manner provide a visual display of procedures, making it easy to explain, scrutinise, modify, export and reproduce.

Tools in the model diagram are shown in orange boxes with one or more input and output: the input variables, also known as data variables, are shown in blue ovals representing existing data or output. Output on the other hand is the product of a process known as the derived variable, represented by green ovals.

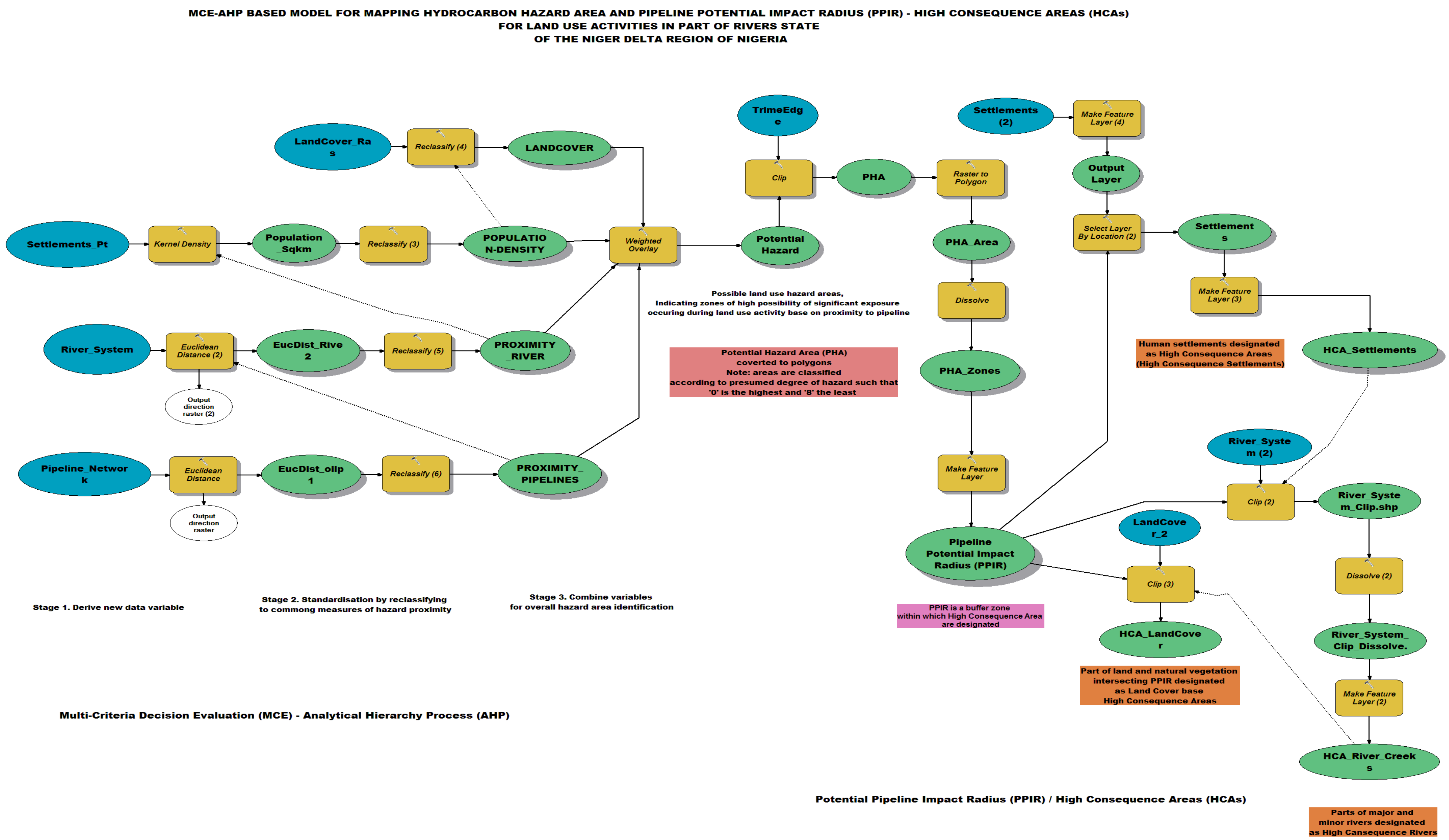


Figure 9-4: Multi-Criteria-Decision-Evaluation-Analytical Hierarchy Process (MCE-AHP) flow diagram for modelling land use hazard areas and Potential Pipeline Impact Radius (PPIR).

The colour codes indicate the type of tools and steps executed in the modelling (blue represents criteria map layers, yellow the tool, and green the output of a process).

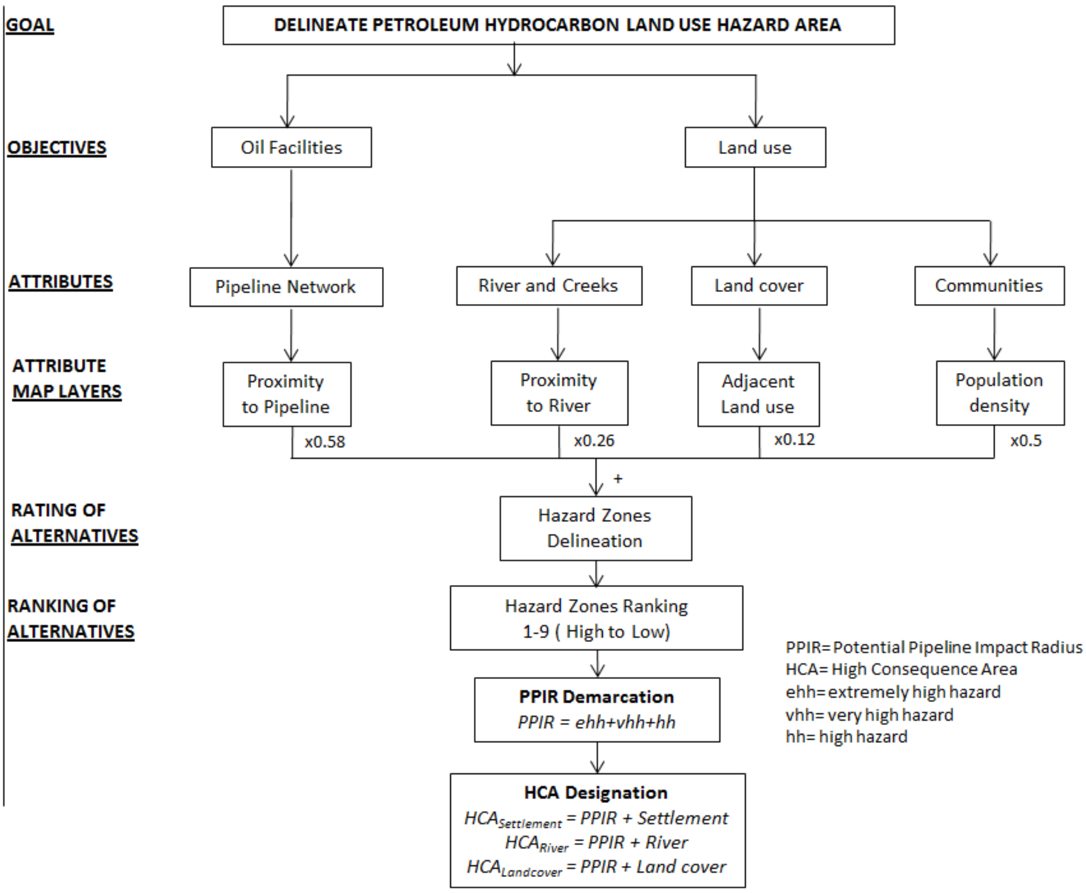


Figure 9-5: Analytic Hierarchy Process layout of the model.

The first step creates multiple ring buffers for proximity to rivers and pipelines using equidistance; this was reclassified according to factors and constraints guidelines in Table 9-1. The second stage creates a population point-density layer for the settlements and was reclassified. Finally, an overlay operation using WLC was performed to produce the map shown in Figure 9-3 depicting different levels of hazard zones according to the degree of intensity. There are three outputs from Figure 9-4: the first is the hazard zone classification in Figure 9-3, the second is the PPIR demarcation, and the third is the HCAs designation (Section 9.3). Figure 9-5 shows the AHP procedure and output derived by the model.

9.2.2 Criteria Weights' Sensitivity Analysis

This is important when weights are assigned based on subjective expert opinion, or personal preference (Mitchell, 2012). Sensitivity analysis examines how a change in criterion weight can affect the model; if the effect is significant, the model is said to be sensitive to that particular criterion. Changes can be examined by visual inspection or statistical comparison.

The criteria incorporated in the MCE-AHP model were allocated weights by pairwise comparison (Subsection 9.1.3). For the sake of sensitivity analysis, the weights were redistributed systematically between criteria (Table 9-7). Figure 9-6 and Figure 9-7 show no significant difference in the band of interest (i.e. the extremely high hazard zones).

Table 9-7: Sensitivity testing and weights alteration.

No.	Criterion	Weight in percentage (%)			
		Original	1st Test	2nd Test	3rd Test
1	Land Cover	12	58	26	5
2	Population Density	5	26	12	58
3	Proximity to River	26	5	58	12
4	Proximity to Pipeline	58	12	5	26

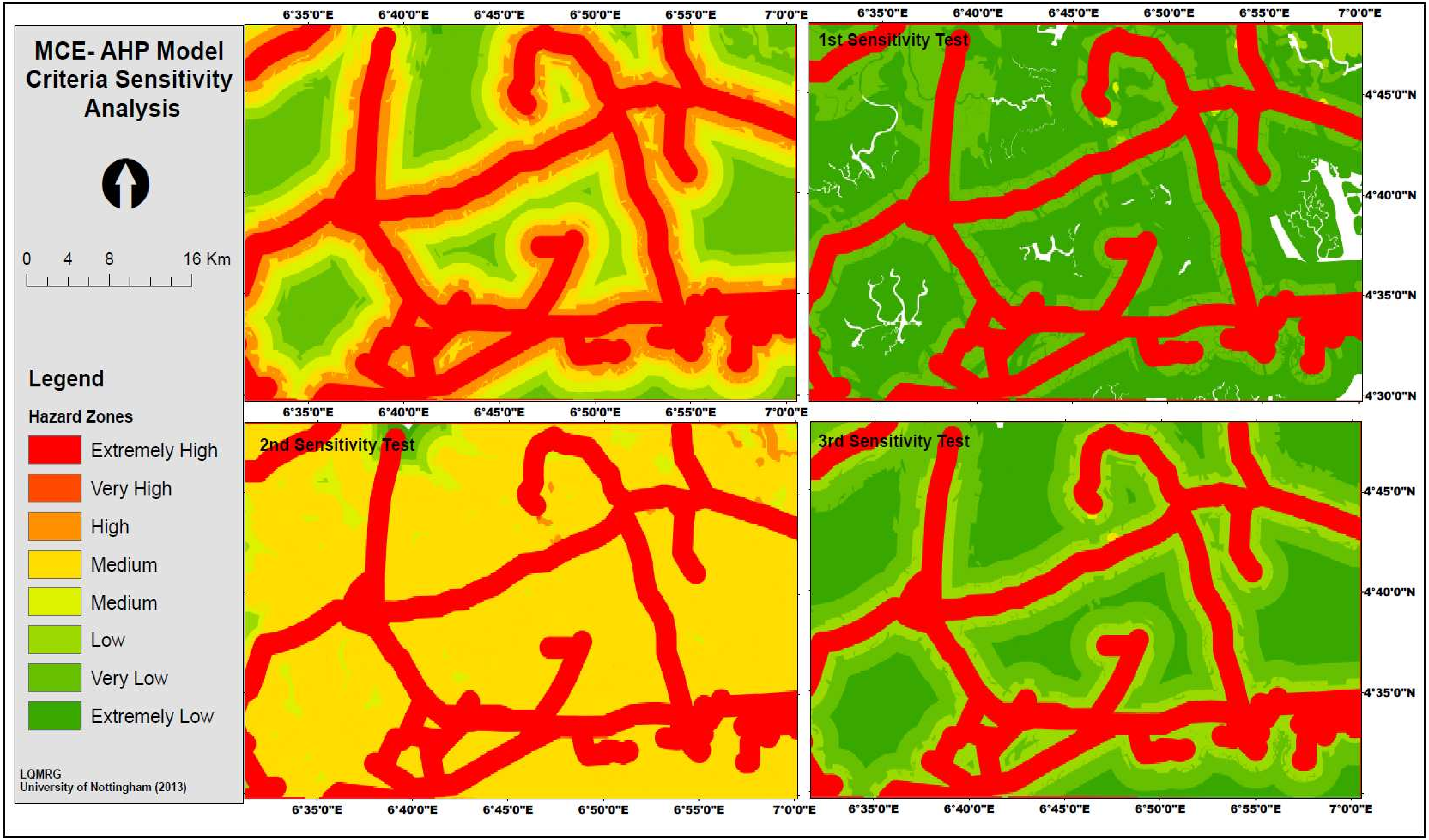


Figure 9-6: Output of Multi-Criteria Evaluation model sensitivity analysis, criterion weights systematically tested according to Table 9-7.

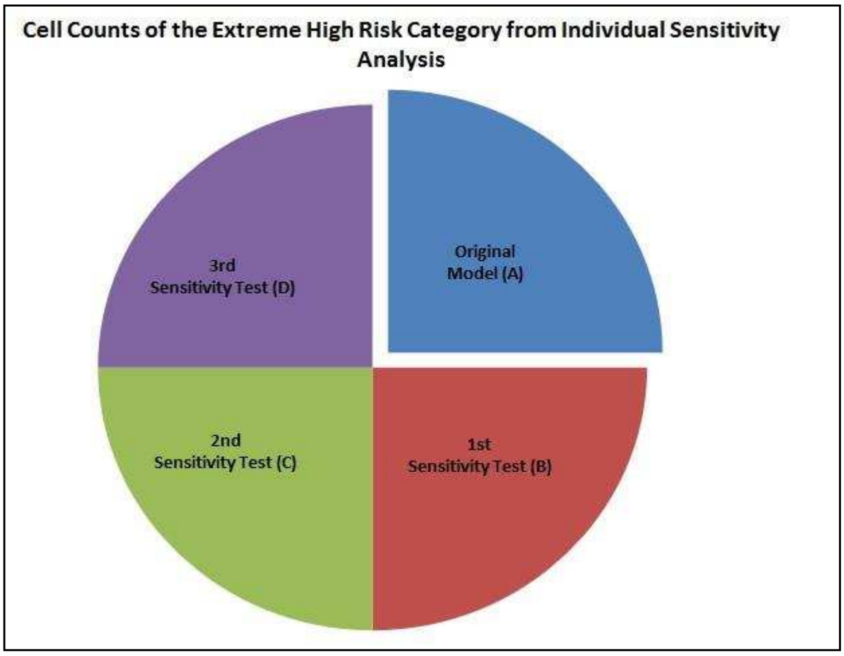


Figure 9-7: Comparison of cell counts of the extreme high-risk band from sensitivity analysis.

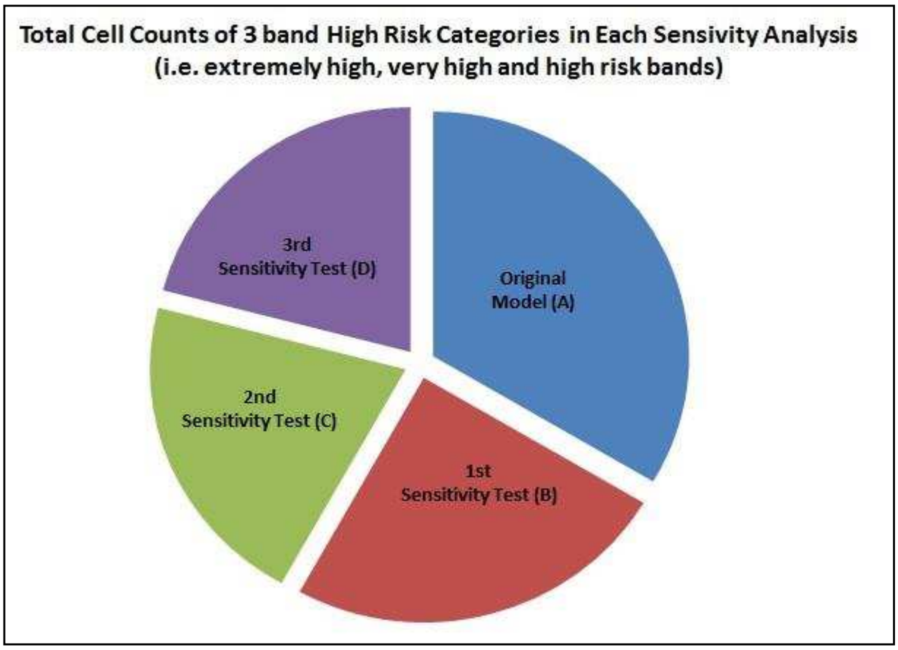


Figure 9-8: Cell count variations in the bands of interest.

However, further comparison of values from other high hazard bands like "Extremely High, Very High and High hazards" showed a slight difference in Figure 9-6 and Figure 9-7. A comparison of the second sensitivity test, in which proximity to river has the highest weight, almost changed the pattern by eliminating the low hazard zones and extending the medium hazard zones over the area in Figure 9-6 (2^{nd} Sensitivity Test). This behaviour is an indication that the model is sensitive to proximity to river. However, since the zones of interest are the first three high hazard zones, and there is minimum difference in cell count shown in Figure 9-8, the model can be accepted with reasonable confidence.

9.2.3 Multivariate Analysis of MCE Sensitivity Outputs

Band collection statistics is a tool in ArcGIS spatial analysis used to perform multivariate analysis for raster bands. The tool computes minimum, maximum, mean, and standard deviation, as well as covariance and correlation matrix for raster layers (Table 9-8).

Table 9-8: Band analysis of MCDM criteria.

MCE Model Criteria Sensitivity Analysis				
Statistics of Individual Layers				
Layer	Min	Max	Mean	Std.
1	0.0000	8.0000	3.4370	2.5254
2	0.0000	9.0000	2.8088	1.9325
3	0.0000	9.0000	5.2858	3.6071
4	0.0000	9.0000	4.8511	3.3449
Covariance Matrix				
Layer	1	2	3	4
1	6.44638	4.19108	8.12102	7.89547
2	4.19108	3.92513	7.15487	6.57884
3	8.12102	7.15487	13.6621	12.5166
4	7.89547	6.57884	12.5166	11.7317
Correlation Matrix				
Layer	1	2	3	4
1	1.00000	0.83318	0.86535	0.90790
2	0.83318	1.00000	0.97705	0.96949
3	0.86535	0.97705	1.00000	0.98866
4	0.90790	0.96949	0.98866	1.00000

The matrixes provide values of variance and covariance. A variance is a statistical measurement indicating how much variance there is from a mean (Ebdon, 1985); it expresses how increase or decrease in one dataset results in a proportional increase or decrease in another (Mitchell, 2009). A covariance of zero means no relationship, and relationships can be negative or positive. To calculate covariance, squares of differences between values of each cell and the means of all cells were averaged. The variances of each layer are read diagonally from upper left to lower right (i.e. the part not shaded in the covariance matrix section of Table 9-8). The shaded entries of the covariance matrix are the covariance between all pairs of the model raster derived from Equation 9-1 for layers *i* and j.

Equation 9-8:

$$Cov_{ij} = \frac{\sum_{k=1}^{N}(Z_{ik} - \mu_i)\,(Z_{jk} - \mu_j)}{N-1}$$

Where: Z = the value of a cell; ij = layers of a stack; μ = mean of a layer; N = number of cells; and k = specific cell.

While covariance of two layers is the intersection of particular rows and columns, the correlation matrix on the other hand shows correlation coefficients of the relationship between two datasets. The correlation of two layers measures dependence between layers as a ratio of covariance of two layers divided by the product of their standard deviation according to Equation 9-9.

Equation 9-9:

$$Corr_{ij} = \frac{Cov_{ij}}{\delta_i \delta_j}$$

Where: $Corr_{ij}$ = the correlation of layer i and$j$; Cov_{ij}= the covariance of layer i and$j$; and $\delta_i\delta_j$ = the product of the layer's standard deviations.

Reading correlation is also diagonal from upper left to lower right. Therefore, from the unshaded entries in the correlation matrix section of Table 9-8, the MCDM-AHP sensitivity outputs showed strong positive correlation. This means there is a direct relationship between results of each test.

9.3 Modelling PPIR and Designating HCA

The concepts of PIR and HCA are detailed in Subsection 5.5.2. The industrial-based PIR is defined based on pipeline properties (see Table 5-4), but in this model a new method for defining PPIR is developed using environmental (land use) variables. The method (MCDM-AHP) established PPIR in Figure 9-9 from the interaction of physical variables (Table 9-6) to identify HCAs in Figure 9-10 as areas where pipeline failure is likely to cause significant adverse impact on human population, domestic source of water, and ecologically sensitive resources (US Department of Transportation, 2011).

The UNEP (2011) revealed wide-spread TPH concentrations at several metres away from source of discharge; this can imply the ease with which hydrocarbons migrate in the Niger Delta. Therefore, the minimum 1km requirement for hydro-census investigation of suspected contaminated sites in South Africa (Department of Environmental Affairs, 2010), and the 500–2,500 metres primary and secondary pipeline impact buffers hypothesised by the Guadalupo-Blanco River Authority (2011) gives credence to the average distance of the 1km MCDM-AHP model specification.

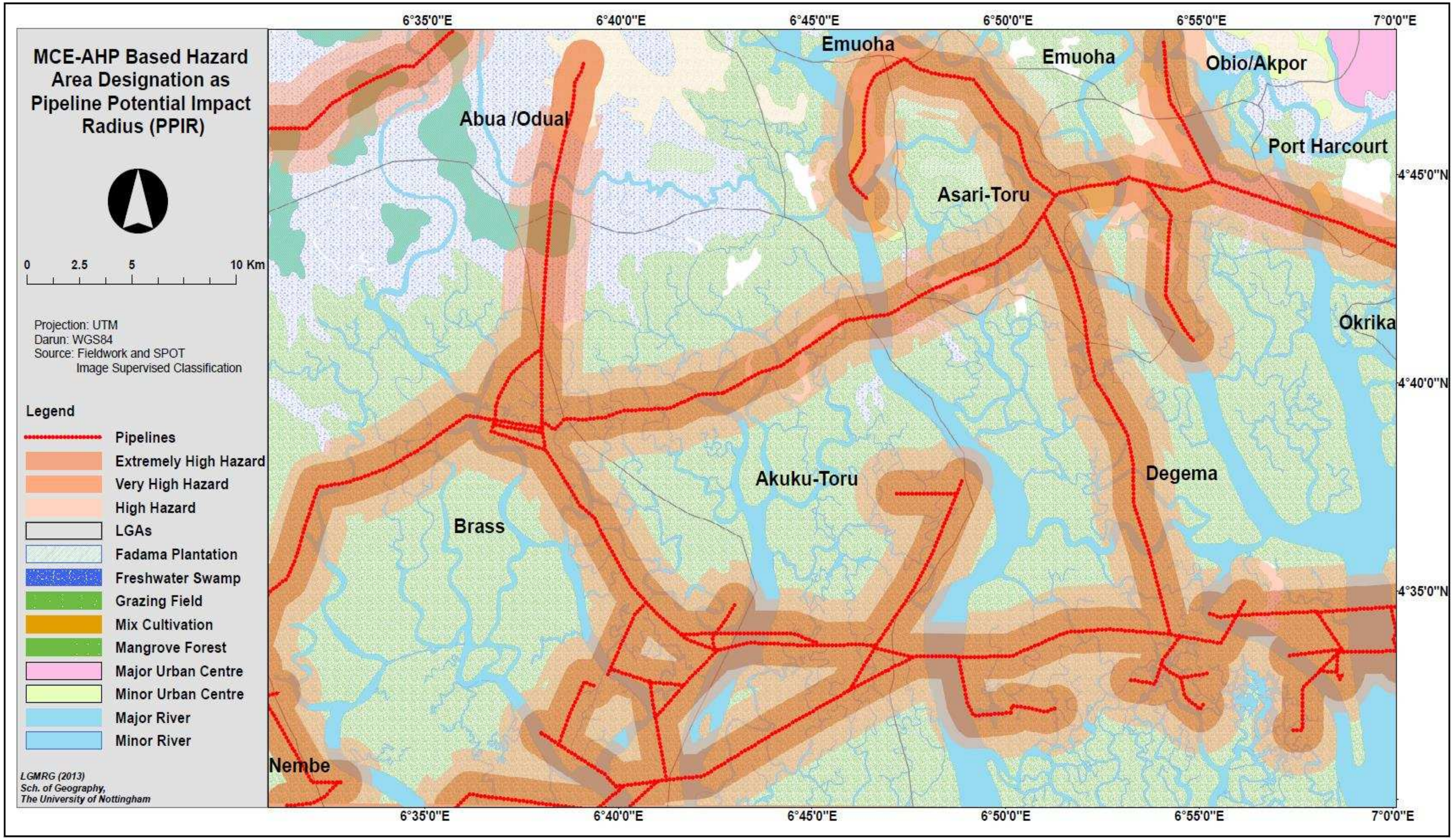
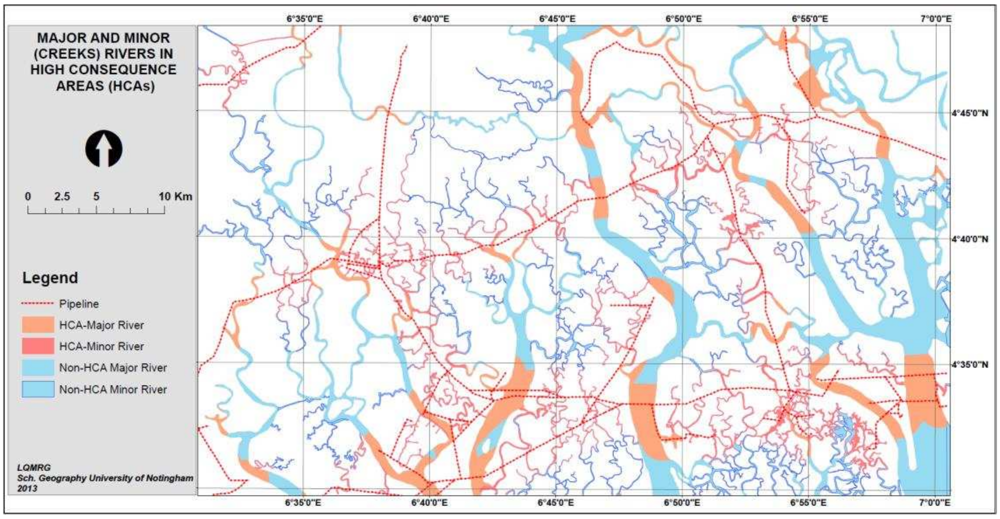
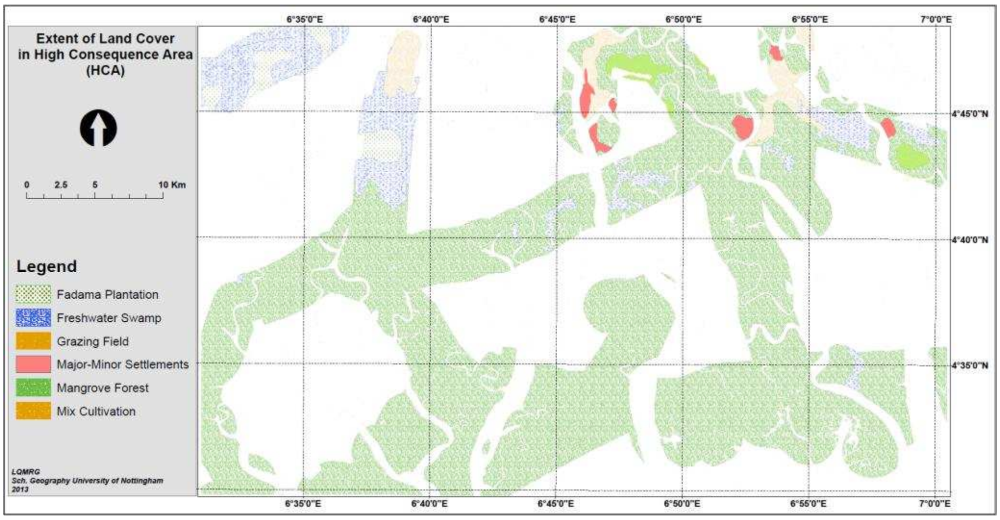


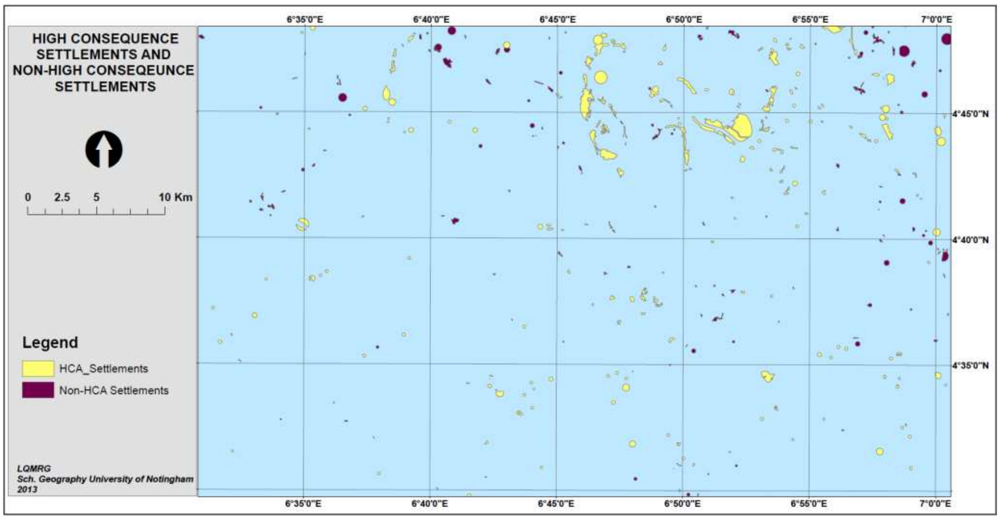
Figure 9-9: Delineation of PPIR extracted from MCE-AHP hazard zones.



A. HCA rivers and creek.



B. HCA land-cover.



C. HCA settlements.

Figure 9-10: Rivers, land cover and settlements in HCAs.

9.3.1 Designating High Consequence Areas

The presence of settlements in risk areas (HCAs) indicates existence of human habitats, which also suggests the possibilities of pollutant linkages. Thus, rivers and creeks that surround the settlements can serve as exposure pathways bringing hydrocarbons in contact with people, e.g. hydrocarbon plumes that are migrating up and down stream of pipeline-river intersections can pose a risk to human health. Consequently, about 62% of 374 settlements in the area were found in the HCAs and no fewer than 69% of 1.3 million people in the area live in the susceptible communities.

9.3.2 Criteria for Designating HCAs

The most important factor focused mainly on human habitat within the predefined analysis area indicated by the MCDM-AHP model hazard zones. The intensity of hazard decreases with distance from source (pipeline), hence the introduction of direct and indirect HCAs. The direct HCAs are areas within the immediate vicinity of a pipeline segment (which can be impacted directly), and the indirect HCAs (those affected through hydrocarbon migration along a pathway). The definition of the HCAs in the context of land use includes settlements of all sizes from where human movements originate: river and creek networks that serve for fishing, domestic water supply, and land cover on which farming, hunting, and wild gathering are conducted. Table 9-9 shows the characteristics of areas covered by HCAs and non-HCAs. Non-HCAs are areas presumably outside the PPIR corridor. The HCA registry (Appendix E) contains information of settlements designated high consequence settlements; the information can determine population statistics and number of households that are likely to be at risk.

Table 9-9: Characteristics of HCA and non-HCA areas.

Category	HCA (%)	Non-HCA (%)
Settlement	231 (61.9%)	142 (38.1%)
Population	909,519 (69.4%)	401,178 (30.6%)
Est. No. of Household[17]	113,689.9	50,147.2
Male	410,464.2	181,052.1
Female	499,054.8	220,125.9
Under 14 years	333,496.2	147,231.7
River (sq.km)	134,470.9 (39.2%)	208,680.3 (60.8%)
Major	101099.3 (sq.km)	162621.5 (sq.km)
Minor (Creeks)	33371.6 (sq.km)	46058.8 (sq.km)
Land Cover (sq.km)	765,275.5 (39.9%)	1,154,097.9 (60.1%)
Fadama Plantation	16,417.9 (sq.km)	26,592.7 (sq.km)
Freshwater Swamp	63,037.7 (sq.km)	147.929.6 (sq.km)
Grazing Field	9,734.9 (sq.km)	9,506.3 (sq.km)
Mangrove Forest	628,752.7 (sq.km)	565,756.4 (sq.km)
Mixed-Cultivation	27,646.3 (sq.km)	35,014.5 (sq.km)
Others	19,686 (sq.km)	369,298.4 (sq.km)

In light of the above, an HCA is an area with potential risk of damage to properties and exposure. However, the intensity of exposure may reduce due to loss of concentration with distance from source, but exposure can also increase as people go to the source. As a result:

i. properties like farms, fishing grounds etc. outside HCAs would not be affected;

ii. people working in and living in settlements within HCAs are likely to become exposed; and

iii. people working or living outside HCAs would have a low chance of exposure.

[17] The state average household is made up of eight family members based on the 2006 Census (NPC, 2012). This was adopted to estimate the number of households.

9.3.3 Pipeline Class Classification

A similar principle was discussed earlier (Subsection 5.5.3) as a procedure for classifying pipelines using fixed distance to population density and number of dwellings. The criteria set out in 49 CFR1.192 (2005) are not suitable for the Niger Delta for the following reasons. Firstly, dependence on number of dwellings within a specific distance, i.e. 220 yards (201.2m); secondly, priority on pipeline integrity management guideline, which requires a change in class level with an increase in number of dwellings and population; and thirdly, non-inclusion of land-use activities such as farming, wild gathering, hunting etc. Those are the predominant activities bringing rural people in contact with pipelines, which predispose them to unnecessary exposure opportunities.

The new approach divides the pipeline network into equal segments of 1.6 kilometres according to Figure 5-6 and use the fixed distance of 201.2m (Subsection 5.5.3) to classify pipelines into class categories (Table 9-10 and Figure 9-11). About 46 communities are located within class 1 (201.2m), which should require the highest form of pipeline integrity, land use and easement regime. Hence, pipe standards should conform with 'Location Class 3' (Subsection 5.5.3), i.e. 0.540inch minimum for a typical 30inch-outside diameter and a design factor (DF) ≤0.3 for high consequence areas based on ASME's (2007), Steiner's (2010) and Kiefner's (2011) estimations.

Another alternative method is to use pipeline-river intersections as criteria (Figure 9-12) in class location. About 214.4km of 123 pipe segments intersects with river or creek while 101km of 84 pipe segments did not intersect with any water body.

Table 9-10: Pipeline class categories.

Class	Distance (m)	Pipe Segments	Length (km)	Number of Settlements	Population		
					Total	Mean	STD
1	201.2	56	90.9	49	252245	5148	252245
2	402.4	77	129.6	80	347441	4343	8089
3	804.8	105	173.3	118	499736	4235	7329
4	>804.8	102	142.3	373	1310697	3514	6092

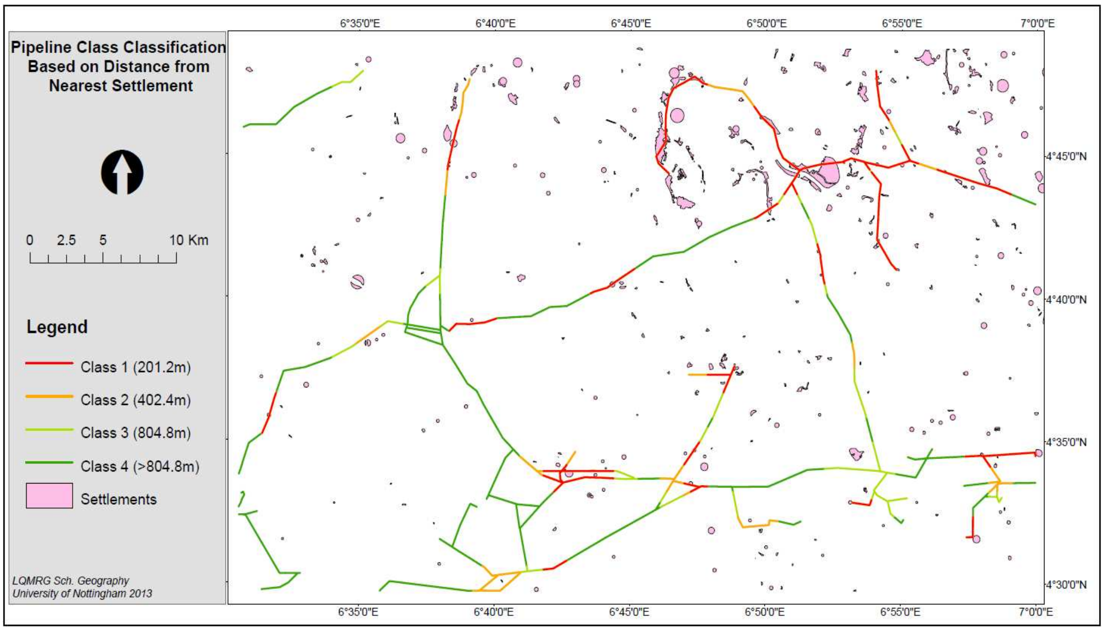


Figure 9-11: Pipeline prioritisation based on distance from settlements.

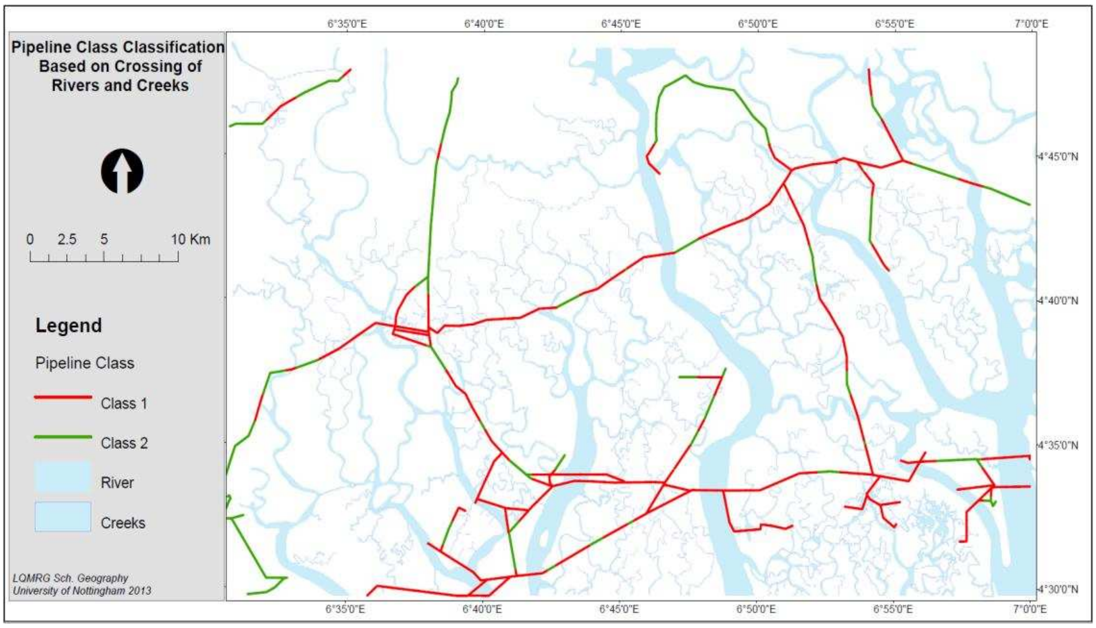


Figure 9-12: Pipeline prioritisation based on crossing of water bodies.

The choice of method of classification depends on cost, monitoring, and surveillance strategy, but with an extensive network such as this the first method is preferable because it can be a reliable and sustainable approach of pipeline class classification for pipeline management in the Niger Delta.

9.4 Model Transferability and Validation

The transferability of the MCE-AHP model was tested on the Ogoniland area where the UNEP conducted oil pollution assessment. Options for validating a model such as this are:

i) by physical site inspection to ascertain whether or not the PPIR area is realistic;

ii) to use a high resolution satellite image or aerial photograph to measure the known impacted area and compare with the model;

iii) use previous oil spill sites to provide reasonable assurance on the feasibility of the modelled PPIR.

9.4.1 Model Transfer

The UNEP (2011) work in Ogoniland between 2010 and 2011 provided locations of sampled areas and TPH concentrations available in the public domain (see Figure 3-7). In addition, spatial datasets were acquired by on-screen digitisation and supervised classification at a resolution compatible with the original MCDM-AHP model.

The Ogoniland spatial datasets were introduced in the MCDM-AHP model, to produce Figure 9-13. Figure 9-14 shows the demarcated PPIR overlaid on the land cover. About 121 out of 247 settlements fall within the HCAs along with a small proportion of rivers in the southern part of the area.

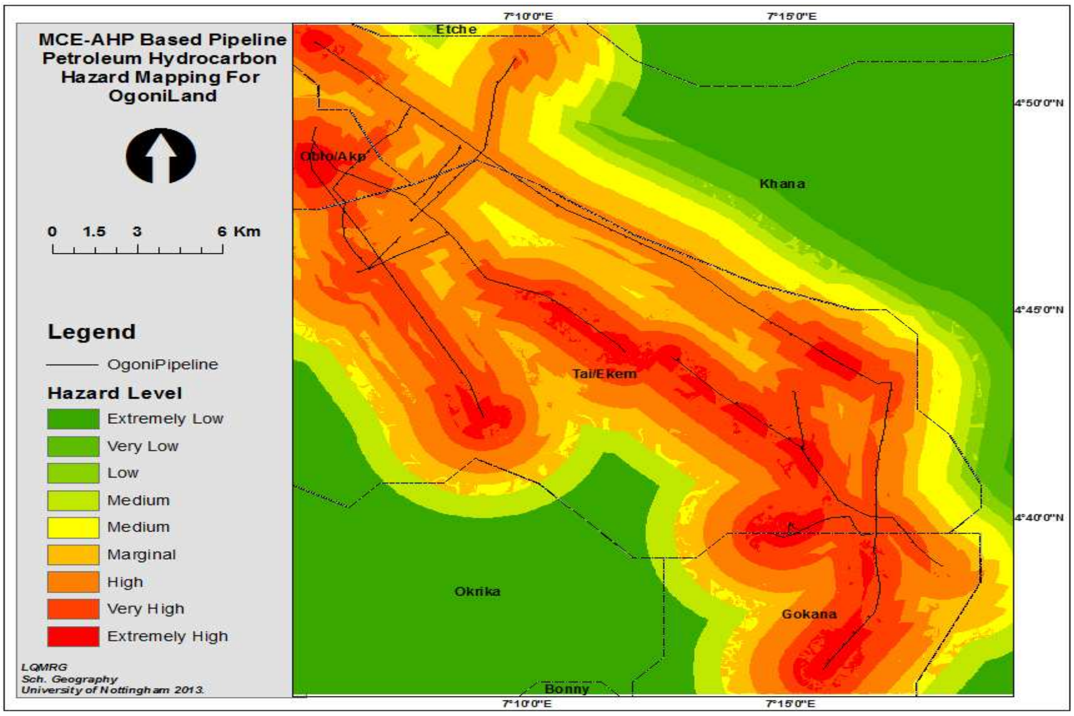


Figure 9-13: MCE-AHP hazard mapping for Ogoniland.

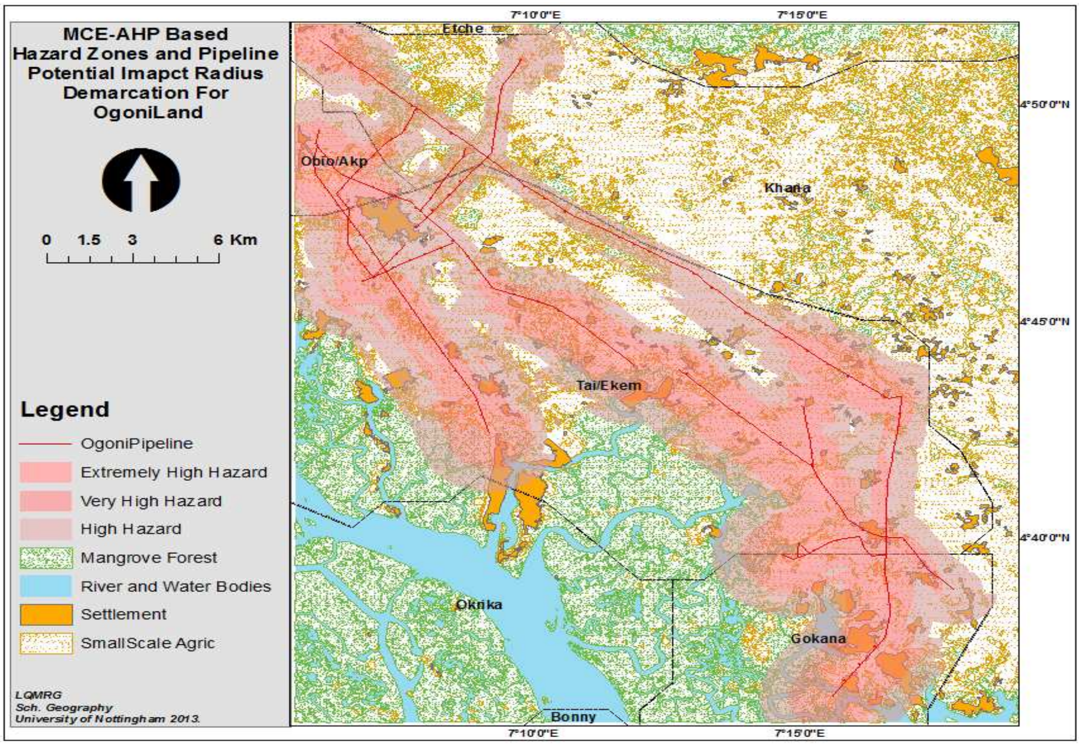


Figure 9-14: Demarcation of HCA using PPIR.

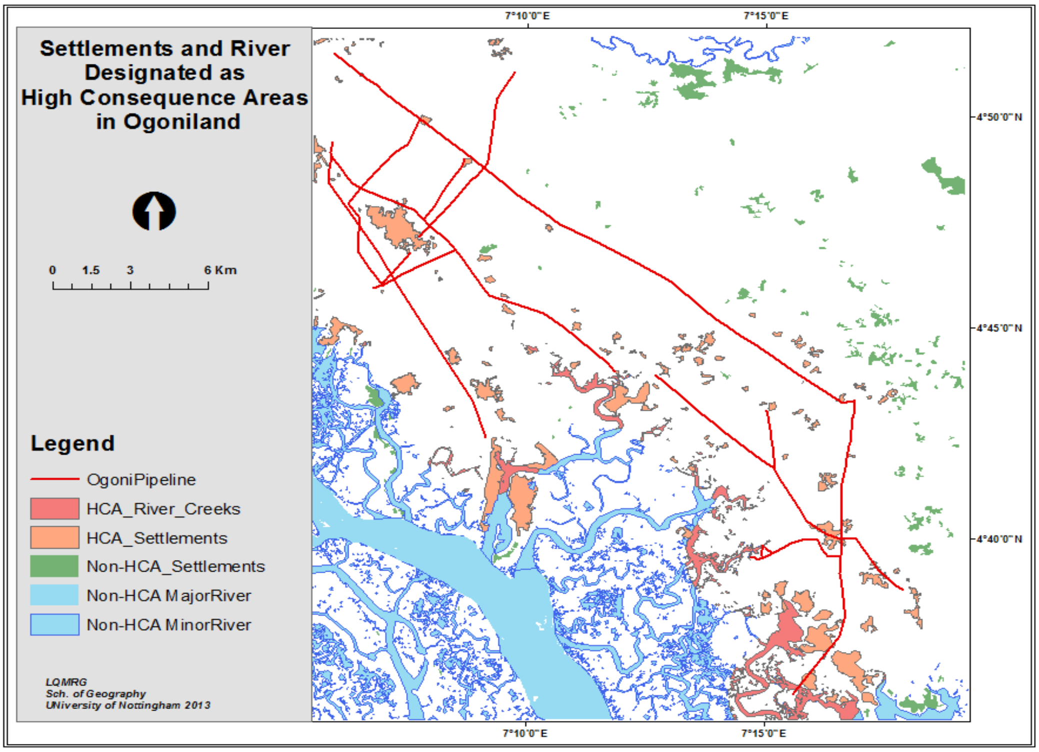


Figure 9-15: HCA rivers and settlements in Ogoniland.

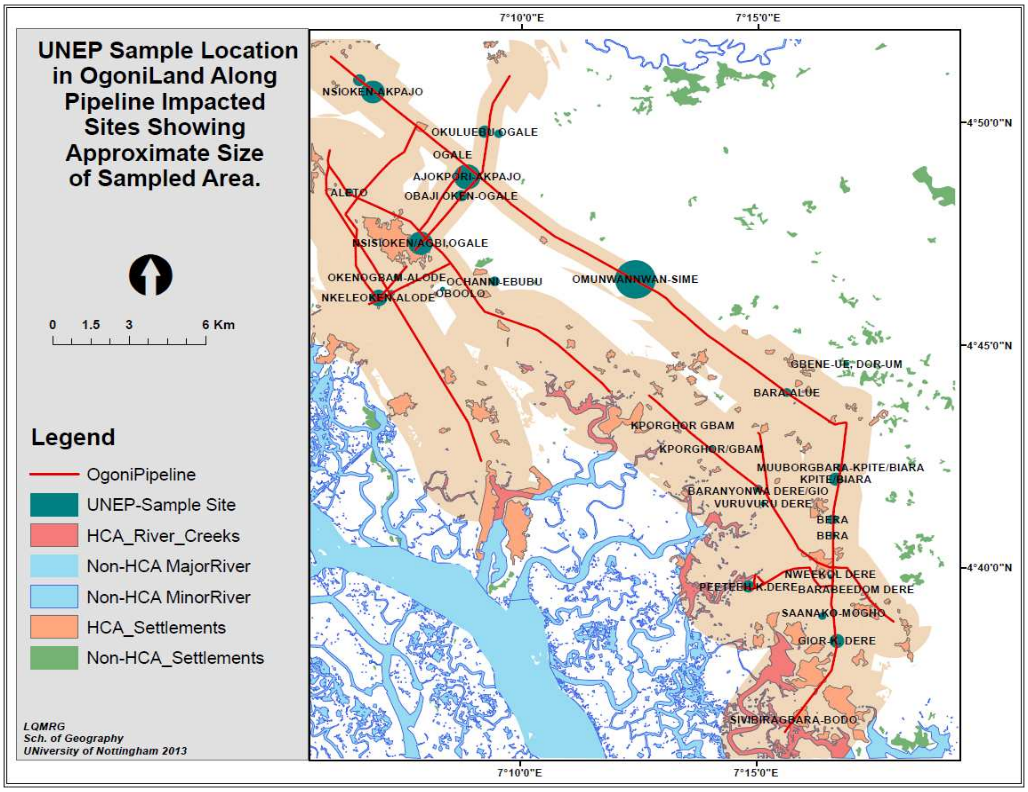


Figure 9-16: PPIR buffer showing UNEP sampled sites and estimated area of extent.

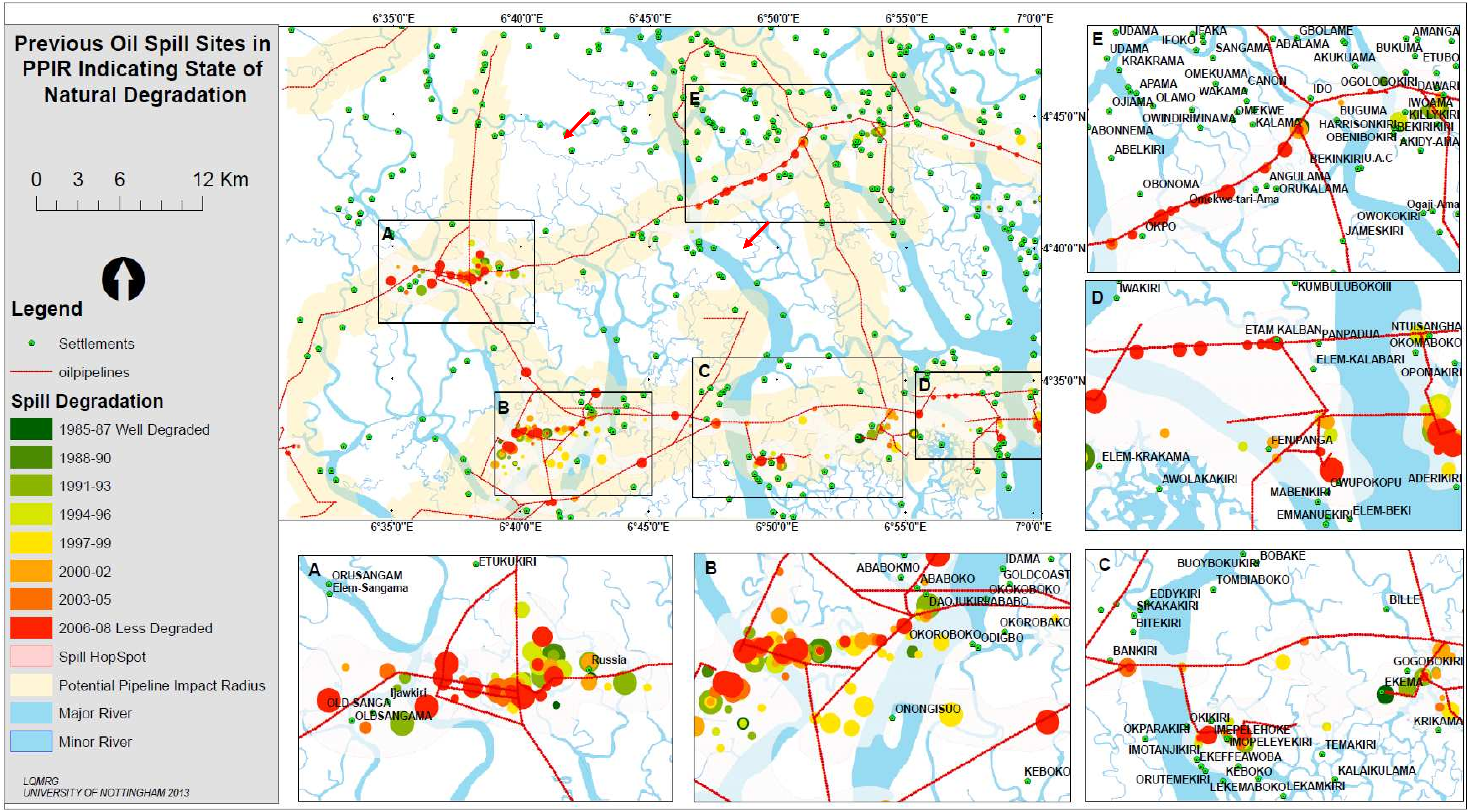


Figure 9-17: PPIR buffer showing extent of PIR and previous oil spill affected areas, insert showing possible state of natural degradation of hydrocarbons and settlement nearby.

Also, of the 822,266.5km^2 of rivers in the area, only about 10,475km^2 (12%) was found in the HCA (Figure 9-15). The UNEP investigated 65 polluted sites, 38 of which were caused by pipeline discharge, shown in Figure 9-16.

Consequently, the only way to validate the model is to use locations of previous oil spill sites in the area to justify the PPIR buffer. Hence, by overlaying spill locations, as in Figure 9-7, it is evident that the extent of the PPIR (distance) is reasonable for a worst-case scenario.

9.5 Establishing Pollutant Linkages

Land-use activities provide the basis for evaluating exposure according to the source-pathway-receptor paradigm. A source is a potential contaminant capable of causing harm; in this case, oil pipeline spills. A receptor is the object at risk of damage if the contaminant is present at levels sufficient to cause harm. A pathway is the direct and indirect routes through which contaminants can migrate (Environment Agency, 2009; Canadian Council of Ministers of the Environment, 2010). Thus, the obvious pathways in the present scenario are: surface, subsurface water and saturated soil vadose.

There is tendency for a two-way interaction between receptors and source. For instance, situations where people perform land use activities on already contaminated land on the one hand, and contaminants migrating to where people conduct land-use activities on the other. The two-way interaction illustrated in Figure 9-18 describes how components complete pollutant linkages. Risk in this case is defined by Equation 9-10.

Equation 9-10

$$risk = hazard(source) \times pathway \times receptor\ (human)$$

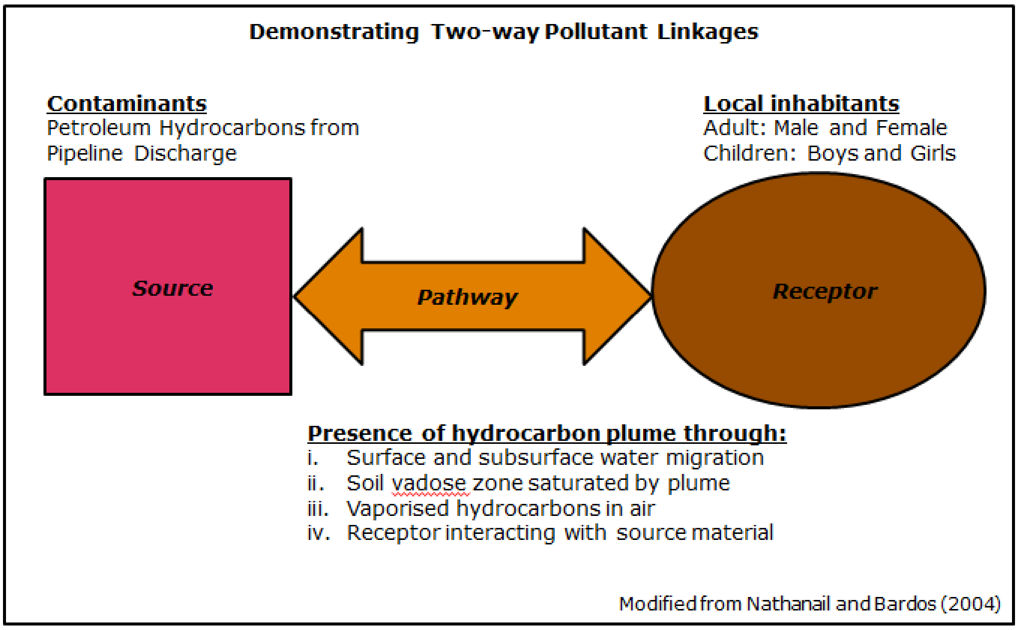


Figure 9-18: Possible two-way interaction between source and receptor.

Figure 9-19 shows sections of the river network that are susceptible to pipeline impact and pathway for hydrocarbon migration up and downstream. Fishing and domestic water consumption in these areas can lead to dermal contact, inhalation, and ingestion. In addition, land-based activities such as farming, hunting etc., which are conducted along pipeline routes (shown in Figure 9-20), may complete pollutant linkages and lead to exposure.

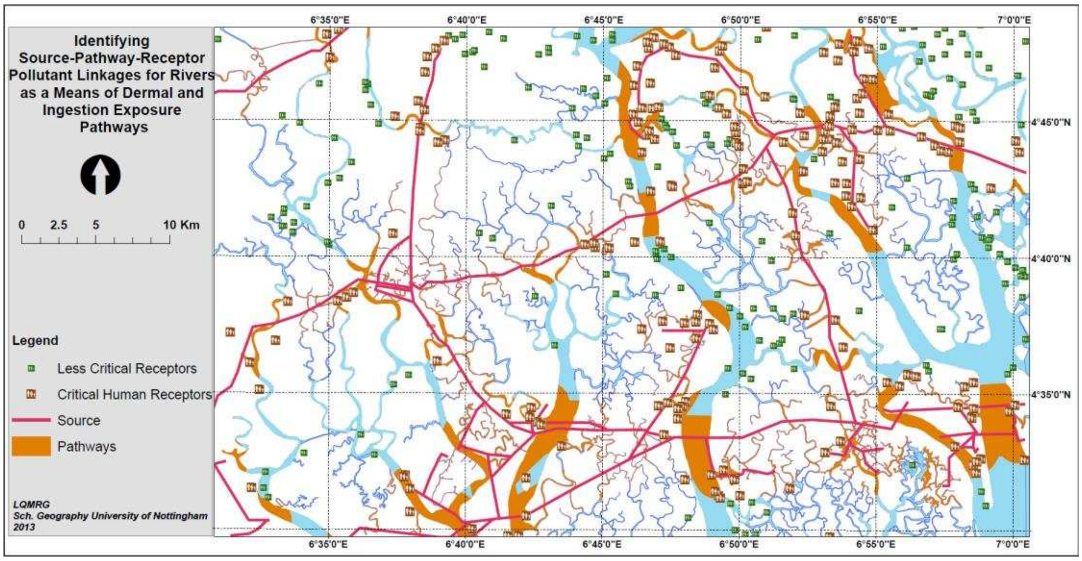


Figure 9-19: Water-based exposure pathways and pollutant linkages.

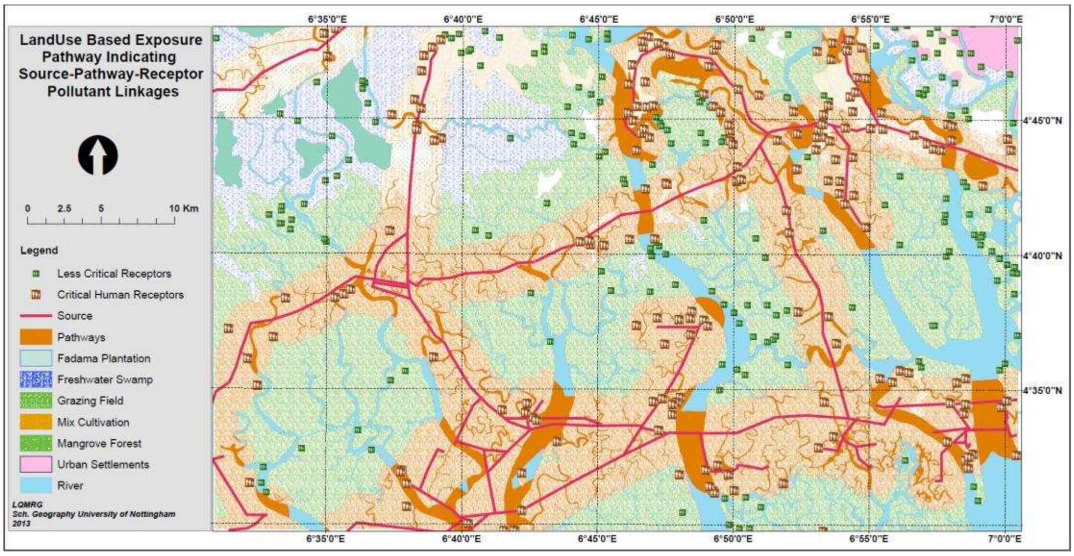


Figure 9-20: Land-based exposure pathways and pollutant linkages.

Conclusion

The use of the MCDM-AHP technique for spatial decision making allows subjective and objective factors in decision making. However, this does not interfere with the result because decision makers use rational reasoning built on experience and knowledge in their judgement (Ascough II et al., 2002; Malczewski, 2006). The implementation of the technique in demarcating the pipeline impact area is the first in literature, which extends the frontier of MCDM application in GIS. Therefore, it provides the basis for further research in the use of the technique for solving spatial related problems where there is a paucity of data; so far, MCDM has proved useful in this research, which has suffered from a paucity of data. In addition, the use of the GIS model builder makes it easy to scrutinise, understand, and replicate for similar studies. Already the transferability of the model has been demonstrated (Section 9.4.1) and showed that the model can be applied in a similar environment.

The established PPIR introduced a new dimension in land-use exposure management, unlike the industrial-based method that was based on pipeline parameter and integrity. This method allows susceptible communities to be identified and organised according to their proximity to pipeline class locations. The new system is especially suitable for rural communities like the Niger Delta, where people who depend on local ecosystem services for livelihood become exposed to pipeline-impacted environmental media in the process of fending for themselves. The PPIR can be used to identify possible pollutant linkages and exposure pathways, which is critical in land-use exposure management.

Having developed a method for mapping land-use pipeline impact areas in this chapter, the following chapter discusses the implication of oil and gas activities in the study area and human-induced pipeline interdiction on rural land use and risk to human health.

CHAPTER 10

DISCUSSION

10.0 Introduction

This study used oil spill datasets to analyse quantity (Figure 7-6), and frequency of oil spill incidents by cause (Figure 7-7, Figure 7-8, Figure 7-9 and Figure 7-10) in parts of the Rivers state of Nigeria, and identified possible land-use exposure scenarios (Table 8-2). At the end a method was developed for mapping the pipeline impact area, a procedure for identifying susceptible communities, and Generic Assessment Criteria (GAC) were developed for three rural land uses (Sections 8.3 and 8.4) because none exists in Nigeria. This chapter integrates the results of the research into the broader framework of land-use exposure and human health risk assessment for people in the Niger Delta. For application, a framework for public integration in decision making is proposed to facilitate public participation in pipeline monitoring, hazard mitigation and land-use exposure mitigation for the Niger Delta.

10.1 Approach and Strategies

Continuing to discharge and the accumulation of petroleum hydrocarbons in the environment can impair productivity of and pose a threat to human health and the environment. Therefore, oil pollution is a major concern in the Niger Delta. Prolonged exposure to hydrocarbon contaminants either through skin contact, inhalation of contaminated air or dust particles, and/or ingestion of contaminated water or food can cause systemic and localised effects on human health (Section 3.4.2). An effort by the federal government to address this led to the funding of the UNEP to assess polluted sites in Ogoniland in 2010-2011 (UNEP, 2011). The UNEP's report and recommendation (Appendix F) is expected to give impetus to intellectual capacity development and acquisition of technical skills required to avert an impending environmental catastrophe in the Niger Delta. Consequently, this study has set out "to develop a method for mapping land-use hazard areas from oil pipeline spills" (Section 1.2) as a means of mitigating human health risk associated with oil pollution. For this to be done, it is important to identify potential pollutant linkages relevant to the Niger Delta area. Given that exposure can occur through direct and indirect contact between a receptor and chemical contaminants, land-use activities are undoubtedly significant drivers of pollutant linkages responsible for unnecessary exposure opportunities.

To achieve this, an analysis of historic oil spill sites was performed to determine spatial distribution (Figure 7-26), cause, frequency, and quantity of crude discharged in order to understand the pattern and severity of occurrence (Subsection 7.1). Risk assessment criteria for petroleum hydrocarbons were developed for rural land uses using CLEA v1.06 software since none exists in Nigeria (Subsection 8.4.1). The GAC are the first for any land-use assessment in Nigeria; therefore, it would help mitigate unnecessary exposure and manage risk associated with land-use activities in oil-producing communities. This is important because several exposure opportunities abound in rural areas and yet there are no specific risk assessment models.

The MCDM-AHP model framework was built on physical, economic, and human variables in a spatial decision-making process (Chapter 9) to perform three important functions. First, to establish hazard zones based on proximity to pipelines (Section 9.2), second to delineate PPIR (areas) (Section 9.3), and third, to identify susceptible communities in HCAs

(Subsection 9.3.1, Appendix E). The results of the model can be considered conservative because the PPIR buffer extends father than the industry-based PIR (Subsection 5.5.2) and does not differentiate between sizes of pipelines. In the industry-based PIR, a 36inch pipe would have a 239.57-metre buffer (Table 5-4) according to Equation 5-1. This is not suitable for the Niger Delta where, aside from a poor response time (Subsection 7.1.1; Figure 7-12), there are access problems and environmental variables that would allow hydrocarbons to spread fast and wide in a limited time.

Therefore, extending the buffer zone to an average of 1km is a worst-case scenario that ensures dwellings and properties within this buffer are accommodated in the oil spill contingency plans. The model was successfully tested on Ogoniland (Subsection 9.4.1) and found to be easy to transfer in principle. However, the limitation of the model is restricted to the use of similar criteria variables and the effect of size of area on factors and constraints specification (Section 9.1.1).

10.1.1 Modelling Hazard Areas

MCDM and AHP are very popular techniques in GIS, judging from the plethora of academic materials published in the field (Chapter 5). While MCDM emanated outside GIS (Section 5.2), AHP on the other hand is a process in GIS modelling (Subsection 5.2.3) developed by Saaty to allow prioritisation of alternatives and criteria judgement (Saaty, 1980, 2008; Dawotola et al., 2010). The integration of the two techniques has been successfully implemented in spatial decision making for land-use planning, land-use suitability (housing) mapping, woodland fire risk and hazard vulnerability, flood risk and vulnerability, pipeline routing, pipeline section prioritisation etc. (Section 5.4). However, the technique has never been used to map areas likely to be impacted by pipeline accidents; hence, its implementation in this study demonstrated the robustness of the technique in spatial decision making.

The benefit of MCDM is its capability to accept the decision maker's preference in decision making (Ascough II et al., 2002), which allows decision makers to contribute their wealth of experience and knowledge without necessarily influencing the outcome of the process. This very capability informed the choice of MCDM for the study, i.e. as a means to overcome data paucity by building on experience and expert elicitation. The spatial and non-spatial secondary datasets gathered from different sources (Table 6-1) were prepared by the researcher to make them fit for purpose, by updating old data and generating new ones from them in the form of shapefiles and attribute values, such as polygon shapefiles for communities, population distributions, projection to Universal Transverse Mercator, improved resolution etc. (Subsection 7.0.1). This way, true representation of physical features and attributes in the area were developed, which is good enough for the purpose of the research but would have been better if current and original datasets were available to remove uncertainties and improve credibility. For instance, using current polygon shapefiles and population data for communities would give true population size and shape, just as oil spill data from other MOCs would have introduced a variety of sources of oil spills and different categories of pipelines in the hierarchy (e.g. surface pipelines, buried pipelines, and capacity).

10.1.2 The MCDE-AHP Model Framework

The MCDM-AHP application framework outlined in Figure 10-1 represents the four stages of risk assessment (Table 4-1). By integrating selected decision criteria (Section 9.1), hazard zones were developed for land use scenarios described (Chapter 8) for communities potentially susceptible to direct and indirect impact from pipelines (Appendix E) to assess their risk to hydrocarbon exposure.

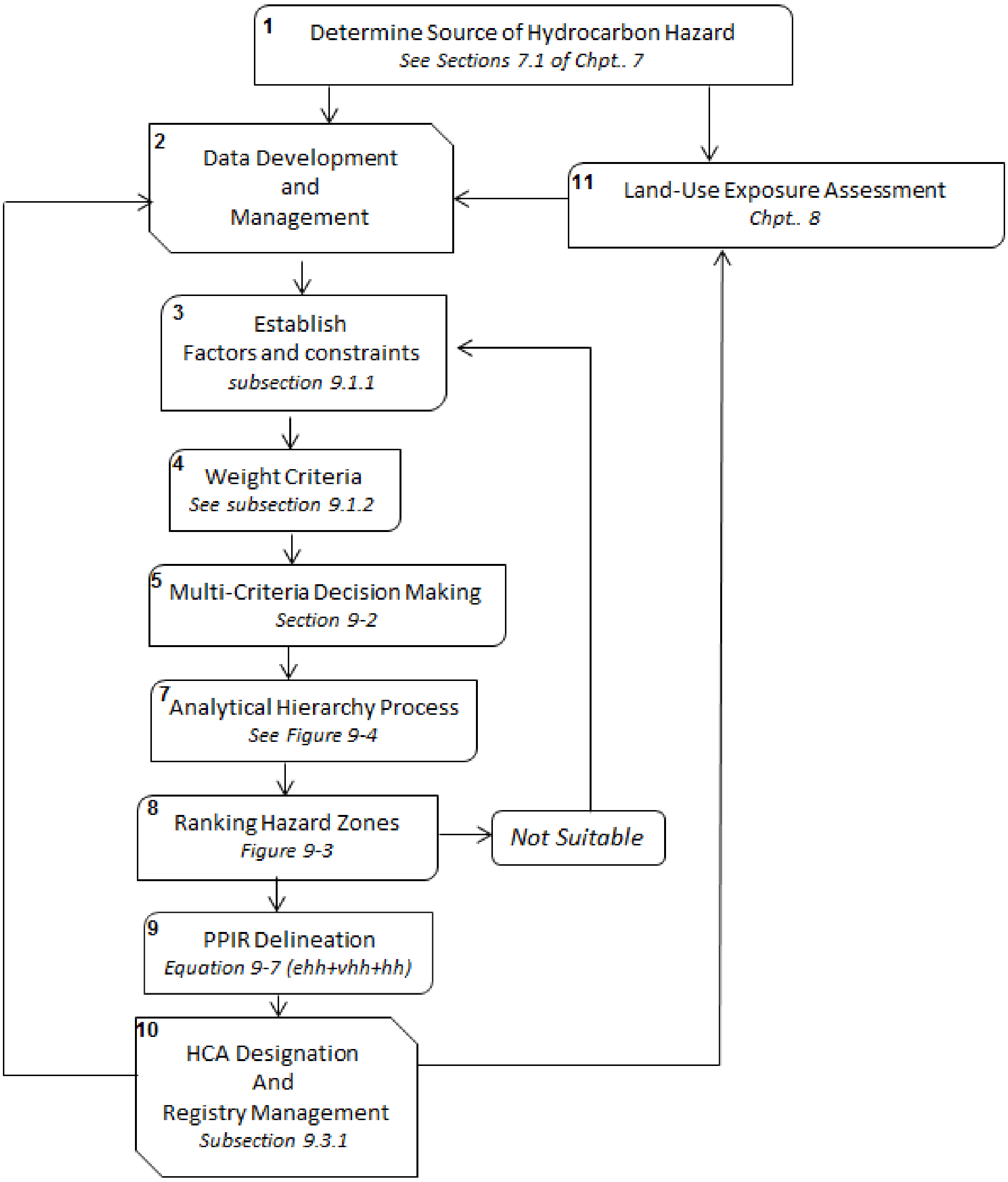


Figure 10-1: MCDE-AHP framework for modelling hazard zones, PPIR delineation, and HCA designation.

The framework begins with the determination of source of hydrocarbons hazard in step 1 (Figure 10-1), which is consistent with the hazard identification stage of the risk assessment procedure described in Table 4-1 where site characteristics are presented in a conceptual model. Steps 2-8 are synonymous with the hazard assessment stage where information gathered from the conceptual model is used to determine pollutant linkages and acceptability of risk inherent in the area. If more information is required, the assessor undertakes site-specific assessment similar to the factors and constraint step where the decision maker refines the resolution by redefining inclusive and exclusive parameters (Subsection 9.1.1). Step 9 estimates the extent of direct and indirect impact (magnitude) from pipeline accident based on proximity and exposure pathways (Figure 9-19), which is consistent with the risk estimation stage. The final stage of the risk assessment process, which is risk evaluation, evaluates the results of the risk assessment to define the magnitude of risk and uncertainty in the assessment (Petts et al., 1997; Smith and Petley, 2009). This is similar to step 10 where the decision maker may decide to repeat the whole process by reverting back to performing more specific land-use exposure assessment or use existing information to resolve uncertainty in the areas identified as susceptible based on the magnitude of exposure, e.g. proximity of communities (receptor) to hazard.

The model which was developed on the ArcGIS 10 platform is automated as a stand-alone tool (Figure 9-4) that can run repeatedly and yet produce the same result each time. For validation (Section 9.4), an overlay (Figure 9-17) with previous oil spill sites was done since physical inspection is not possible due to access restriction and insecurity in the area. A high resolution image like IKONOS 0.6-4m in Figure 10-2 or an aerial photograph that would have been suitable for change detection and spectrial analysis of impacted oil spill sites for validation was not available.

Nevertheless, in Section 9.4 an overlay with previous oil spill sites was done, and the result showed that all oil spill sites fell within the buffer which is suitable for a receptor-focused PPIR definition.

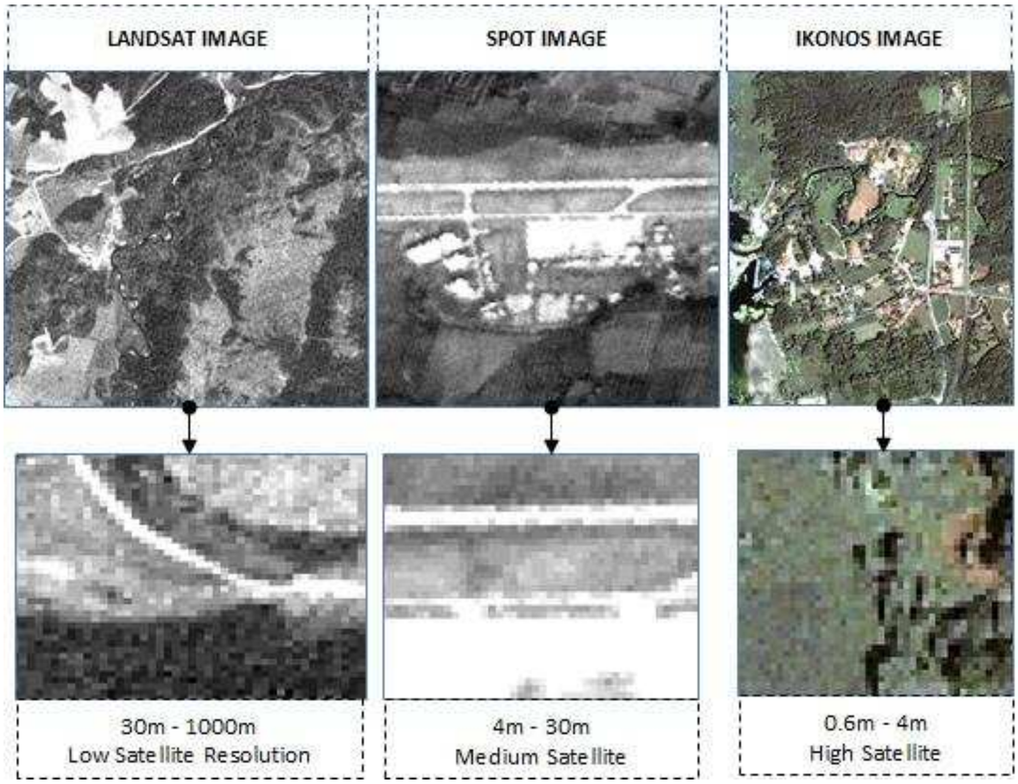


Figure 10-2: Comparison of satellite image resolutions.

Moreover, the dense mangrove vegetation in the area makes it impossible to identify footprints of settlements (Figure 7-27). But since the buffer is about 1,000m on either side of the pipeline, it is within the 500-2,500-metre buffer specified for the primary and secondary pipeline impact area by the Guadalupo-Blanco River Authority (2011), thereby giving the model credence and acceptability. The traditional PIR based on Equation 5-1 gives a pipeline with a diameter of 36inch about a 786ft (239.57m) PIR buffer (Table 5-4). Thus, assumming no pipe in the Niger Delta is greater than 36inch, the 1,000-metre PPIR buffer provides an additional safety margin of 760.43 metres (1,000 minus 239.57), which should be acceptable not only as a worst-case scenario but should also accommodate the influence of the extensive interconecting drainage pattern and water table flunctuation on contaminants' migration. Also, the model's transferability was sucessfully tested (Section 9.4.1) on UNEP sites in Ogoniland to support its applicability in a similar environment. The model is designed to support user input; however, care must be taken not to allow sensitive criteria to affect the output (Subsection 9.2.2).

10.1.3 Developing Alternative Pipeline Impact Area Approach

Regulators and experts in the oil and gas industries developed the Pipeline Impact Radius (PIR) as a guideline for protecting human dwellings and sensitive ecosystems along pipeline routes from pipeline impact (Subsection 5.5.2). The approach is more widely known in the pipeline industry and among regulators than in the academic arena (proven by scarce academic publications on the subject). The application of PIR is already embedded in the Pipeline Safety and Regulatory Certainty Act 2011 in the United States of America (ASME, 2004; US Department of Transport, 2011), and has been adopted as "good oilfield practice" by the American Society of Mechanical Engineers (ASME), the American Petroleum Institute (API) and their affiliates (Steiner, 2010; ASME, 2012; Amnesty International, 2013).

Considering that the approach is industrial-based, third-party application is difficult due to the paucity of data required for the formula. Therefore, the approach is not suitable for the Niger Delta because the formula (Equation 9-7) calculates the buffer distance based on pipeline diameter and pressure (see Table 5-4). Already hydrocarbons have demonstrated the ability to migrate easily on water, soil surface, and subsurface strata according to reported sightings of hydrocarbon plumes farther away from the source of discharge. Often people see crude oil seeping from the ground, the logical explanation relating to migration through subsurface openings, i.e.:

i) crude migration through subsurface soil structures to reappear where the water table rises to the surface; or

ii) surface migration from high topography areas to low topography areas by run-off, infiltration and other processes (Subsection 3.5.3); and

iii) leaching from unprotected borrow pits where excavated oil-contaminated soils are dumped by contractors (UNEP, 2011).

These and others help spread and widen oil-contaminated areas. Again, paucity of data makes it difficult to ascertain the level of compliance with the PIR application in the Niger Delta region either for pipeline safety and integrity management, or for the protection of human health and the environment. However, the new method uses information that is readily available or easily developed, thereby allowing users to make a decision on their input parameters from value judgement and experience. This new approach integrates physical, human, and economic attributes in a pairwise comparison weighting (Subsection 10.1.2) to develop an automated model for mapping land-use hazard areas and PPIR. The advantage of the new approach is non-dependence on pipeline properties (MOCs often restrict access to pipeline information for security reasons), and allocation of hazard zones is a function of distance from source (pipeline).

10.1.4 Proposing a New Pipeline Class Classification Method

The guideline for pipeline class location or classification uses human dwellings and population density to tag pipeline segments according to class locations (Subsection 5.5.3). Each class has its corresponding pipeline requirement and integrity management standard. However, rapid expansion in occupied areas due to population increase and proliferation of land-use activities along pipeline ROWs exposed the limitation of the method. For instance if the class location guidelines were implemented in the Niger Delta, the majority of the pipelines would fall into a Class 3 location category, i.e. "… *containing more than 46 or more dwellings and pipelines within 91.44m of small* …" (Subsection 5.5.3). This would require a low design factor to reduce the risk of pipeline failure and impact. Thus, a new method which is receptor-focused considered all pipelines the same but adopted the distance of 201.2 metres (Figure 5-6) provided in the class location guideline (Subsection 5.5.3) to organise pipelines for risk management. Two methods were considered:

i) pipeline segments with settlement within 201.2m (Figure 9-11); and

ii) pipelines intersecting with rivers and creeks (Figure 9-12).

The first method produced four classes with few pipeline segments, while the second method produced a large number of pipeline segments that would be expensive to manage. The numbers of pipeline segments in each class category are shown with the number of settlements, estimated households, and population (Table 9-10). The first method is much more reasonable in terms of cost, time, and impact surveillance and monitoring. What this implies is that operators of pipeline facilities can channel resources into maintaining the highest possible safety standard and asset integrity on those pipelines in Class 1. Monitoring and surveillance can be scheduled regularly in collaboration with communities assigned to the area in line with the proposed Petroleum Industrial Bill plan (Subsection 3.3.3).

10.2 Oil Pollution and Oil Spill Characteristics

The report presented by the UNEP on the state of oil pollution in Ogoniland (Figure 3-6) represents a situation in just 4 out of 185 local government areas in 9 Niger Delta states (Figure 10-3).

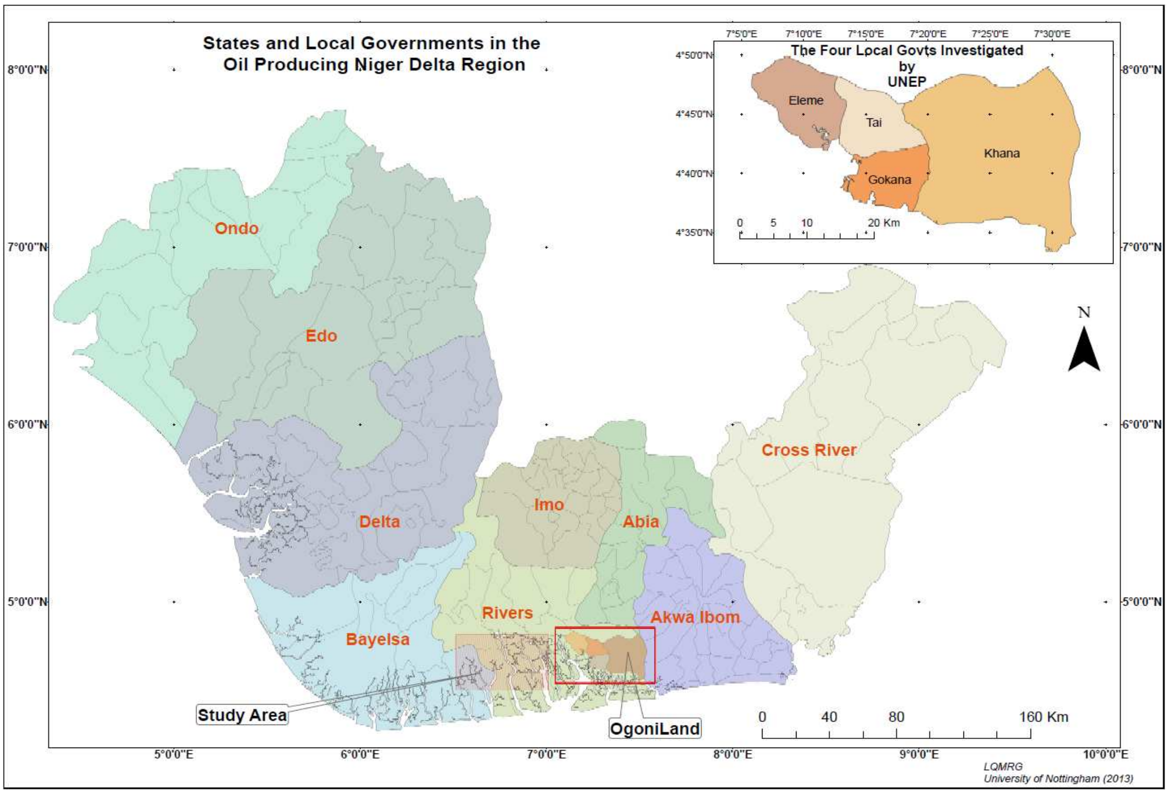


Figure 10-3: States in the Niger Delta and local governments investigated by UNEP.

The remaining 181 local government areas may have communities with a similar situation or worse than Ogoniland; it is on record that Shell, the only licensed operator in Ogoniland stopped operating in Ogoniland in 1995 (UNEP, 2011). If what was published by the UNEP occurred before 1995, the fate of other oil-producing communities where production has not been interrupted can only be imagined. For instance, the study area that is not part of Ogoniland (Figure 10-3) has experienced 443 oil pipeline spills in 24 years (this is from documented pipeline spills alone) with communities listed in Table 7-1 and Appendix D recording repeated oil spill incidents.

Therefore, extensive assessment of the entire region needs to be done if recommendations proposed by the UNEP (Appendix F) are to be effective because Ogoniland cannot be treated in isolation. Although there are several sources of oil spills apart from pipelines, e.g. oil wells, flow stations, storage, and gathering tanks, vehicular accidents etc. (Steiner, 2010; Achebe et al., 2012), these discharge oil into the environment and the hydrologic flow spreads the oil about. Plate 10-1 and Plate 10-2 show trapped and stranded hydrocarbons floating on water and spread on the land surface.

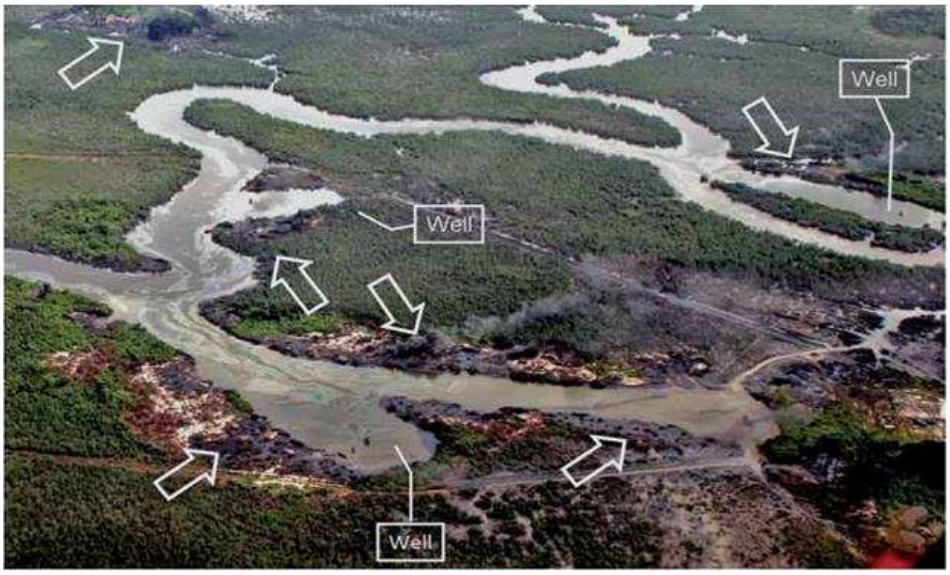


Plate 10-1: Oilfield in Bodo west showing migratory plume (UNEP, 2011).

Assessment of oil spills indicates a cluster of spills in isolated areas with fewer population and sparsely-distributed communities. Meanwhile, it is important to clarify that this data is from a single MOC operation and only for pipelines; there are other MOCs operating in the area. Thus, this does not in any way represent all oil spill incidents in the area as there are other possible spills from oil wells, storage tanks etc. that are not included in this data. In addition, the proliferation of artisanal refineries and interdiction (see video documentaries in Appendix L) are major sources of petroleum contaminants responsible for many unreported oil spills (Field Interview, 2010).

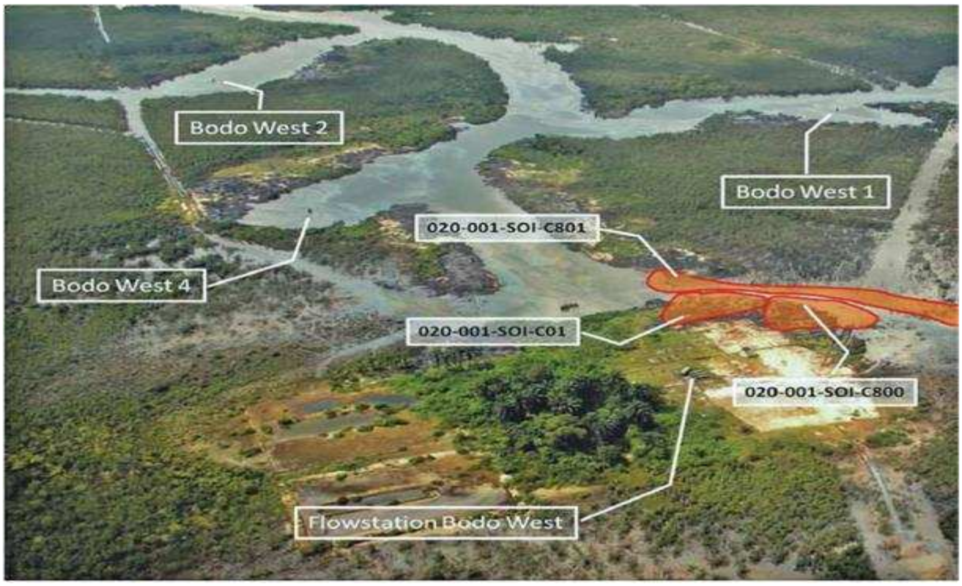


Plate 10-2: Spreading of oil plume on land and water (UNEP, 2011).

10.2.1 Politics of Oil Spills and Institutional Weakness

Although the issues of political isolation, resource control, poverty and environmental degradation feature prominently in public discussions as contributing factors in persistent interdiction and oil spills in the region, complacency on the part of government is also responsible (Interview, 2010; NNPC, 2013). The government's participation in Joint Venture (JV) contracts makes it indirectly part of the MOCs as the majority shareholder (Figure 10-4), a position that compromises government agencies' ability to enforce laws and policies.

It is this very reason that the Niger Delta crisis persists until today (Section 2.3) because the communities feel that the government supports the MOCs at their expense. The failure of the government to enforce laws or sanction companies for damages caused by oil pollution, or secure royalties for petroleum resources, pushed the communities to civil disobedience and agitations (Section 2.3).

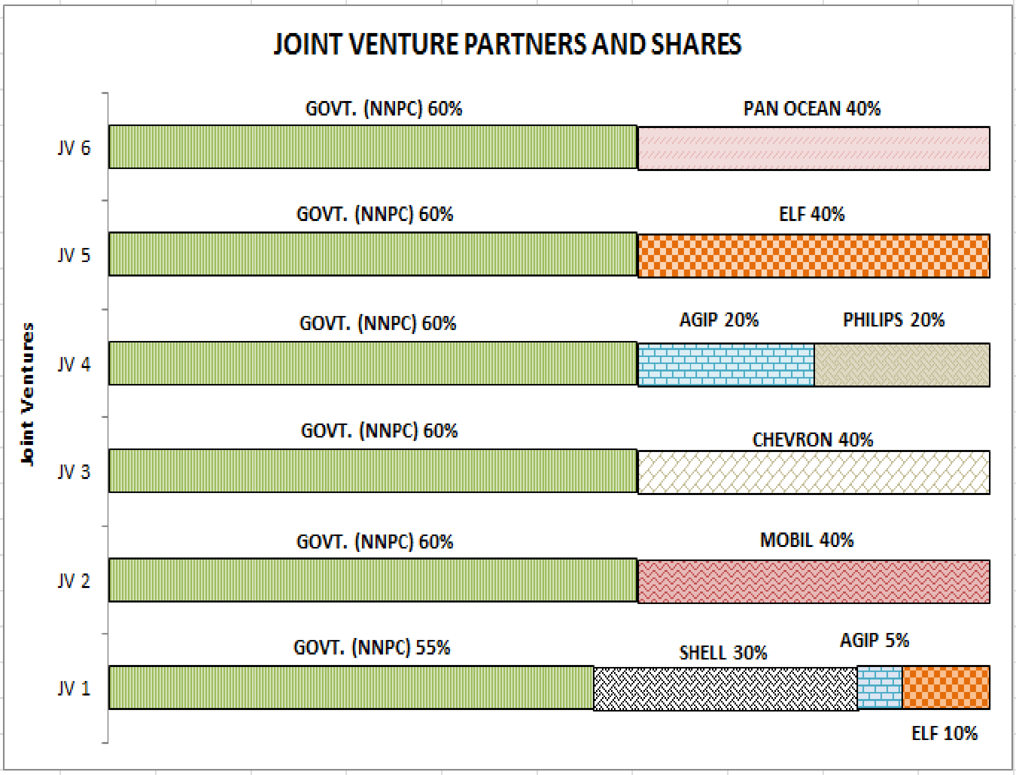


Figure 10-4: Joint venture partnership and shares (NAPIMS, 2013).

The communities are at the receiving end of environmental degradation, zero distributive justice, poverty, and unemployment; therefore, they are not willing to concede any opportunity to grab from the MOCs. They receive financial benefits by forcing MOCs to:

i) pay Freedom To Operate (FTO) charges;

ii) refuse to concede/agree any spill caused by sabotage;

iii) deny entry until honorarium is paid;

iv) delay spill inspections so that more compensation is paid for impacting more area; and

v) sabotage oil production in order to facilitate negotiations or renegotiate conditions.

Another political point concerns the determination of the cause of spill. While it is convenient to attribute spills to operational error, accidental discharge or sabotage (Aroh et al., 2010; Achebe et al., 2012), the JV teams must reach agreement with host communities (Field Interview, 2010; Amnesty International, 2013). Thus, while the MOC attributes the cause to interdiction, the community would blame equipment failure or operational error (just so that their right to compensation is not affected). As a result, many oil spill cases remain on record as "unknown" or "yet to be determined" (Section 7.1). A company may choose to hide behind the law (Oil Pipelines Act, 1990) in order to avoid paying compensation, based on a provision in Part III Clause 11(5c) of the same law that states:

> "*The holder of a licence shall pay compensation to any person suffering damage (other than on account of his own default or on account of the malicious act of a third person) as a consequence of any breakage of or leakage from the pipeline or an ancillary installation, for any such damage not otherwise made good.*" (Oil Pipelines Act, 1990).

It is obvious that the communities are actually liable based on findings in this research, looking at the number of oil spills caused by interdiction (Figure 7-6), and the proportion of interdiction to total spills per community (Figure 7-25) is an indication that the communities condone interdiction (vandalism).

EGASPIN (Subsection 3.3.1), on which basis environmental regulation in the oil industry in Nigeria is formed, lack consistency specifically on criteria for spill response. The standard requires spills less than 100kg (<0.1

tonne) be handled internally by MOCs, while greater than 100kg (>0.1 tonne) is reported to the Department of Petroleum Resources (DPR) for the Joint Investigation Team (JIT) (Section 3.2.2). Yet another government agency called the National Oil Spill Detection and Response Agency (NOSDRA), which is responsible for executing the National Oil Spill Contingency Plan (NOSCP), is part of the JV team using EGASPIN even when NOSCP operates an entirely different approach (Subsection 3.2.2). This conflict is perhaps responsible for NOSDRA's different interpretation of EGASPIN, which gives MOCs closure on remediation processes before contaminants are completely eliminated (UNEP, 2011, p.12). To reiterate the government's complacency, since NOSDRA's establishment in 2006 (Table 3-10), government allocation is not enough to carry out its functions properly (Field Interview, 2010). As a regulatory authority, NOSDRA relies on MOCs for logistic support on many occasions, a situation exploited by MOCs to their advantage (Field Interview, 2010; Steiner, 2010; UNEP, 2011).

10.2.2 Oil Spill Response and Contingency Plan

The delay in mobilising JITs (Amnesty International, 2013; John, 2013) can be attributed to the composition of its members who are drawn from different organisations, in addition to poor logistics, timing, and accessibility (Field Interview, 2010). Subsection 7.1.1 showed that it takes an average of three weeks to respond to a spill, despite an official claim of twenty-four hours (Field Interview, 2010). In fact, Figure 7-12 shows that only about 26.2% of spills were attended to within 20 days. The reporting procedure is faulty as it is not responsive over twenty-four hours, seven days a week, and there is no emergency response team on standby. Another issue is the demand for FTO fee from responders and JITs by community members before granting them entrance into their communities (Field Interview, 2010).

Already some schools of thought opine that communities or aggrieved youths deliberately cause the delay so that the crude would spread wider, and give them an advantage in negotiating for compensation. As lame as this may sound, the practice is common even when the law (Oil Pipelines Act, 1990) prohibits payment of compensation for spills caused by sabotage (interdiction). There are also speculations that delaying entry allows unscrupulous elements to scoop oil before and while negotiation for FTO is going on (Field Interview, 2010).

10.3 Receptors' Susceptibility to Land-Use Exposure

Land-use activities (Table 8-1) can be regular or intermittent based on the prevailing season. Some activities are performed during the rainy or the dry season (Subsection 2.1.2) alone, while others extend through both seasons. For instance, farming takes between four to five months after land citation and cultivation to harvest, but some crops take more than a year to cultivate, e.g. yam. Fishing is favourable in the dry season but is done on a full-time basis throughout the year, just like hunting and wild gathering (Section 7.4). People who undertake more than one activity may do so concurrently or intermittently, thereby becoming exposed all year round. This means households doing more than one activity would be susceptible to multiple exposure scenarios, e.g. farming and water collection and/or fuel wood gathering.

To assess land use exposure scenarios, consideration was given to the nature of labour and weather conditions (high temperature) while estimating parameters for the GAC (Subsection 8.3.1). This means the magnitude of exposure, via inhalation for instance, can increase with an increase in breathing cycle due to the intensive nature of work and weather conditions. Therefore, some human-based parameters recommended for exposure assessment by the US Environment Protection Agency and Environment Agency (Chapter 4) were modified for exposure assessment in Nigeria. For example, in developed societies, the use of mechanised tools and protective clothing is common when preforming land-use activities, but poverty, ignorance, perception, and weather in the rural Niger Delta makes people wear less clothing (Subsection 7.4.2 and Appendix G: Table G14). For instance, people dress very lightly when performing activities either because of harsh weather or because of comfort, thereby leaving parts of their body uncovered, which allows a variety of direct and indirect exposure opportunities to manifest. Subsection 7.4.2 showed a strong correlation between non-use of protective clothing and working with parts of the body exposed across all ages.

The relationship between land use and exposure increases with proximity to source and a contaminant’s ability to migrate to point of contact (Figure 9-18). As a result, exposure can occur while going about gathering firewood in the field; the same firewood can contain trapped hydrocarbons that are released into ambient air when burnt and inhaled in the process.

Water collection from streams and rivers provides opportunities for direct contact with contaminated water. Fishing can cause exposure through both dermal contact and inhalation during fishing, processing, and ingestion. Although there is no evidence to indicate concentrations of TPH in fish (UNEP, 2011), there are complaints of fish dying and losing taste because of oil pollution (Field Interview, 2010). Farming and gardening provide edible vegetables, fruits, and crops. The common exposure pathway is through dermal contact with loose soil materials and inhalation of dust particles during tilling and weeding or ingestion of contaminated farm and garden produce.

Plate 10-3: Local fisherman on his canoe (UNEP, 2011).

Hunting and animal herding provide meat and milk for consumption; exposure exists mostly in performing these activities. Although there is no information on exposure through meat consumption because meat is well cooked before consumption, it is very unlikely to lead to significant exposure, as most hydrocarbons would be volatilised during cooking. However, as herders and hunters move from one location to another through different layers of polluted environment, there is a tendency for different exposure scenarios to ensue, e.g. carrying an animal coated with crude oil or walking through oil-polluted fields.

10.3.1 Communities Susceptible to Risk of Land-Use Exposure

There are quite a number of communities located close to existing oil spill sites, pipeline network and rivers (Section 7.2), but those most liable to exposure are the ones located at hotspot areas where spills have occurred repeatedly. The deltaic system and topography provide easy movement for fresh and stranded hydrocarbons through surface run-off, and subsurface migration supported by a shallow water table (Subsection 2.2.3) can contaminate a wide area and create multiple exposure pathways. The susceptible communities such as those in Appendix E may be assumed to have a significant chance of direct and indirect impact from pipeline hazards (Subsection 9.3.1) because of proximity. In terms of cumulative impact, however, those communities with repeated spill incidents (Table 7-1) are likely to experience cumulative effects of hydrocarbons in their domain due to regular replenishment by recurring oil spills.

Going by the toxic unit (TU) profile in Figure 7-5, it is evident that most of the lighter hydrocarbon fractions have escaped, leaving behind the less toxic but heavy hydrocarbon components. However, the fact that these heavy hydrocarbons have a high octanol/water partition coefficient (K_{ow}) and are hydrophobic does not imply that no toxins are being released into the environment (Di Toro et al., 2007 ; Rial et al., 2013). This is possible due to photo-oxidation of heavy hydrocarbons by solar radiation (sunlight) and heating (high temperature) to generate polar and water-soluble compounds (Section 4.2.3). There is always abundant water to act as a vector for transporting such hydrocarbons to a fresh location, or replenish old polluted sites which are the source of domestic water or where home-grown vegetables are cultivated.

Plate 10-4 shows the effects of oil pollution on vegetation along a pipeline ROW. The evidence of plant stress suggests previous oil spills that resulted in fire or recurring flooding of the area with fresh and weathered crude oil. The water in the trenches can provide mobility to hydrocarbons along the lines and adjoining soil zones.

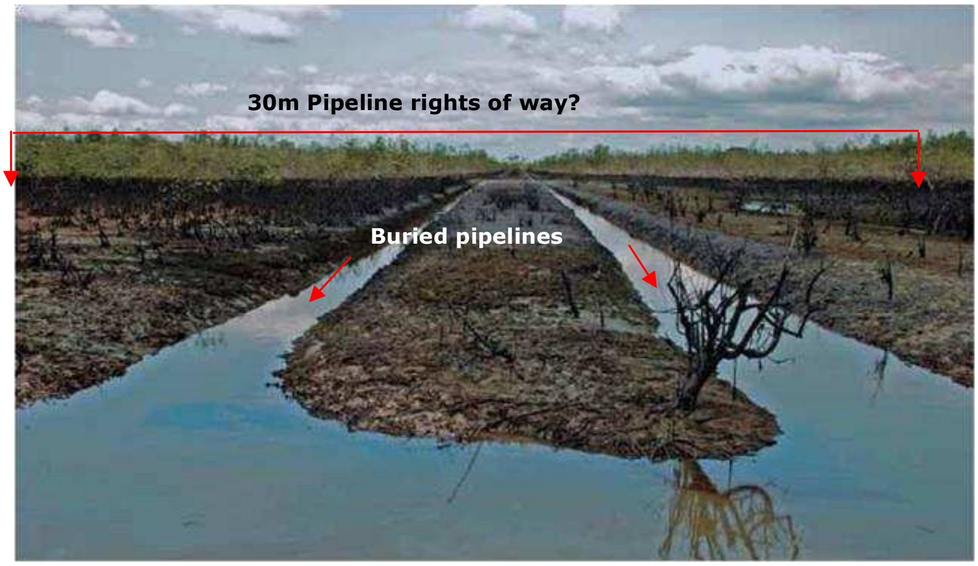


Plate 10-4: Vegetation on pipeline ROW affected by oil pollution (UNEP, 2011).

10.3.2 Exposure Criteria and Assessment Framework

Guidelines are standards developed to regulate the release and accumulation of toxic substances in the environment. The EGASPIN provided target and intervention values for soil/sediments and groundwater (Table 3-9), but is silent on assessing the human health risk from indoor and outdoor exposure. The trigger and intervention values are not compatible with the conventional EC number developed by the Total Petroleum Hydrocarbon Working Group (TPHCWG), which has been adopted internationally (Section 4.3).

Apart from the absence of human health assessment criteria in EGASPIN, there is no specific average daily intake for hydrocarbon fractions, just as there is no regulated method for estimating exposure through ingestion, inhalation, and dermal contact. These procedures have long been established in the United States and the United Kingdom by government institutions and private organisations (DEFRA, 2008; US Environmental Protection Agency, 2011). The organisations work in collaboration with local and international institutions to develop risk assessment criteria for assessing human health risk for their respective countries. For instance, the UK Environment Agency published a TOX report (Section 5.5) which contains estimates for mean daily intake of chemical substances in food, water, and air. There is also the Contaminated Land Exposure Assessment (CLEA) model for deriving Soil Guideline Values (SGV) in standard UK land uses (Subsection 4.1).

Lack of similar guidelines in Nigeria necessitated the derivation of the GAC for land uses (Section 8.4). Before using the GAC, a preliminary site risk assessment should be performed to determine the following:

i) the depth and risk to ground and surface water;

ii) land use area within a distance capable of completing pollutant linkages.

The decision-tree (Figure 10-5) is a simplified approach for assessing risk on oil-polluted sites. An initial qualitative risk assessment enables decision makers to make a decision on whether to proceed on remediation or engage a risk management strategy, before embarking on a detailed risk assessment if required. This way, sites can be prioritised and the most critical selected for a detailed risk assessment, thereby saving considerable time and costs.

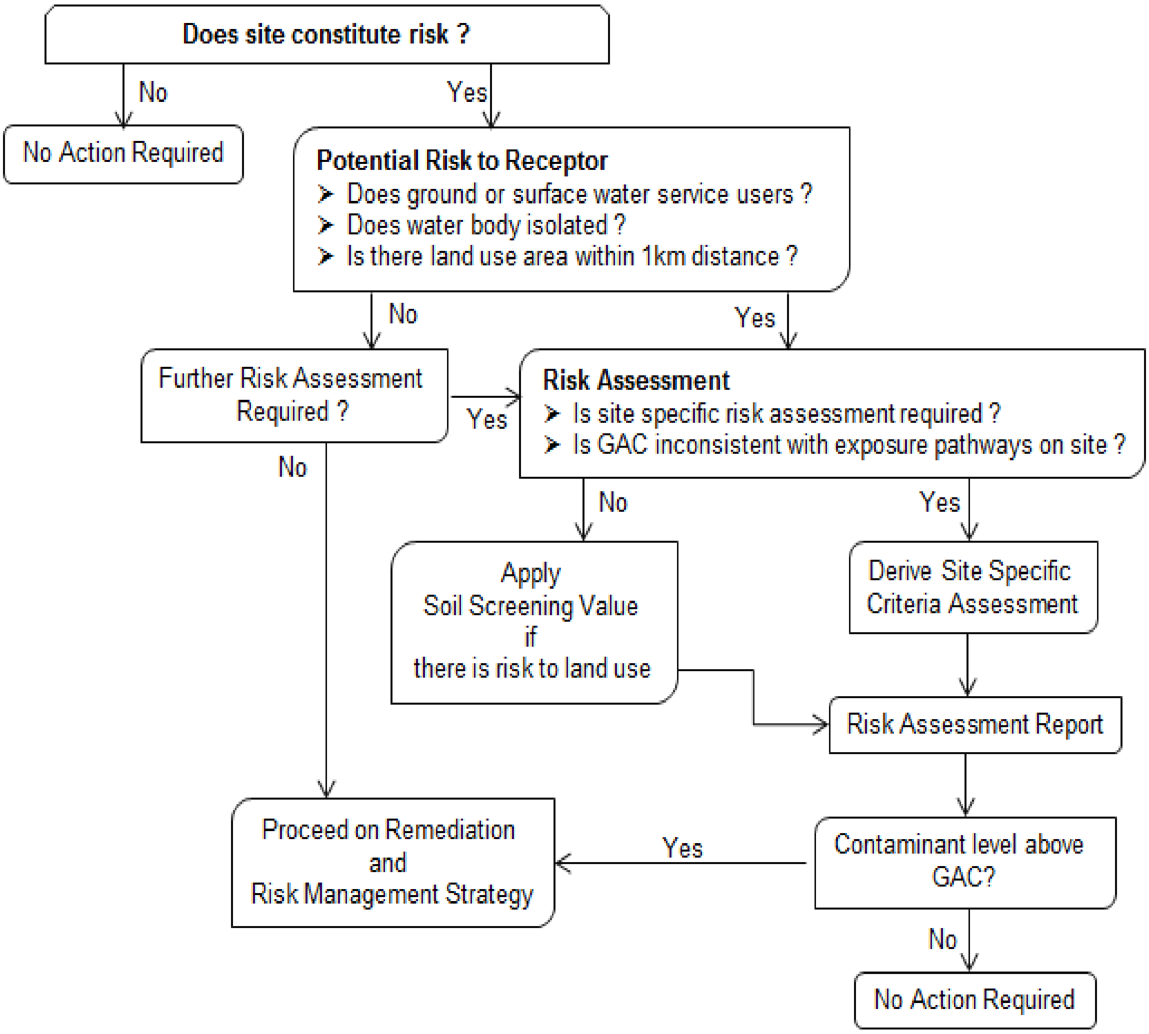


Figure 10-5: A proposed decision-tree for assessing human health risk from oil spill sites (adapted from the South African Department of Environmental Affairs, 2010).

10.4 Developing Framework for Stakeholder Integration

The failure by the Nigerian Government to draw a limit on the extent to which its relationship with MOCs ends and its responsibility to the people begins is a major problem that should be addressed. Already the people have no confidence in the government, which is why they have resorted to vandalism, kidnappings, production disruption, oil theft, and agitations for resource control (Section 2.3 and media documentaries in Appendix L). The MOCs on the other hand took advantage of the government's poor oversights to operate with impunity, and blame the people and the government for their poor environmental performance (Field Interview, 2010; Steiner, 2010). This breakdown in relationship can lead to severe environmental consequences, poverty, and even death to people in the area, if allowed to linger. Nevertheless, this can be overcome if all stakeholders (i.e. government, MOCs and communities) come together in a mutually-beneficial relationship. Figure 10-6 identifies the scope of participation and responsibilities of stakeholders for a sustainable relationship, which guarantees public participation and integration in decision making (pipeline safety and by extension human health risk mitigation).

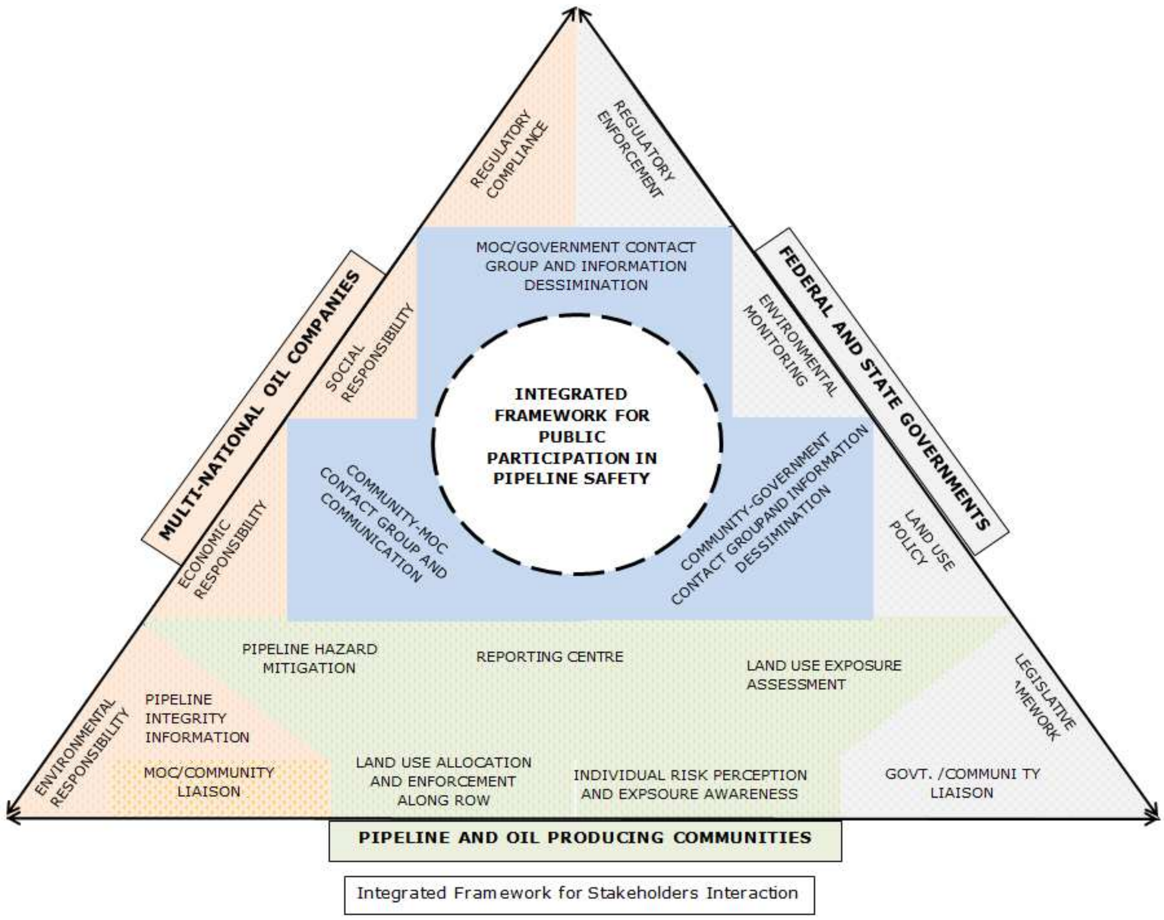


Figure 10-6: Stakeholders' responsibilities in pipeline/human health risk management (source: Author, 2013).

One of the objectives of the proposed Petroleum Industry Bill (Subsection 3.3.3) seeks to recognise host communities as stakeholders in the oil and gas industry by assigning to them specific roles, and creating a dedicated fund to drive social, economic, and physical development in oil-producing communities (Petroleum Industry Act, 2008; HoganLovells, 2012; NNPC, 2013). In a similar vein, the UNEP in their recommendations (Table 3-8 and Appendix F), recognised the role the stakeholders, i.e. government, MOCs and host communities, can play in terminating the oil spill crisis in the area, and addressed specific recommendations to each with the hope of staving off pipeline interdictions and oil spills. Figure 10-6 serves as an implementation framework for the actualisation of controlled oil pollution and increased cooperation from host communities.

Every community traversed by pipelines and oil-producing communities is at the base of the triangle, because they bear the burden of government policies and environmental consequence of the MOCs' activities. Central to the framework is emphasis on communication and information flow from liaison units at the local level and contact groups in the centre.

The liaison groups link communities with government, and communities with MOCs. The contact group on the other hand connects the three stakeholders to form a central focal group whose responsibility is to deal with issues brought forward by the liaison units (e.g. problems requiring policy redirection or legal backing to be forwarded to the government). The responsibility of the liaison units is to address issues at the local level, e.g. problems between local communities and MOCs or the federal government. This bottom-to-side-side-to-centre approach was designed to improve relations and ensure free information dissemination among stakeholders, in addition to eliminating the safety and security problems discussed elsewhere in this thesis. By integrating oil-producing communities in the decision-making processes, such communities would own stakes in oil operations, i.e. from semi-skilled employment like jetty operators, bunker technicians, and security to trained professionals and ad hoc staff. The logic is that, when people's livelihoods revolve around a system, they are most likely to protect and guard it. Now, this is lacking in Nigeria and it appears to be the major weakness of the current method of operation within the oil industry (Anifowose et al., 2011).

10.4.1 Expectation from Stakeholders

The federal and state governments have the mandate to provide regulatory enforcement through environmental monitoring. To do this, existing legislations and institutional frameworks must be streamlined and new ones instituted to provide legal support or for prosecuting culprits. According to the Land Use Act (1990), the government liaises with communities in enforcing land use policies, bearing in mind population dynamics and demand for land, so that pipeline ROWs are not encroached on. Where ROWs have been encroached on, the government should allocate another area of land for people to relocate to since it owns the land (see Appendix M for Land Use Act). Since people are exposed through land-use activities, the MOCs can liaise with communities to create awareness on exposure opportunities, and dangers by informing them about spill events and trajectory. Perhaps doing so would change people's perception and make them understand the dangers of oil pollution, which is worsened by their involvement in interdiction and delay tactics even though they deny it.

The MOCs also have the responsibility to operate sustainably in compliance with regulatory requirements and international standards. Because laws in

Nigeria are not strict, it does not stop them from using the "Best Available Technology" or maintaining "good oil field practice" in compliance with international standards recognised by bodies like the API and the ASME (Steiner, 2010). Information on pipeline location and integrity should be available in the public domain or presented on request for public scrutiny. Most importantly the public should know the age and condition of pipelines in their domain, so that pipeline failure can be anticipated and an alternative location for land use can be arranged beforehand as a means of avoidance or hazard mitigation.

Pipeline integrity can be compromised by environmental conditions, human interference and manufacturing defects. Nevertheless, while manufacturing defects are minimised by close supervision and adherence to ASME and API standards in pipeline design and construction, environmental and human factors are difficult to manage because they are unpredictable and change over-time (e.g. soil and water pH, and human behaviour). Due to the significance of environmental and human factors in pipeline integrity and safety in the Niger Delta, Figure 10-7 proposes a working framework for integrating public participation in pipeline integrity and human exposure management.

The age and state of corrosion of older pipelines has been put to question (Achebe et al., 2012), and Shell Nigeria already admits to having a backlog on its asset integrity assessment programme (Steiner, 2010; Amnesty International, 2013). Because the extensive network and remote location of some pipelines can create access difficulties and isolation from the list of pipelines to inspect, MOCs should incorporate communities closer to these pipelines for monitoring purposes.

Although Shell Nigeria initiated Community and Shell Together (CAST), communities have not accepted the programme because representatives are handpicked from sympathisers of the government and MOCs; most importantly, they have not been trained (Filed Interview, 2010).

10.4.2 Pipeline Integrity and Exposure Management

The first task in Figure 10-7 is to establish a PPIR (Section 9.3) and develop class location for pipelines (Subsection 9.3.3) to identify communities to be targeted (Subsection 9.3.1).

In the event of a pipeline failure (accident), an initial report would specify whether the spill is on land or river and if the settlement is on the high consequence settlement register (HCSR); if not, upgrade PPIR to include the community in HCSR. A spill on a river with foreseeable pollutant linkages would require activation of exposure mitigation and/or remediation measures; whereas, if on land, the land use affected is assessed based on Figure 10-5 using the relevant SSV or GAC (Chapter 8). A functional communication channel should allow free flow of information and feedback about oil spill location, warning on trajectory, potential exposure pathways, mitigation measures instituted, and the type of remediation strategy adopted.

The information should be readily available to communities and relevant non-governmental organisations (NGOs) for review or complaint through respective liaison units and contact groups (Section 10.4 and Figure 10-6). The stakeholder forum is the final decision-making body and it is at this stage that oil spill response strategies should be formulated, pipeline surveillance and monitoring be organised and issues regarding land-use exposure and human safety are to be addressed. It is imperative that communities are involved all the way; their participation is sacrosanct to the effectiveness of this model and, if successfully implemented, can erase doubt on MOCs and government involvement in oil production.

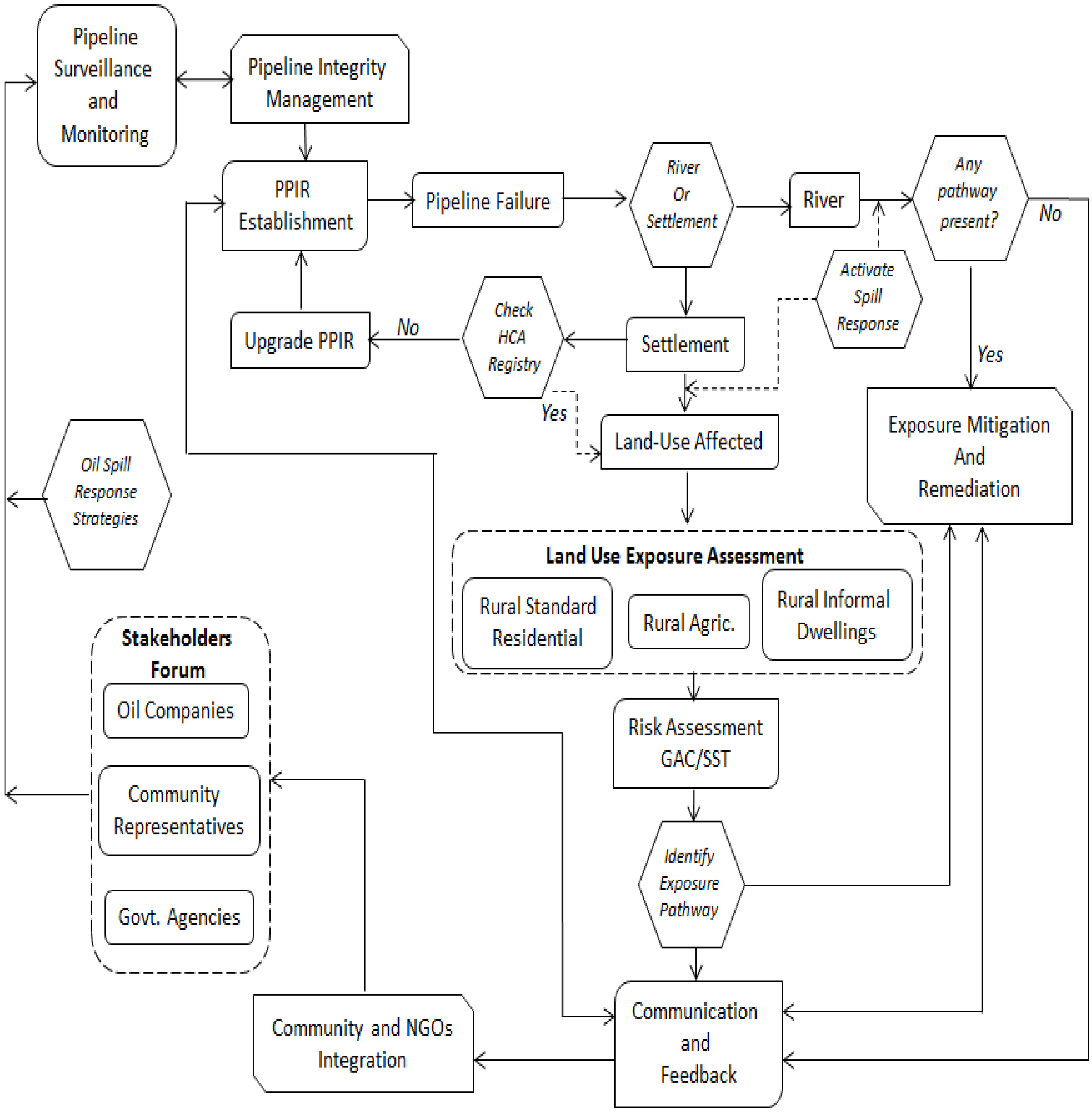


Figure 10-7: Integrated approach for pipeline integrity and exposure management.

Conclusion

Delineating PPIR with the MCDM-AHP model (Section 9.3) eliminates the problem of data paucity by allowing interaction of criteria to delineate the

PPIR buffer instead of pipeline size and dimension, and in the process has produced a method different from the formula-based PIR (Subsection 5.5.2). This is important for places like Nigeria where regulators and operators regard information on pipelines as confidential and keep it away from the public domain. The model used a simple GIS spatial decision-making technique to provide a base for building public participation in decision making. Because the problem of the Niger Delta cannot be resolved by compulsion from the government and MOCs, the collaboration of local communities is sacrosanct to avoid an environmental disaster. By integrating the local people, they are likely to develop a sense of belonging by considering themselves as part of something relevant to their wellbeing. Meanwhile, the federal government must establish a line where its relationship with the MOCs ends and its responsibilities to the people begins. The ripple effects may lead to a general decline in oil interdiction and reduction in human-induced oil pollution, which would allow clean-up to progress; however, a proper clean-up would be effective if all forms of oil spills ceased.

By establishing PPIR along pipelines and HCSR database, rural land use can be organised in order to monitor and regulate susceptible areas, and communities whose farms and source of domestic water have been compromised can be assisted to mitigate impact. In addition, a functional land-use policy in collaboration with local communities can discourage people from using land designated for oil infrastructure and stop pipeline operators from constructing pipelines close to human dwellings or sensitive ecosystems, irrespective of easement arrangement. It is important to note that the model can only work with transparency, communication, commitment and trust from all stakeholders.

CHAPTER 11

CONCLUSION

11.0 Introduction

Oil pollution in the Niger Delta has reached a crescendo, in that people are unnecessarily exposed to hydrocarbons from land-use activities they perform. It is necessary to identify areas vulnerable to hydrocarbon discharge in order to develop modalities for mitigating exposure, and prevent impact. To achieve this, an effective institutional and legislative framework (Section 3.3) must first function to curtail oil spills caused by MOCs non-compliance with "good oil field practice", third-party damages (TPD) inflicted by host communities, and complacency by government (Section 10.2). The 2011 UNEP report (Subsection 3.2.3) revealed a weak regulatory framework and inconsistency in standards for assessing hydrocarbons in the country. In effect, Nigeria lacks the capacity and commitment to protect human health and the environment, and to restore polluted sites to a pristine condition due to corruption-induced complacency. To this end, this research developed a MCDM-AHP-based method (Chapter 9) to identify communities susceptible to pipeline hazards, rural land-use exposure assessment criteria (Chapter 8), and a framework for integrating oil communities as stakeholders in order to eliminate indiscriminate oil spill incidents (Section 10.4). Furthermore, this research has wider implications for an indigenous risk assessment framework and implementation of suggested recommendations from the UNEP report (Appendix F). This chapter brings together findings and process of developing the framework in fulfilment of research aims and objectives (Subsection 1.2).

11.1 Developing the GIS Model

GIS-based spatial decision making provides a means of integrating MCDM with AHP techniques in a loose coupling approach (Section 5.3) to solve spatially-related problems. The technique has been used in aspects of pipeline management (Subsection 5.4.2) in literature, except for mapping areas of pipeline impact. Ordinarily, buffers can be constructed along pipeline routes based on arbitrary distance specifications (Guadalupo-Blanco River Authority, 2011), or derived with a formula (Subsection 5.5.2) to delineate potential areas of direct and indirect impact from pipeline failure. The former lack justification while the latter require pipe parameters (Table 5-4) to be substituted into the equation (Equation 5-1). However, lack of pipe parameters informed the choice of the MCDM technique to decide in conjunction with decision makers' preference the extent of the pipeline impact area.

Thus, the MCDM presents a platform for combining different variables and allowing their interaction to decide the extent of impact areas in accordance with allocated weights. The benefit of this approach is not only in its simplicity or in automation, but also because it allows collective decisions and utilises fewer data (spatial and non-spatial) which in effect resolved the problem of data paucity. Furthermore, the successful implementation, transfer, and validation (Section 9.4) of this model not only extend the frontier of MCDM application, but are also an indication of its versatility and robustness in spatial decision making.

11.1.1 Model Components and Outputs

The purpose of the model is to identify possible land use areas and communities likely to be affected by pipeline accidents (Section 9.1). To achieve this, two objectives were formulated (i.e. source of impact and land use), under which four other alternative (attributes) criteria were categorised (Section 9.1). The main components consist of pipeline, river, population, and land cover developed from a SPOT satellite image of the area at a 5x5 metre-resolution by supervised classification (Figure 9-1). For assigning weights to attribute layers, a pairwise comparison matrix was employed after allocating scores of significance in accordance with Saaty's approach (Saaty, 1980), while the hazard zones were developed by combining the attribute layers with the weighted linear combination (WLC) tool in ArcGIS (Chapter 9). Basically the model produced three outputs: i) map of hazard zones (Figure 9-3), ii) PPIR margin (Figure 9-9) and iii) designated HCAs for settlements, rivers and land cover (Figure 9-10).

11.2 Concept of Exposure Scenarios

The bulk of oil produced in Nigeria comes from the Niger Delta where crude oil reserve is estimated at around 36.2 billion barrels (Benedict, 2011), and several MOCs operate. Therefore, the presence of pipelines among other oil infrastructures in remote rural areas has far-reaching implications not only on communities that produce oil, but also on those whose domain pipelines traverse them. Oil pipeline spills introduce petroleum hydrocarbons into the environment, directly contaminating sites or migrating offsite to contaminate other areas, e.g. farms, rivers, source of domestic water, soil, and air.

From the spills data analysis (Section 7.1), it can be seen that spills were caused by intentional or accidental pipeline discharge, but the TPD by interdiction is presumably prompted by general aggression towards MOCs and theft (Subsection 10.2.1). Although the spatial distribution of spill sites was not random, their locations suggest clusters in remote mangrove forests where settlements are smaller and dispersed. However, this does not suggest that only pipeline segments in remote areas are tampered with or discharge crude, because rupture can occur anywhere irrespective of location due to operational stress and/or corrosion. Hence, it is logical to anticipate discharge from any segment in the entire pipeline network. Consequently, communities located along these pipeline routes were classified as potential receptors while rivers intersected by pipelines were regarded as pathways and receptors (Section 9.5). Rivers are pathways because water transports hydrocarbons from the source point to other locations; as a receptor, the river's capacity to support aquatic life is impaired, thereby losing value and usefulness. As a result, community location can indicate degree of vulnerability; for instance, communities close to pipelines and rivers are directly vulnerable because of proximity to pipelines or rivers intersected by pipelines. The behaviour and movement of hydrocarbons in the environment has been described (Section 3.5); hence the topography of the study area has far-reaching implications on surrounding communities, due to the ability of the flat terrain and interconnecting rivers and creeks to support surface and subsurface migration of hydrocarbons, especially during inundation and change in flow direction.

11.2.1 Exposure Assessment and Evaluation

Since rural inhabitants depend on the natural ecosystem services for survival, the opportunities provided for fishing, farming, hunting, wild gathering etc. become impacted with petroleum hydrocarbons and cause exposure (Section 8.1) when people conduct land use on such sites. However, due to lack of risk assessment criteria in Nigeria, it was not possible to establish a threshold of exposure for different land uses. Consequently, a framework for evaluating exposure was developed for three rural land uses (Section 8.2) consistent with methodologies elsewhere. For instance, the United States of America, the United Kingdom, and Canada categorise land use into residential/parkland, commercial, allotments/agricultural, industrial, and recreational in order to evaluate human health risk from different land-use scenarios (US Environmental Protection Agency, 1991; Environment Agency, 2009; Canadian Council of Ministers of the Environment, 2010).

The exposure evaluation took into account the influence of weather and intensity of manual labour put into land uses described (Section 8.2), while estimating exposure parameters for the CLEA model (Subsection 4.1) and soil-screening formula (Equation 8-1 and Equation 8-2). Already, data from the questionnaires have provided information on frequency and duration of different activities (Section 7.4). This information was used to determine exposure frequency (EF), exposure duration (ED) and attenuation time (AT), while body weight was provided by Ayoola et al. (2010). Together, the data provided a true reflection of activity pattern and human parameters in a typical rural setting.

In the case of inhalation, it was necessary to introduce variations from estimates provided by the US EPA because the intensity of work done and the weather conditions can increase the rate of inhalation vary dramatically, e.g. working in a field above 29^{o}C. Change (increase) in inhalation rates was tested and found to have an impact that is more significant on children than adults (Subsection 8.4.3). It is therefore necessary to develop short-term and long-term exposure inhalation rates based on intensity and age for land-use assessment in the Niger Delta. Other parameters that need investigating are inhalation of soil and dust, direct ingestion of soil and dust, and consumption of home-grown vegetables.

The CLEA model estimated values were derived for aliphatic (EC5–EC44) and aromatic (EC7–EC44), and EC44-EC70 for aliphatic and aromatic hydrocarbon fractions at 1%, 2.5%, 5%, and 10% soil organic matter (SOM) for rural agricultural, rural informal dwelling and rural standard residential land uses (Subsection 10.3.2). With these criteria, the average daily exposure (ADE) for human receptors can be assessed, to determine whether concentration of specific hydrocarbon fractions exceed or fall below the screening value.

11.3 Conflict of Interest in Environmental Stewardship

In Chapter 3, a review of oil and gas activities in Nigeria confirmed the government's involvement in oil production through joint venture agreements with MOCs (Figure 10-4). Accusations and counter-accusations have raged for far too long on who is responsible for oil pollution in the Niger Delta. In the conduct of this research, three primary stakeholders were identified, each with its share of responsibilities.

Stakeholder 1: the people blame MOCs for non-compliance with good oil field practice, operating with impunity, causing poverty, creating unemployment and failing to fulfil their corporate responsibilities to the host communities. Although it is obvious that MOCs exploit the government's poor oversight and the joint venture clause that prevents MOCs from unilaterally funding projects as an excuse (Steiner, 2010), Shell has however proven to be committed to delivering its corporate responsibilities to host communities, judging from claims in recent publications (Subsection 2.2.3).

Stakeholder 2: the federal government is complacent because of the joint venture contract between it and the MOCs. The joint venture requires profits and liabilities to be shared proportionately according to contributing shares (Figure 10-4). Thus, the government is seen to be protective of its shares by taking sides with MOCs on matters of financial implications at the detriment of host communities. The government's conspiracy against the oil-producing communities includes:

i) lack of communication with and side-lining of communities;

ii) use of the Land Use Act 1978 (see Appendix L) to concede land to MOCs without consultation with communities or landowners;

iii) failure to empower or fund agencies to checkmate activities of MOCs and ensure proper implementation of existing legal and institutional framework for combating oil-based environmental degradation;

iv) inequality in oil revenue distribution in which parts of the country that do not produce oil benefit more than the oil-producing states; and

v) lack of reciprocal infrastructural and socio-economic development in the area.

Stakeholder 3: the host communities are at the receiving end of all negative impacts associated with petroleum production, and they feel unprotected by the government. Because the people are faced with a low or no share of the oil revenue, lack of development, poverty, and unemployment, they resort to helping themselves by vandalising oil facilities to force negotiations, or steal oil to make money.

As pointed out elsewhere in this thesis, accidental and operational discharge of crude oil is common with oil production anywhere in the world, but failure to control or clean up affected sites is taken seriously in developed countries. This is contrary to the Niger Delta where companies spill oil without cleaning up, local people spill oil during interdiction, and the government continues to be complacent in demanding environmental stewardship (Steiner, 2010; Kandiyoti, 2012). Clearly, there is a breakdown in relations because communities do not trust the government or MOCs, and MOCs are comfortable dealing with the government alone. Therefore, until a mutually beneficial arrangement is reached, the issue of oil spills, contamination, and land use exposure could continue in perpetuity.

11.3.1 Public Participation and Stakeholder Integration Framework

It is very important for the government to redefine its role in oil production and make allowance for a tripartite relationship in which all stakeholders have equal participation. Thus, a tripartite framework for integrating stakeholders (Section 10.4) in oil and gas production was developed (Figure 10-6). Although with specific emphasis on pipeline safety and human health risk management, this was done to provide background for the development of an indigenous framework for a contaminated land management regime in the country. Unlike current practice, the framework depends on constant interaction and communication between stakeholders in a bottom-side-side-centre approach.

Decisions and policies are made in the centre where the three stakeholders representing government, MOCs, and community representatives chosen through democratic process are located. Information and decisions are communicated down through the two focal units located at the bottom right and left corners of the triangle (Subsection 10.4.1). It is opined that, if the public have access to decision making, table their problems or grievances by themselves, and be part of deliberation, this could help create trust and acceptance of decisions reached because they participated.

In terms of pipeline safety, host communities should be fully involved in pipeline monitoring, survey and inspection because they are local and in constant contact with the pipelines as they go about their daily life activities. Field Interview (2010), and investigation by Amnesty International (2013), showed that oil spills are reported by community members. To fit the scheme around communities, a pipeline class location was developed (Figure 9-11) to facilitate designation of communities to specific pipeline segments for monitoring and oil spill response (Subsection 9.3.3) strategy. Local people must be trained in response and containment, and encouraged to develop traditional methods of containment that can be activated immediately a spill occurs, and/or prior to the arrival of the JI team. To be effective, community representatives must be based in the communities and be reachable at all times.

11.4 Research Implications

This research has both theoretical and policy implications for practitioners, and regulators in the oil industry of Nigeria. Experiential deductions in the course of this research indicate inconsistencies in the implementation of laws and policies and non-performing regulatory standards in the petroleum sector (Section 10.2.1). The following subsections discuss three main theoretical and policy implications.

11.4.1 Theoretical Implication of Risk Assessment

The theory underpinning human health risk assessment evolved over the years to provide internationally recognised guidelines for evaluating exposure from hazardous chemical substances in workplaces and homes. Consequently, some advanced countries have developed guidelines and standards for land-use risk assessment in their countries. As a prelude to establishing a similar approach in Nigeria, this study developed a rural land-use based framework for assessing exposure to petroleum hydrocarbons in the Niger Delta region. The procedure conforms to the internationally recognised approach, which describes different land-use scenarios and estimates threshold values for petroleum hydrocarbons. Unlike the current legislation for the petroleum sector in Nigeria (EGASPIN), which lacks guidelines for assessing specific land-use exposure and TPH, the framework developed in this study derived screening values for TPH aromatic and aliphatic EC fractions.

11.4.1.1 Policy Implication

Furthermore, this study has used experiential deductions (Section 10.3) to demonstrate the relevance of land-use-based exposure assessment for the Niger Delta (Section 8.4). The theoretical argument supports an immediate review of EGASPIN to include land-use exposure assessment because, as it stands, EGASPIN is only good for remediation purposes and not for a human health-based clean-up goal. An effective contaminated land management regime/policy is required for the country should the government choose to implement UNEP recommendations for cleaning up polluted sites in Ogoniland.

11.4.2 Theoretical Implication of Pipeline Hazard

A pipeline right of way is an open corridor separating the pipeline from communities to prevent impact from pipeline hazard and to provide access to facilities during emergencies. Similarly, PIR serves the same purpose but with the emphasis on pipeline integrity management. Pipeline ROW is a uniform distance buffer (i.e. 30.480 metres in Nigeria); PIR, on the other hand, is calculated based on pipeline properties using a formula (Section 10.1.3). These buffers are narrow and cannot guarantee safety beyond their boundaries, because petroleum hydrocarbons have been found beyond such distance in the study area. Consequently, the MCDM-AHP model provides another method for demarcating pipeline hazard areas based on land-use interaction and exposure. The philosophy underpinning the MCDM-AHP PPIR buffer is the identification and collation of susceptible communities, which are maintained in a registry of communities targeted for land use regulation and periodic soil and water quality monitoring.

11.4.2.1 Policy Implication

One particular policy implication of this study is the violation of pipeline corridors (ROW) and the revelation that pipeline corridor specification is not adequate for protecting land-use exposure. The Oil Pipeline Act of 1956, amended by the Oil Pipeline Act of 1965 drafted into CAP 338 of the Laws of the Federation of Nigeria (LFN), empowers the federal government to regulate pipeline construction, design, maintenance, and inspection. In addition, the Land Use Decree of 1978 empowers it to manage all land acquired for projects (e.g. land along pipeline routes). Therefore, the theoretical position of this study suggests a policy review in which stringent conditions are introduced for pipelines in Class 1 locations in order to control pipeline failure, and extend the pipeline corridor against future land use encroachment.

11.4.3 Theory Implication of Stakeholder Integration

The distributive justice crusade is a product of dissatisfaction with the unequal distribution policy (Ogwu, 2011). The way the federal government shares benefits and costs of petroleum raises moral questions, because oil-producing communities bear direct environmental consequences of oil production, while other parts of the country benefit more. The prevailing mistrust that the government is siding with the MOCs to deprive oil communities of their rightful wealth (as per the revenue sharing Subsection

2.2.3) can be addressed by involving the people in the decision-making process. It is the opinion of this study that those in control of the decision-making process have privilege in the distribution of cost and benefits, and can therefore ensure fairness. Conversely, it is imperative that the government and MOCs accept host communities as partners and begin to operate (Section 10.4) in the open and transparent manner desired in the Petroleum Industry Bill (PIB) (Subsection 3.3.3).

11.4.3.1 Policy Implication

The PIB, among other things, proposes to reduce the government's involvement in oil and gas activities by transforming existing joint ventures with MOCs, to make the government focus more on its regulatory responsibilities (NNPC, 2013). It also proposes the establishment of a fund in which upstream petroleum-producing companies would contribute 10% of their net profits every month for use in providing economic, social, and infrastructural development in oil producing communities (HoganLovells, 2012). These proposed policies reinforce the need for an integrated management framework in which oil-producing communities are included as stakeholders in oil pipeline management (Figure 10-6).

11.5 Recommendations for Further Studies

There are four main areas identified for further research in this study. They are:

1) develop standard estimates for ingestion of soil and dust, drinking water, consumption of home-grown produce, rates of inhalation under different intensities, preferably according to age and gender for assessing land-use exposure in contaminated environmental media for Nigeria;

2) map oil well impact areas to determine overall land-use hazard areas based on pipelines and oil well impact;

3) develop a model for predicting hydrocarbon toxicity/concentration overtime in the Niger Delta and;

4) investigate the influence of pipeline construction on settlement location.

These topics are further explained in the following subsections.

Derivation of Exposure Parameters and Criteria: an area for future research should develop Nigerian-based exposure parameters for estimating inhalation rates, dermal absorption, and ingestion of water, food, and vegetables. These parameters can be developed from scratch or adopt the UK and USA recommended values (Chapter 4) as a national standard for the time being until locally-derived estimates are developed. The empirical findings in this study indicate the possibility of strong variations in certain human parameters because of cultural and climate differences. It is therefore envisaged that these attributes may necessitate an increase in exposure parameters (Section 4.2), e.g. inhalation rate in a tropical climate, ingestion of locally-grown vegetables, exposed skin area, soil, and dust ingestion etc. Data from this study would provide a national standard on which other human health risk assessments may be performed to create consistency.

Hazard areas for oil well: the paucity of data and the scope of the study did not permit the mapping of oil well impacted areas using the MCDM-AHP model. This can be done by substituting the pipeline shapefiles with the oil well shapefiles (point) and re-defining the factor and constraint conditions (Subsection 9.1.1). Areas to be demarcated as potential impact radiuses can be decided according to the size of the area. By combining the pipeline impact area with the oil well impact area, complete petroleum hazard areas would be produced for an effective hazard management plan. However, this research would require access to high-quality data and high-resolution spatial images. This particular research area would provide data for high-risk area selection and distribution of response resources.

This study discovered a lack of publications or literature on hydrocarbon degradation in the Niger Delta; it was therefore difficult to develop weighting for the oil spills (Section 7.1). In order to improve the linear regression model (Figure 7-2) developed to estimate TPH degradation in the Niger Delta, a field-based research would be required to conduct this investigation taking into account site-specific conditions and microbial productivity overtime. This particular area has a significant impact on prioritising areas with repeated or cumulated hydrocarbons.

In many cases, it is not clear whether settlements came before or after pipeline construction, as there was no information on year of community establishment or pipeline construction. In theory, settlement location in relation to pipeline would allow adequate risk assessment, a plan mitigation strategy, and socioeconomic and environmental monitoring. However, due to data paucity and lack of current research in most developing countries (Lawler, 2003), especially Nigeria, this research was unable to develop an evidence-based conclusion on the role of pipelines in settlement locations in the rural Niger Delta. This area can provide an insight for policy makers in pipeline hazard management.

It is hoped that, as Nigeria decides to implement the UNEP recommendations and improve environmental quality in oil-producing areas of the Niger Delta region, exploring the above research areas would help in policy strategy and development of targets concerning land contamination and land-use exposure.

Conclusion

This study has developed a method for mapping areas susceptible to oil pipeline impact (Figure 9-3), and land-use risk assessment criteria (Subsection 8.4.1) through the following findings.

i) The literature review provided an insight into the geographic distribution of the ethnic population in Nigeria, and how distributive justice and lack of development is causing animosity of host communities towards MOCs and government (Chapter 2).

ii) The government's involvement in oil and gas activities through joint ventures with major MOCs is responsible for its complacency (Chapter 10) in enforcing environmental legislations and regulations (Chapter 3), which MOCs took advantage of to operate without regard for the environment, thereby instigating reprisals from host communities.

iii) The largest volume of oil was discharged by interdiction even though it is lower than production error in frequency. It is evident that communities condone interdiction because several communities had repeated oil spill incidents associated with interdiction (Figure 7.26) based on the Thiessen polygon method. There was clear evidence of slow response to oil spill incidents due to logistics and bureaucratic procedures (Chapter 7).

iv) Proximity analysis indicates that about 25%, 46%, and 93% of communities are located within 1.5km of oil spill sites, pipeline network, and rivers respectively. Although there was no direct correlation between distance of communities to pipelines and rivers, it is logical to conclude (without empirical evidence) that these communities are likely to be susceptible to direct and indirect exposure based on proximity alone (Chapter 7).

v) A pipeline classification for prioritising pipeline segments was developed; with this, it is possible to effectively manage pipeline hazards by ensuring pipeline segments designated under the Class 1 category meet the highest safety specification. The classification can be used to plan surveys, and monitor programmes.

vi) Possible source of land use exposure was conceptualised for three rural land use types, based on subsistence economic lifestyles to derived rural land use assessment criteria using the CLEA model (Chapter 8).

vii) Communities in HCAs were selected using PPIR buffer, demarcated by the MCDM-AHP model. The model-mapped areas are potentially susceptible to pipeline hazard, as an alternative to the formula-based PIR and ROWs, because their dimensions are not sufficient to guarantee safety for adjoining areas (Chapter 9).

viii) Empirical deductions suggest a poor relationship between stakeholders in the oil and gas sector; therefore, this study has developed a framework integrating both in a symbiotic relationship, with which it is hoped existing animosity would be resolved and human-induced oil pollution would be eliminated (Chapter 10).

This study supports recommendations proposed by the UNEP (Appendix F). However, to be effective, Ogoniland cannot be treated in isolation as proposed. The recommendations must be extended to all areas producing oil in the Niger Delta, the reason being that oil spills have the potential to migrate to and from far distances, especially in the creeks. Oil can move back and forth with tides to reach the coast and downstream villages (according to direction of prevailing tide). Therefore, a holistic approach is required to ensure that contaminants do not migrate across boundaries to areas being treated; for instance, no oil production has been conducted in Ogoniland since 1993, yet there is evidence of fresh petroleum hydrocarbons in soil and water (UNDP, 2011).

The evolution of environmental risk management emanates from the need to protect man and his environment from adverse effects caused by man himself and natural events; therefore, knowledge of areas prone to hazards, frequency of hazard, and cause of hazard are critical in management planning. For this purpose, this research has developed a method to identify communities directly and indirectly susceptible to pipeline hazard and location of hotspots from where clean-up can begin. It also provides a framework that, if successfully utilised, would eliminate all forms of future oil spills caused by people and allow uninterrupted clean-up programme. The screening criteria developed herein can provide a base for future land-use exposure assessment and a mitigation strategy for regulators and policy makers in the oil industry.

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Appendix A: Questionnaire and Interview Extracts

A-1: Questionnaire

This questionnaire is designed to provide information on certain land use practice in rural Niger Delta as part of a PhD research. Information provided herein would be used specifically for this purpose.

(Please tick appropriate box to your response)

1. Tick one or more land use economic activities you perform.

   A. Farming ☐ B. Fishing ☐ C. Animal herding ☐ D. Hunting ☐ E. Gathering ☐

2. Other activities undertaken not listed above.

   A. Yes ☐ (if yes please specify.......................................) B. No ☐

3. How far do you go to perform these activities?

   A. <1km ☐ B. 1–2km ☐ C. 2-3km ☐ D. >3k ☐ E. Approx. Distance...........km

4. How many days do you perform these activities in a week?

   A. 7days/week ☐ B. 5 days/week ☐ C. 3 days/week ☐ <3 days/week ☐

5. What time would you normally spend performing this activity in a day?

   A. <3hrs ☐ b. 3-4hrs ☐ C. 4-5hrs ☐ D. >5hrs ☐

6. What is your normal mode of transport to where you perform the activity?

   A. By foot ☐ By boat ☐ C. By car ☐ D. By motorcycle ☐ E. Specify ....

7. What is the source of labour you used?

   A. family members' ☐ B. hired hands ☐ C. communal help ☐ D. individual ☐

8. What type of labour do you used.

   A. mechanised ☐ B. manual labour ☐ C. both ☐

9. Do you wear protective clothing when performing the activity?

   A. Yes ☐ B. No ☐

10. If yes, are all parts of the body protected i.e. covered?

    A. Yes ☐ B. No ☐

11. Which part or parts of the body is usually exposed (left uncovered).

    A. The leg region (knee downwards) ☐ B. The hands (from elbow) ☐ C. The upper torso region (chest and back) ☐ D. all of the above ☐

12. Would you consider the activity you undertake as energy intensive?

    A. Yes ☐ B. No ☐

13. Rate the intensity from not intensive to very intensive.

    A. not intensive ☐ B. less intensive ☐ C. intensive ☐ D. very intensive ☐

Thank you for your time and response.

A-2: Interview 1st (Operator)

Name: Mr. Usman Anibasa **Position:** Lead Spill Response (SPDC)

Location: Port Harcourt **Date:** 2nd June 2010.

Q: What is the main cause of oil spill?

A: The main reasons we have more crude oil stealing after the militant issues, is that politician and thugs now refine oil in barges and drums and sale to companies using fuel to power their machineries. This is because refineries in Nigerian, which are not performing optimally, cannot supply enough fuel for these companies. They therefore patronise people who sale-stolen crude oil, which by effect promotes oil bunkering by creation of market for stolen oil.

Another group is the attention seekers who deliberately vandalise pipeline to attract attention. For instance, around 2003 or 2004 a community came to the company seeking audience but felt they were not well received. They went back and cut about 35 points on one single pipeline around their village. We also discovered that people deliberately cut pipelines in order to create job opportunity since our oil spill management approach encourage the use of local labour for clean up. This approach was initiated to empower local people and give them a sense of involvement in the company. However, people began to deliberately impact their environment by causing spills so that they would be employed or contracted for clean-up exercises. The other cause is people who deliberately blow up oil pipelines just to cripple the oil industries, but with the introduction of the presidential amnesty programme, the use of dynamites in blowing up pipelines has reduced.

Now the most frequent technique is to tap directly from pipelines or oil wells and pump crude onto barges, then offload on a ship already waiting on the high sea. They have also established inland markets for stolen crude, which are regularly patronised by companies and individual in need of fuel. In addition, there are illegal (artisanal) refineries sprouting everywhere in the region. People who stole oil for sale in the high sea, local markets and for illegal refineries cause most of the spills we respond. From 2005, we record an average of 240 and 250 oil spill incidents every year. (0:00 – 4:14).

Q: Which sector of the oil industry contributes the most spills?

A: We do not have data with which to compare between the upstream and downstream sector, information on the downstream is with the Pipeline Product Marketing Company (PPMC). However, because of the length of pipelines in the upstream, it is easy to conclude that spills in the upstream are higher than in the downstream, which only transport refined petroleum products. In the upstream, there are more spills in the onshore than offshore, mainly because facilities in the offshore are relatively new and sophisticated; beside they are so far on the high seas for vandals to reach. The onshore facilities on the other hand are easily accessible, so they are easily attacked. (4:15-6:06).

Q: Has spill incidence increased since 2000?

A: From our records, oil spill incidence from 2000 to date increased significantly in 2007 then dropped in 2008. The drop is however not a steady but fluctuates. (6:07-7:12).

Q: How do you know when there is a spill?

A: We get reports from our surveillance teams who work in conjunction with local communities along pipeline routes. We also have community representative with whom we interact regularly as well as our own surveillance teams that inspect our lines at regular intervals. We use an approach established between communities and shell, call "Community And Shell Together" (CAST). The pipelines are divided into segments, which are assigned to the nearest community. The community reports directly when spill occur as well as patrol the lines against criminals. However, sometimes our teams cannot confront the gangs (vandals) because some of them are armed. (7:14-8:52).
Q: What is your average response time for any spill? **A:** Our average typical response time is immediately except when it is reported late. For instance if a case is reported at about 4 to 5pm when the office is closing or closed, nothing can be done until next day (so with weekends). The reason is we need to invite the joint venture investigation team, which comprises of representatives of JV partners to inspect the site and ascertain the spill. In most cases, we respond within 24 hours but there are cases where this may take longer, because the company needs to negotiate for Freedom To Operate (FTO) with the concerned community. (9:00-10:19)
Q: When attending to spills, is your priority on stopping the spill or protecting humans and the environment. **A:** We try to protect human and sensitive areas using the Environment Sensitive Index (ESI) mapping. When we receive report of a spill, the first team to visit the site are responsible for shutting down all lines connected to the affected line by isolating it. The procedure is to contain the spill so that it does not spread further. We construct risers over river crossings because we do not lay pipes under water, doing so allow our teams to use valve install on the riser to control or disrupt oil flow in times of emergency. (10:19-12:49).
Q: What is the compensation to affected community or individual like? **A:** Compensation payment guideline can be found in EGASPIN and the Petroleum Act. The first thing done is to determine the true cause of the spill by assessing the site and evaluating available evidence. If the spill is caused by sabotage, then no compensation is given but the site would be prepared for clean up none the less. However, if it is not sabotage, arrangement is made to pay individuals or communities affected. Therefore, the company uses government guideline to negotiate compensation. (12:52-16:27).
Q: Do you encourage people to report spill incidence? **A:** We engage communities in reporting oil spills through an initiative aimed at creating awareness on the impact of oil spill on the environment. Many community members are becoming more aware of this, but the unscrupulous few are the once causing the problem. Another aspect is in rewarding people to report spill incidence, for instance farmers and fishermen are the once who report the first sight of oil spill because they go far. (20:12-23:05).
Q: Does your organisation work independently or with others during spill events? **A:** Joint venture team comprises of JV partners like the Department for Petroleum Resources (DPR); National Oil Spill Detection and Response Agency (NOSDRA); The Nigerian National Petroleum Corporation (NNPC); Our Company (MOC); The village representatives; Law

enforcement agencies and the State Ministry of Environment.
Q: Under what legislation do oil pollution, remediation, and cost operate? **A:** In oil spill response, we first attend to the spill then send the bill to the government to pay their own counterpart funds, which is according to the joint venture agreement (share). In terms of clean-up, the EGASPPIN and NOSDREA act stipulate who should pay in line with the Polluter Pay Policy, but Shell as a stakeholder that is interested in creating conducive relationship with host communities often go out of the way to effect clean-up event when Shell is not responsible but in its area of operation (14:47-15:35).

A-2: Second Interviewee (Operator)

SPDC Position: Environment and Safety Officer
Location: Port Harcourt **Date** 5th June 2010.
I do not give interviews because this is a very sensitive issue and one would not want to be misquoted. You know, it can have implication on my job, but since you reiterated that, the interview is to help you in your research I would allow it for this purpose only.
Q: How do you detect and respond to oil spills **A:** Oil spill occur on daily basis without us knowing, we therefore depend on villagers because more than 90% of our onshore pipelines do not have leak detection systems and are located in remote locations. A spill could go on for ages without us knowing, especially in remote areas where access is by helicopter or speedboats alone. It is true that some spills are not recorded or reported due to the rigour of JV inspection. Since we are allowed to handle less than 100kg spills, we often underestimate the quantity to avoid bureaucratic procedure of reporting to DPR or initiating a JV inspection, which always cause delays in our response effort.
Q: How do you determine the cause of spill? A: We always have difficulties in agreeing on the cause of a spill. Ordinarily it is easy to decipher the cause simply by looking at the pipe, but because all parties must agree, we spend a lot of time debating. Determination of spill is no rocket science, when you see rupture due to pressure dent or corrosion you would know. Therefore, even if the spill was caused by sabotage and every sign indicate so, the community leaders would refuse to sign declaration attributing the cause to sabotage for fear of missing compensation. The law categorically stipulates non-payment of compensation for spills caused by sabotage.
Q: How do you ensure people are not exposed unnecessarily? **A:** We try as much as possible to ensure that people are protected from oil spills, but the nature of the Niger Delta environment makes it almost impossible to contain oil spill plume. On several occasions our response units report to a site only to discover there is no sign of hydrocarbons; the water has flushed it away into the creeks and rivers. In such situation what do you? Nothing, nature has taken care of itself. However, where crude oil is still present, we cordon the area, restrict access, which is difficult to maintain because people living in the area are predominantly

farmers, and may have converted rights of way to footpaths passing through the site. Do you therefor create a detour in order to prevent them from passing through?
Q: I understand that rights of ways are meant to be restrictive. **A:** The rights of way are constructed to provide easy access to facilities for emergencies or repairs. Usually landowners use parts of the same land for farming or something else while under lease. In most cases, they are allowed to use the land bearing in mind the consequences while at the same time they serve as guards for the company.
Q: How is the relationship between the people and the company like? **A:** The relationship between oil companies and host communities would always be soar, because members of the community want companies to perform the role of government in providing developmental infrastructure and other needs. Even though the company try as much to ensure it perform its corporate social responsibilities to the host communities. For instance, the company built schools, hospitals, roads, and provided scholarships to indigenes from secondary to tertiary levels, but they want more. Most people who come here in the name of community elders or youth leaders do so for sefish reasons rather than communal. They often ask in the name of the community but when given, they share (money) amongst themselves. Another group would come forward with similar demand, until you realise they are all phantoms. For example, the company did a need assessment for one community and decided to construct a road for them as part of its social responsibility. We (Company) made consultations with the community leaders and offered contract for tender, in the middle of the process, they sent a delegation with request that the contract should be awarded to one of their sons. Since that is what they wanted and in order to nurture relationship, they were given go ahead. Until this very day the road has not been constructed, they obviously collected the money and shared it among themselves. Annoyingly this is a typical example of the way people milk the company.
Q: What is the best way to resolve hostilities toward oil companies? **A:** Personally, I think the issue of poverty and unemployment must be addressed first, because people are becoming so dependent on easy money, which they get either by blackmailing the company, or from stealing crude oil. The company I believe would continue to do its best to ensure good relations with host communities with the hope that government would step up its own obligation to the people. As a company there is little it can do, Government has the powers, the laws and apparatus to resolve the Niger Delta crisis.

A-3: Third Interviewee (Regulator)

DPR Position: Technical Officer Environment and Safety
Location: Lagos **Date:** 17th May 2010
Our mandate is to regulate the oil and gas sector by monitoring operations of oil companies to ensure they operate within the laws of the land and conform to international best practice.
Q: What happens when there is an oil spill incident? **A:** The regulation demands oil spill incidents to be reported to the DPR within 24 hours after which a joint inspection team is assembled to investigate the cause of spill, determine quantity

spilt, extent and map area impacted. The operator is thereafter instructed to initiate clean-up using requirement prescribed in EGASPIN.
Q: You mean if there is a spill in Port Harcourt, report has to be sent here in Lagos for you to organise JV inspection. **A:** DPR has zonal offices and each zonal office has its area of jurisdiction. In the case of Port Harcourt, it is handled by the Port Harcourt zonal office, which in turn sends report to the headquarters here in Lagos.
Q: This means you have record of all oil spills. **A:** The companies send quarterly report of oil spill situations in their areas of operation to the DPR; unfortunately, DPR is currently planning to build an electronic database for all oil spill incidents using GIS. Now records are kept in hardcopy files, some are still there while many were lost when relocating to this office. Nevertheless, when the GIS platform become operational, information on oil spills from onshore and offshore facilities would be harmonised so that information can be easily accessed.
Q: Has any oil company ever been prosecuted for oil pollution? **A:** EGASPIN and relevant laws provide basis for prosecuting oil companies, but in most cases issues like this are settled out of court especially if the community affected settle for compensation. Oil companies have been prosecuted in the country before but I cannot mention a specific case at the top of my fingers right now, but yes, the government do prosecute.
Q: Who is responsible for managing pipeline rights of way, and what is the duty of DPR in the event an operator fails? **A:** The pipeline operator is responsible for maintaining pipeline rights of way all year round. It is their responsibility to clear vegetation and make it accessible. Companies that fails to do so are reprimanded, besides this has never been an issue except may be in remote areas where accessibility is difficult.
Q: How do you determine that a remediated site has achieved clean-up goal and which agency decides, DPR or NOSDRA? **A:** soil and water samples are tested to ascertain levels of hydrocarbon contaminants especially the BTEX, if found to be below target value (EGASPIN) the site is considered clean but if otherwise, further remediation is recommended. DPR decides because everything is based on EGASPIN, which is a guiding document developed by DPR.

A-4: Fourth Interviewee (Regulator)

NAPIMS **Position:** Technical Officer Environment and Safety
Location: Lagos **Date:** 26th June 2010
NAPIMS is the business arm of NNPC in-charge of all Joint Venture and Production Sharing contracts. NAPIMS checks and approves expenditure of joint partners. For example if Shell wants to buy this PEN, which cost one hundred naira, it is the duty of NAPIMS to approve or review the request. For every one hundred naira spent by Shell, the government through NNPC invest 60 naira (60%) according to the joint venture participatory contributions. This particular department

is responsible for Health Safety and Environment issue, therefore oil spill accidents falls within our purview.
Q: In that case, what is your role in oil spill management? **A:** our duty is to collect and maintain records of oil spill incidents in the joint venture. At the end of every year, joint partners are required to provide budgetary reports detailing money spent on clean-up, hiring of equipment and compensation etc. before "cash call". Government must approve money used for this purpose, so that joint partners share in the responsibility according to their percentage shares. We also inspect the sites to ensure the report is correct. We work closely with DPR and NOSDRA, although people say we have overlap but no. DPR is the regulatory arm, NAPIMS makes sure financial investment is in proportion with approve JV formula, and NOSDRA is in charge of oil spill management.
Q: Does a company require approval and money before embarking on clean-up exercise? **A:** No, the company use its funds, which is reimbursed after approval based on the JV shares.
Q: Any limit to the amount they can spend. **A:** No, the company has discretion as long as fund is available; each JV Company is at liberty to spend as much as reasonably possible in the running of the JV operations.
Q: Can I have your oil spill data so that I can compare with the ones in literature? **A:** No, the DPR is the custodian of such information and only they can give you, I can however direct you to the person that can help you.

A-5: Fifth Interviewee (Regulator)

NOSDRA Position: Oil Spill Inspector
Location: Lagos **Date:** 10th June 2010
NOSDRA is an agency under the Federal Ministry of Environment with the responsibility to manage oil pollution in the country. We work in collaboration with DPR to coordinate oil spill clean-up and inspection. The agency was established in 2006 to coordinate the country's National Oil Spill Contingency Plan. Four years after creation, we are still struggling to establish offices across the nation recruit and train staffs. All these requires money that has not been forth coming, thus we are struggling to establish our authority in the sector. In the meantime, we are working closely with DPR and MOCs to achieve our mandate.
Q: What is your response procedure to oil spill incident like? **A:** For the time being, we operate two approaches. The first is through participation in JV inspection and secondly we act on reports from the public. The JV is organised by DPR in which case EGASPIN guideline is used to determine cause, quantity, size, and map incident sites. Every party in the JV keeps copies of the report; it is from these reports that we build our database. On the other hand, if we respond to public report, we use the National Oil Spill Contingency guideline. In whichever case, our priority is to ensure that polluted sites are returned to pristine state, we do this by regular monitoring of remediation site to ensure that remediation process is working according to plan and when the site clean-up meets our standard, it is given a "clean bill of health" (closure).

Q: In that case, how do you harmonise your oil spill database? **A:** Yes, this is a problem. We always end up with different data with other regulators because we use two approaches. As you know not all spills are reported for JV inspection, just as we do not report oil spills reported to us by the public to any organisation. As a result**,** the data we may have in NOSDRA would be different from the one with DPR and the company in question. This is because DPR keeps record of oil spills from JV inspections while NOSDRA keeps both JV inspection data and oil spills reported by the public, while the oil company may also have data of oil spills they handled in house (less the 100kg) as well as the JV inspected ones. It is therefore difficult to have the same result across agencies.
Q: You mentioned poor funding in the beginning of our discussion, how does this affect you duties? **A:** it is difficult, because we find ourselves on many occasions where the operators provide us with logistics for carrying out our duties. In such situation the officer is compromised, I mean how can you write unfavourably report against an organisation that paid your transport, feed and accommodate you while auditing them. The budgetary allocation is not enough and staffs' salary is another issue. I mean how can you regulate an organisation with well-paid and well-trained staffs than yourself who might be looking for opportunity to work in such organisation.
Q: On remediation, how do you determine a site has achieved regulatory closure? What approach do you use, levels of Total Petroleum Hydrocarbons (TPH) or Equivalent Carbon (EC) number fractions. What range for soil and water contamination? **A:** As I said, we are a new organisation not really grounded on the chemistry part of things. Nevertheless, it is the responsibility of the contractor to test samples collected through reputable laboratories locally or internationally. Once again, we depend on the target value in EGASPIN to determine closure. Most contractors use target and intervention values for mineral oil levels in EGASPIN, a site is passed once the laboratory satisfies that the level is less than 5,000 mg/kg. Meanwhile this particular role is still under DPR who in turn delegate responsibility to the oil companies.
Q: Are you implying that the oil companies decide when closure is reached? **A:** Yes
Q: Who contract and pay the contractor? **A:** The oil company
Q: Don't you think there might be conflict of interest whereby the company gives closure to a site with or without proper clean-up? **A:** It is complicated, allow me to say "no comment"

A-6: Sixth Interviewee (Farmer)

Local Farmer Location: Port Harcourt   Date: 3rd June 2010
I am a farmer and I was born and raised from this very locality. Farming is what we know and we are finding it very difficult to survive because of oil pollution. The day oil was first discovered

in Bayelsa state, people celebrated with a football match even though a lot of oil spewed to the ground, nobody bothered because of excitement and the prospect of direct benefit of oil development. Now all the fish in the rivers are dead due to oil pollution, in fact the few we are lucky to catch have lost test, the fish is no longer delicious like before. This is why people prefer imported fish to local fish**,** the reverse was the case in the "old good days" when we had sufficient fish in the river, but all is lost now because of oil pollution.
Q: Shell said they have a CAST programme to help you people. **A:** Yes, it is true Shell established an initiative called CAST i.e. "Communities and Shell Together." The idea was to create a forum for closer interaction with local people in communities they operate. The forum was to be a first contact for employment nomination, training, scholarships, and determination of need based projects. The initiative is good, but people do not trust Shell and politicians have highjacked the project by appointing their cronies as representatives of the people. Meanwhile these same politicians sponsor oil bunkering and artisanal refineries in our communities. We know them, the government know them and the oil companies know them, but they are untouchable because they give returns to government officials and security agencies. In fact, they use oil workers, otherwise where can a poor man get money to buy a berg and pay security men to set up local refinery or bunker oil?
Q: you mentioned oil pollution threatening your survival, how is that? **A:** Everywhere you go, you see oil spill, and our source of drinking water is contaminated. You cannot dig a well and find clean water anymore, if you come here around August-September this footpath will be inundated and you would see oil sheen floating on the water surface, sticking to your legs, and clothing. You do not have to live close to oil facilities to be affected; the river and rain water flushes oil to your home, your farm and play ground. Nothing can be done to stop it, because there is so much oil pollution everywhere that no place is clean.
Q: is there any reported illness resulting from exposure to oil spills? **A:** Yes, there is suffering due to level of poverty, people cannot afford to visit hospitals in the city, which is why we patronise local traditional herbalist instead.
Q: Do oil companies pay adequate compensation for farms impacted? **A:** The oil companies don't like paying compensation, which is why they would insist that oil spill is caused by our people, even when evidence show it is their fault. All these pipelines you see have been here for ages, old age and corrosion has weaken them that at the slightest contact it would rupture, but still they blame people and hide behind the law preventing payment of compensation for spills caused by sabotage or vandalism. If they eventually pay, the money is not adequate to compensate for loss of farm produce or drinking water or fishing ground.

Appendix B: Soil Screening Target Parameter

Benzene Carcinogenic (Non-Threshold)

Parameter / Land Use activity Description	Symbol	Unit	AGRIC	DWELLING	RESIDENTIAL
Body Weight	BW	kg	75.1	75.1	75.1
Averaging Time	AT	days	12825	27375	27375
Exposure Frequency	EF	days/yr	171	365	365
Exposure Duration	ED	yrs	75	75	75
Ingestion Rate (soil)	IRs	mg/day	400	400	200
GI absorption factor	GI		1	1	1
Surface Area Exposed Skin	SA	cm^2	27920	16920	15380
Soil to Skin Adherence Factor	AF	$mg/cm^2/day$	0.07	0.07	0.07
Dermal Absorption Factor	ABS		0.1	0.1	0.1
Inhalation Rate (air)	IRa	m^3/day	25	25	25
Particulate Emission Factor	PEF	m^3/kg	7.24E+08	7.24E+08	7.24E+08
Volatilisation Factor	VFi	m^3/kg	585	585	585
Volatilisation Factor	VFo	m^3/kg	55866	55866	55866
Target Hazard Index	THI		1	1	1
Target Risk	TR		1.00E-05	1.00E-05	1.00E-05
Toxicological Data for Benzene					
Slope Factor (Oral)	SFo		0.029	0.029	0.029
Slope Factor (Inhalation)	SFi		0.029	0.029	0.029
Slope Factor (Dermal)	SFd		0.029	0.029	0.029
SSV Benzene (mg/kg)			**1.46**	**1.17**	**1.18**

Toluene Non-Carcinogenic (Threshold)

Parameter / Land Use Activity Description	Symbol	Unit	AGRIC	DWELLING	RESIDENTIAL
Body Weight	BW	kg	53	75.1	25.1
Averaging Time	AT	days	2880	10950	2190
Exposure Frequency	EF	days/yr	180	365	365
Exposure Duration	ED	yrs	16	30	6
Ingestion Rate (soil)	IRs	mg/day	400	400	200
GI absorption factor	GI		1	1	1
Surface Area Exposed Skin	SA	cm^2	20630	14030	4400
Soil to Skin Adherence Factor	AF	$mg/cm^2/day$	0.2	0.2	0.2
Dermal Absorption Factor	ABS		0.1	0.1	0.1
Inhalation Rate (air)	IRa	m^3/day	22	25	17
Particulate Emission Factor	PEF	m^3/kg	7.24E+08	7.24E+08	7.24E+08
Volatilisation Factor	VFi	m^3/kg	375	375	375
Volatilisation Factor	VFo	m^3/kg	13072	13072	13072
Target Hazard Index	THI		1	1	1
Target Risk	TR		1.00E-05	1.00E-05	1.00E-05
Toxicological Data for Toluene					
Reference Dosage (Oral)	RfDo		0.2	0.2	0.2
Reference Dosage (Inhalation)	RfDi		0.11	0.11	0.11
Reference Dosage (Dermal)	RfDd		0.2	0.2	0.2
SSV (mg/kg) Toluene			**191.81**	**239.38**	**117.86**

Ethyl benzene Non-Carcinogenic (Threshold)

Parameter / Land Use Activity Description	Symbol	Unit	AGRIC.	DWELLING	RESIDENTIAL
Body Weight	BW	kg	53	75.1	25.1
Averaging Time	AT	days	2880	10950	2190
Exposure Frequency	EF	days/yr.	180	365	365
Exposure Duration	ED	Yrs.	16	30	6
Ingestion Rate (soil)	IR_S	mg/day	400	400	200
GI absorption factor	GI		1	1	1
Surface Area Exposed Skin	SA	cm^2	20630	14030	4400
Soil to Skin Adherence Factor	AF	$mg/cm^2/day$	0.2	0.2	0.2
Dermal Absorption Factor	ABS		0.1	0.1	0.1
Inhalation Rate (air)	IR_A	m^3/day	22	25	17
Particulate Emission Factor	PEF	m^3/kg	7.24E+08	7.24E+08	7.24E+08
Volatilisation Factor	VFi	m^3/kg	709	709	709
Volatilisation Factor	VFo	m^3/kg	13072	13072	13072
Target Hazard Index	THI		1	1	1
Target Risk	TR		1.00E-05	1.00E-05	1.00E-05
Toxicological Data for Ethyl benzene					
Reference Dosage (Oral)	RfDo		0.1	0.1	0.1
Reference Dosage (Inhalation)	RfDi		0.029	0.029	0.029
Reference Dosage (Dermal)	RfDd		0.1	0.1	0.1
SSV (mg/kg) ethyl benzene			**93.31**	**116.45**	**57.33**

Xylenes Non-Carcinogenic (Threshold)

Parameter / Land Use Activity Description	Symbol	Unit	AGRIC	DWELLING	RESIDENTIAL
Body Weight	BW	kg	53	75.1	25.1
Averaging Time	AT	days	2880	10950	2190
Exposure Frequency	EF	days/yr	180	365	365
Exposure Duration	ED	yrs	16	30	6
Ingestion Rate (soil)	IR_S	mg/day	400	400	200
GI absorption factor	GI		1	1	1
Surface Area Exposed Skin	SA	cm^2	20630	14030	4400
Soil to Skin Adherence Factor	AF	$mg/cm^2/day$	0.2	0.2	0.2
Dermal Absorption Factor	ABS		0.1	0.1	0.1
Inhalation Rate (air)	IR_A	m^3/day	22	25	17
Particulate Emission Factor	PEF	m^3/kg	7.24E+08	7.24E+08	7.24E+08
Volatilisation Factor	VFi	m^3/kg	348	348	348
Volatilisation Factor	VFo	m^3/kg	13072	13072	13072
Target Hazard Index	THI		1	1	1
Target Risk	TR		1.00E-05	1.00E-05	1.00E-05
Toxicological Data for Benzene					
Reference Dosage (Oral)	RfDo		2	2	2
Reference Dosage (Inhalation)	RfDi		0.09	0.09	0.09
Reference Dosage (Dermal)	RfDd		2	2	2
SSV (mg/kg) Xylenes			**146.91**	**183.20**	**90.06**

Appendix C: GAC Derivation Table 1c: rural agricultural land use calculated using CLEA v1.06 for 1% and 5% SOM.

	ALIPHATIC							AROMATIC								
	EC5-6	EC>6-8	EC>8-10	EC>10-12	EC>12-16	EC>16-35	EC>35-44	EC>5-7	EC>7-8	EC>8-10	EC>10-12	EC>12-16	EC>16-21	EC>21-35	EC>35-44	EC>44-70
ADE to HCV ratio																
Oral ADE to HCV ratio at GAC	0.50	0.50	0.82	0.82	0.82	0.14	0.14	0.86	0.86	0.82	0.82	0.82	0.78	0.78	0.14	0.78
Inhalation ADE to HCV ratio at GAC	0.50	0.50	0.18	0.18	0.18	0.86	0.86	0.14	0.14	0.18	0.18	0.18	0.22	0.22	0.86	0.22
Per cent (%) pathway exposure contribution (1%) SOM for rural agricultural land use																
Direct soil ingestion	22.48	24.12	24.87	24.98	24.99	33.32	33.32	32.86	38.16	24.87	24.98	24.99	32.97	33.29	33.32	33.31
Consumption of home-grown produce and attached soil	2.51	0.87	0.12	0.01	0.00	0.00	0.00	16.61	11.66	0.12	0.01	0.00	0.35	0.04	0.00	0.01
Dermal Contact with soil and dust	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Inhalation of dust	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Inhalation of vapour (indoor)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Inhalation of vapour (outdoor)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Background (oral)	25.00	25.00	25.00	25.00	25.00	33.33	33.33	0.01	0.05	25.00	25.00	25.00	33.33	33.33	33.33	33.33
Background (inhalation)	25.00	25.00	25.00	25.00	25.00	0.00	0.00	1.02	0.26	25.00	25.00	25.00	0.00	0.00	0.00	0.00
Per cent (%) pathway exposure contribution (5%) SOM for rural agricultural land use																
Direct soil Ingestion	24.39	24.81	24.97	24.99	24.99	33.32	33.32	43.48	46.60	24.97	24.99	24.99	33.25	33.32	33.32	33.32
Consumption of home-grown produce and attached soil	0.60	0.18	0.02	0.00	0.00	0.00	0.00	5.99	3.23	0.02	0.00	0.00	0.07	0.01	0.00	0.00
Dermal Contact with soil and dust	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Inhalation of dust	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Inhalation of vapour (indoor)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Inhalation of vapour (outdoor)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Background (oral)	25.00	25.00	25.00	25.00	25.00	33.33	33.33	0.01	0.05	25.00	25.00	25.00	33.33	33.33	33.33	33.33
Background (inhalation)	25.00	25.00	25.00	25.00	25.00	0.00	0.00	1.02	0.26	25.00	25.00	25.00	0.00	0.00	0.00	0.00

Table 2c: Relevant pathway contribution to total exposure for rural informal dwelling calculated using CLEA v1.06 for 1% and 5% SOM.

	ALIPHATIC							AROMATIC								
	EC5-6	EC>6-8	EC>8-10	EC>10-12	EC>12-16	EC>16-35	EC>35-44	EC>5-7	EC>7-8	EC>8-10	EC>10-12	EC>12-16	EC>16-21	EC>21-35	EC>35-44	EC>44-70
ADE to HCV ratio																
Oral ADE to HCV ratio at GAC	0.50	0.05	0.82	0.82	0.82	0.14	0.14	0.86	0.86	0.82	0.82	0.82	0.78	0.78	0.14	0.78
Inhalation ADE to HCV ratio at GAC	0.50	0.50	0.18	0.18	0.18	0.86	0.86	0.14	0.14	0.18	0.18	0.18	0.22	0.22	0.86	0.22
Per cent (%) pathway exposure contribution (1%) SOM for rural informal dwelling																
Direct soil ingestion	12.44	16.56	19.18	19.80	21.30	31.98	31.98	10.38	14.52	19.18	19.60	21.30	30.86	32.99	31.98	33.18
Consumption of home-grown produce and attached soil	9.19	3.65	0.62	0.08	0.01	0.00	0.00	36.29	30.21	0.62	0.08	0.01	2.17	0.25	0.00	0.06
Dermal Contact with soil and dust	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Inhalation of dust	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Inhalation of vapour (indoor)	0.34	0.46	0.53	0.54	0.03	0.00	0.00	0.29	0.40	0.53	0.54	0.03	0.00	0.00	0.00	0.00
Inhalation of vapour (outdoor)	3.02	4.02	4.66	4.76	3.64	1.32	1.32	2.52	3.53	4.66	4.76	3.64	0.27	0.07	1.32	0.07
Background (oral)	25.00	25.00	25.00	25.00	25.00	33.33	33.33	0.02	0.05	25.00	25.00	25.00	33.33	33.33	33.33	33.33
Background (inhalation)	25.00	25.00	25.00	25.00	25.00	0.00	0.00	1.02	2.61	25.00	25.00	25.00	0.00	0.00	0.00	0.00
Per cent (%) pathway exposure contribution (5%) SOM for rural informal dwelling																
Direct soil Ingestion	17.43	18.94	19.56	20.40	23.20	32.70	32.70	22.43	28.00	19.56	20.40	23.20	32.71	33.22	32.70	33.26
Consumption of home-grown produce and attached soil	2.84	0.92	0.13	0.02	0.00	0.00	0.00	20.97	13.07	0.13	0.02	0.00	0.46	0.05	0.00	0.02
Dermal Contact with soil and dust	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Inhalation of dust	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Inhalation of vapour (indoor)	0.48	0.53	0.54	0.05	0.01	0.00	0.00	0.62	0.78	0.54	0.05	0.01	0.00	0.00	0.00	0.00
Inhalation of vapour (outdoor)	4.23	4.60	4.75	4.52	1.77	0.60	0.60	5.45	6.80	4.75	4.52	1.77	0.13	0.03	0.60	0.03
Background (oral)	25.00	25.00	25.00	25.00	25.00	33.33	33.33	0.02	0.05	25.00	25.00	25.00	33.33	33.33	33.33	33.33
Background (inhalation)	25.00	25.00	25.00	25.00	25.00	0.00	0.00	1.02	2.61	25.00	25.00	25.00	0.00	0.00	0.00	0.00

Table 3c: Pathway contribution to total exposure for rural standard residential calculated using CLEA v1.06 for 1% and 5% SOM.

	ALIPHATIC							**AROMATIC**									
	EC5-6	EC>6-8	EC>8-10	EC>10-12	EC>12-16	EC>16-35	EC>35-44	EC>5-7	EC>7-8	EC>8-10	EC>10-12	EC>12-16	EC>16-21	EC>21-35	EC>35-44	EC>44-70
ADE to HCV ratio																
Oral ADE to HCV ratio at GAC	0.50	0.50	0.82	0.82	0.82	0.14	0.14	0.86	0.86	0.82	0.82	0.82	0.78	0.78	0.14	0.78
Inhalation ADE to HCV ratio at GAC	0.50	0.50	0.18	0.18	0.18	0.18	0.86	0.14	0.14	0.18	0.18	0.18	0.22	0.22	0.86	0.22
Per cent (%) pathway exposure contribution (1%) SOM for rural standard residential																
Direct soil ingestion	11.43	17.64	22.73	23.67	24.94	33.30	33.30	7.69	11.44	22.73	23.67	24.94	30.06	32.93	33.30	33.22
Consumption of home-grown produce and attached soil	13.00	6.47	1.13	0.14	0.01	0.01	0.01	41.41	26.67	1.13	0.14	0.01	3.26	0.38	0.01	0.10
Dermal Contact with soil and dust	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.00	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02
Inhalation of dust	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Inhalation of vapour (indoor)	0.56	0.87	1.12	1.17	0.03	0.00	0.00	0.38	0.56	1.12	1.17	0.03	0.00	0.00	0.00	0.00
Inhalation of vapour (outdoor)	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.00
Background (oral)	25.00	25.00	25.00	25.00	25.00	33.33	33.33	0.01	0.05	25.00	25.00	25.00	33.33	33.33	33.33	33.33
Background (inhalation)	25.00	25.00	25.00	25.00	25.00	0.00	0.00	1.01	2.59	25.00	25.00	25.00	0.00	0.00	0.00	0.00
Per cent (%) pathway exposure contribution (5%) SOM for rural standard residential																
Direct soil Ingestion	19.22	22.21	23.57	24.89	24.97	33.31	33.31	19.87	28.25	23.57	24.89	24.97	32.60	33.23	33.31	33.29
Consumption of home-grown produce and attached soil	4.82	1.67	0.24	0.03	0.01	0.01	0.01	28.62	20.31	0.24	0.03	0.01	0.71	0.08	0.01	0.02
Dermal Contact with soil and dust	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.01	0.02	0.01	0.01	0.01	0.02	0.02	0.02	0.02
Inhalation of dust	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Inhalation of vapour (indoor)	0.95	1.10	1.16	0.05	0.01	0.00	0.00	0.98	0.09	1.16	0.05	0.01	0.00	0.00	0.00	0.00
Inhalation of vapour (outdoor)	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00
Background (oral)	25.00	25.00	25.00	25.00	25.00	33.33	33.33	0.01	0.05	25.00	25.00	25.00	33.33	33.33	33.33	33.33
Background (inhalation)	25.00	25.00	25.00	25.00	25.00	0.00	0.00	1.01	2.59	25.00	25.00	25.00	0.00	0.00	0.00	0.00

Rural_Agric.xls

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Report generated 25/07/2013

Report title NIGER DELTA

Created by SHITTU at UNI NOTTINGHAM

BASIC SETTINGS

Land Use AGRICULTURAL LAND USE

Building No building
Receptor Female (allot) Start age class 1 End age class 17 Exposure Duration 65 years
Soil Sandy clay loam

Exposure Pathways

Direct soil and dust ingestion	✓	Dermal contact with indoor dust	✗	Inhalation of indoor dust	✗
Consumption of homegrown produce	✓	Dermal contact with soil	✓	Inhalation of soil dust	✓
Soil attached to homegrown produce	✓			Inhalation of indoor vapour	✗
				Inhalation of outdoor vapour	✓

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Land Use AGRICULTURAL LAND USE

Age Class	Exposure Frequencies ($days\,yr^{-1}$): Direct soil ingestion	Consumption of homegrown produce	Dermal contact with indoor dust	Dermal contact with soil	Inhalation of dust and vapour, indoor	Inhalation of dust and vapour, outdoor	Occupation Periods ($hr\,day^{-1}$): Indoors	Outdoors	Soil to skin adherence factors ($mg\,cm^{2}$): Indoor	Outdoor	Direct soil ingestion rate ($g\,day^{-1}$)
1	180	180	0	180	0	180	0.0	7.0	0.00	0.20	400.00
2	269	269	0	269	0	269	0.0	7.0	0.00	0.20	400.00
3	269	269	0	269	0	269	0.0	7.0	0.00	0.20	400.00
4	269	269	0	269	0	269	0.0	7.0	0.00	0.20	400.00
5	269	269	0	269	0	269	0.0	7.0	0.00	0.20	400.00
6	269	269	0	269	0	269	0.0	7.0	0.00	0.20	400.00
7	269	269	0	269	0	269	0.0	7.0	0.00	0.20	400.00
8	269	269	0	269	0	269	0.0	7.0	0.00	0.20	400.00
9	269	269	0	269	0	269	0.0	7.0	0.00	0.20	400.00
10	269	269	0	269	0	269	0.0	7.0	0.00	0.20	400.00
11	269	269	0	269	0	269	0.0	7.0	0.00	0.20	400.00
12	269	269	0	269	0	269	0.0	7.0	0.00	0.20	400.00
13	269	269	0	269	0	269	0.0	7.0	0.00	0.20	400.00
14	269	269	0	269	0	269	0.0	7.0	0.00	0.20	400.00
15	269	269	0	269	0	269	0.0	7.0	0.00	0.20	400.00
16	269	269	0	269	0	269	0.0	7.0	0.00	0.20	400.00
17	269	269	0	269	0	269	0.0	7.0	0.00	0.20	300.00
18	269	269	0	269	0	269	0.0	7.0	0.00	0.20	300.00

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Receptor Female (allot)

Age Class	Body weight (kg)	Body height (m)	Inhalation rate ($m^3\,day^{-1}$)	Max exposed skin factor: Indoor ($m^2\,m^{-2}$)	Outdoor ($m^2\,m^{-2}$)	Total skin area (m^2)	Consumption rates ($g\,FW\,kg^{-1}\,BW\,day^{-1}$): Green vegetables	Root vegetables	Tuber vegetables	Herbaceous fruit	Shrub fruit	Tree fruit
1	6.90	0.7	8.8	0.32	0.31	3.82E-01	21.36	38.07	48.09	5.49	6.69	11.46
2	10.50	0.8	13.7	0.33	0.36	5.02E-01	20.55	9.90	16.38	11.88	1.62	35.88
3	13.20	0.9	13.7	0.32	0.48	5.93E-01	20.55	9.90	16.38	11.88	1.62	35.88
4	15.80	0.9	13.8	0.35	0.48	6.51E-01	20.55	5.31	16.38	11.88	1.62	35.88
5	25.10	1.3	13.8	0.35	0.48	9.61E-01	11.22	5.31	10.14	5.55	0.48	12.78
6	25.10	1.3	16.6	0.33	0.74	9.61E-01	11.22	5.31	10.14	5.55	0.48	12.78
7	26.60	1.3	16.6	0.22	0.74	9.97E-01	11.22	5.31	10.14	5.55	0.48	12.78
8	26.60	1.3	16.6	0.22	0.74	9.97E-01	11.22	5.31	10.14	5.55	0.48	12.78
9	28.00	1.4	16.6	0.22	0.74	1.04E+00	11.22	5.31	10.14	5.55	0.48	12.78
10	28.00	1.4	16.6	0.22	0.74	1.04E+00	11.22	5.31	10.14	5.55	0.48	12.78
11	34.80	1.5	21.9	0.22	1.03	1.20E+00	11.22	5.31	10.14	5.55	0.48	12.78
12	38.80	1.5	21.9	0.22	1.03	1.27E+00	11.22	5.31	10.14	5.55	0.48	12.78
13	40.10	1.6	21.9	0.22	1.03	1.32E+00	11.22	5.31	10.14	5.55	0.48	12.78
14	40.10	1.6	21.9	0.22	1.03	1.32E+00	11.22	5.31	10.14	5.55	0.48	12.78
15	53.00	1.7	21.9	0.21	1.03	1.59E+00	11.22	5.31	10.14	5.55	0.48	12.78
16	53.00	1.7	24.6	0.21	1.17	1.59E+00	11.22	5.31	10.14	5.55	0.48	12.78
17	66.40	1.8	24.6	0.33	1.17	1.81E+00	8.82	4.20	5.37	4.83	0.66	8.91
18	75.10	1.8	16.4	0.33	1.17	1.96E+00	8.82	4.20	5.37	4.83	0.66	8.91

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Building No building

Building footprint (m^2)	0.00E+00
Living space air exchange rate (hr^{-1})	0.00E+00
Living space height (above ground, m)	0.00E+00
Living space height (below ground, m)	0.00E+00
Pressure difference (soil to enclosed space, Pa)	0.00E+00
Foundation thickness (m)	0.00E+00
Floor crack area (cm^2)	0.00E+00
Dust loading factor ($\mu g\,m^{-3}$)	0.00E+00

Soil Sandy clay loam

Porosity, Total ($cm^3\,cm^{-3}$)	5.30E-01
Porosity, Air-Filled ($cm^3\,cm^{-3}$)	1.60E-01
Porosity, Water-Filled ($cm^3\,cm^{-3}$)	3.70E-01
Residual soil water content ($cm^3\,cm^{-3}$)	1.50E-01
Saturated hydraulic conductivity ($cm\,s^{-1}$)	2.37E-03
van Genuchten shape parameter *m* (dimensionless)	3.10E-01
Bulk density ($g\,cm^{-3}$)	1.20E+00
Threshold value of wind speed at 10m ($m\,s^{-1}$)	7.20E+00
Empirical function (F_x) for dust model (dimensionless)	1.22E+00
Ambient soil temperature (K)	2.83E+02
Soil pH	7.00E+00
Soil Organic Matter content (%)	5.00E+00
Fraction of organic carbon ($g\,g^{-1}$)	2.90E-02
Effective total fluid saturation (unitless)	5.79E-01
Intrinsic soil permeability (cm^2)	3.16E-08
Relative soil air permeability (unitless)	5.78E-01
Effective air permeability (cm^2)	1.83E-08

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Soil - Vapour Model

Depth to top of source (no building) (cm)	0
Depth to top of source (beneath building) (cm)	50
Default soil gas ingress rate?	Yes
Soil gas ingress rate ($cm^3 s^{-1}$)	0.00E+00
Building ventilation rate ($cm^3 s^{-1}$)	0.00E+00
Averaging time surface emissions (yr)	65
Finite vapour source model?	Yes
Thickness of contaminated layer (cm)	200

Air Dispersion Model

Mean annual windspeed at 10m ($m s^{-1}$)	5.00
Air dispersion factor at height of 0.8m*	140.00
Air dispersion factor at height of 1.6m*	230.00
Fraction of site cover ($m^2 m^{-2}$)	0.3

* Air dispersion factor in $g m^{-2} s^{-1}$ per $kg m^{-3}$

Soil - Plant Model

	Dry weight conversion factor	Homegrown fraction Average	Homegrown fraction High	Soil loading factor	Preparation correction factor
	$g DW g^{-1} FW$	dimensionless		$g g^{-1} DW$	dimensionless
Green vegetables	0.096	0.05	0.33	1.00E-03	2.00E-01
Root vegetables	0.103	0.06	0.40	1.00E-03	1.00E+00
Tuber vegetables	0.210	0.02	0.13	1.00E-03	1.00E+00
Herbaceous fruit	0.058	0.06	0.40	1.00E-03	6.00E-01
Shrub fruit	0.166	0.09	0.60	1.00E-03	6.00E-01
Tree fruit	0.157	0.04	0.27	1.00E-03	6.00E-01

Gardener type Average

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Report generated 23/07/2013

Report title NIGER DELTA

Created by SHITTU at UNI NOTTINGHAM

Environment Agency

BASIC SETTINGS

Land Use INFORMAL DWELLING

Building RURAL DWELLING (COMBUSTABLE MATERIALS)
Receptor Female (res) Start age class 1 End age class 17 Exposure Duration 65 years
Soil 0

Exposure Pathways

Direct soil and dust ingestion ✓	Dermal contact with indoor dust ✓	Inhalation of indoor dust ✓
Consumption of homegrown produce ✓	Dermal contact with soil ✓	Inhalation of soil dust ✓
Soil attached to homegrown produce ✓		Inhalation of indoor vapour ✓
		Inhalation of outdoor vapour ✓

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Environment Agency

Land Use INFORMAL DWELLING

Age Class	Exposure Frequencies ($days yr^{-1}$): Direct soil ingestion	Consumption of homegrown produce	Dermal contact with indoor dust	Dermal contact with soil	Inhalation of dust and vapour, indoor	Inhalation of dust and vapour, outdoor	Occupation Periods ($hr day^{-1}$): Indoors	Outdoors	Soil to skin adherence factors ($mg cm^{-2}$): Indoor	Outdoor	Direct soil ingestion rate ($g day^{-1}$)
1	180	180	180	180	180	180	8.0	16.0	0.20	0.20	400.00
2	365	365	365	365	365	365	8.0	16.0	0.20	0.20	400.00
3	365	365	365	365	365	365	8.0	16.0	0.20	0.20	400.00
4	365	365	365	365	365	365	8.0	16.0	0.20	0.20	400.00
5	365	365	365	365	365	365	8.0	16.0	0.20	0.20	400.00
6	365	365	365	365	365	365	8.0	16.0	0.20	0.20	400.00
7	365	365	365	365	365	365	8.0	16.0	0.20	0.20	400.00
8	365	365	365	365	365	365	8.0	16.0	0.20	0.20	400.00
9	365	365	365	365	365	365	8.0	16.0	0.20	0.20	400.00
10	365	365	365	365	365	365	8.0	16.0	0.20	0.20	400.00
11	365	365	365	365	365	365	8.0	16.0	0.20	0.20	400.00
12	365	365	365	365	365	365	8.0	16.0	0.20	0.20	400.00
13	365	365	365	365	365	365	8.0	16.0	0.20	0.20	400.00
14	365	365	365	365	365	365	8.0	16.0	0.20	0.20	400.00
15	365	365	365	365	365	365	8.0	16.0	0.20	0.20	400.00
16	365	365	365	365	365	365	8.0	16.0	0.20	0.20	400.00
17	365	365	365	365	365	365	8.0	16.0	0.20	0.20	300.00
18	365	365	365	365	365	365	8.0	0.0	0.20	0.20	300.00

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Environment Agency

Receptor Female (res)

Age Class	Body weight (kg)	Body height (m)	Inhalation rate ($m^3 day^{-1}$)	Max exposed skin factor: Indoor ($m^2 m^{-2}$)	Outdoor ($m^2 m^{-2}$)	Total skin area (m^2)	Consumption rates ($g FW kg^{-1} BW day^{-1}$): Green vegetables	Root vegetables	Tuber vegetables	Herbaceous fruit	Shrub fruit	Tree fruit
1	6.90	0.7	8.8	0.20	0.31	3.82E-01	21.36	38.07	48.09	5.49	6.69	11.46
2	10.50	0.8	13.7	0.23	0.36	5.02E-01	20.55	9.90	16.38	11.88	1.62	35.88
3	13.20	0.9	13.7	0.32	0.48	5.93E-01	20.55	9.90	16.38	11.88	1.62	35.88
4	15.80	0.9	13.8	0.35	0.48	6.51E-01	20.55	5.31	16.38	11.88	1.62	35.88
5	25.10	1.3	13.8	0.32	0.48	9.61E-01	11.22	5.31	10.14	5.55	0.48	12.78
6	25.10	1.3	16.6	0.32	0.74	9.61E-01	11.22	5.31	10.14	5.55	0.48	12.78
7	26.60	1.3	16.6	0.19	0.74	9.97E-01	11.22	5.31	10.14	5.55	0.48	12.78
8	26.60	1.3	16.6	0.49	0.74	9.97E-01	11.22	5.31	10.14	5.55	0.48	12.78
9	28.00	1.4	16.6	0.49	0.74	1.04E+00	11.22	5.31	10.14	5.55	0.48	12.78
10	28.00	1.4	16.6	0.49	0.74	1.04E+00	11.22	5.31	10.14	5.55	0.48	12.78
11	34.80	1.5	21.9	0.69	1.03	1.20E+00	11.22	5.31	10.14	5.55	0.48	12.78
12	34.80	1.5	21.9	0.69	1.03	1.20E+00	11.22	5.31	10.14	5.50	0.48	12.78
13	40.10	1.6	21.9	0.69	1.03	1.32E+00	11.22	5.31	10.14	5.55	0.48	12.78
14	40.10	1.6	21.9	0.69	1.03	1.32E+00	11.22	5.31	10.14	5.55	0.48	12.78
15	53.00	1.7	21.9	0.69	1.03	1.59E+00	11.22	5.31	10.14	5.55	0.48	12.78
16	53.00	1.7	24.6	0.78	1.17	1.59E+00	11.22	5.31	10.14	5.55	0.48	12.78
17	66.00	1.8	24.6	0.78	1.17	1.81E+00	8.82	4.20	5.37	4.83	0.66	8.91
18	75.10	1.8	16.4	0.82	1.17	1.96E+00	8.82	4.20	5.37	4.83	0.66	8.91

Environment Agency

Building RURAL DWELLING (COMBUSTABLE MATERIA **Soil** 0

Building footprint (m^2)	2.80E+01
Living space air exchange rate (hr^{-1})	2.00E+00
Living space height (above ground, m)	1.50E+00
Living space height (below ground, m)	0.00E+00
Pressure difference (soil to enclosed space, Pa)	2.00E+00
Foundation thickness (m)	5.00E-02
Floor crack area (cm^2)	7.07E+02
Dust loading factor ($\mu g\ m^{-3}$)	1.00E+01

Porosity, Total ($cm^3\ cm^{-3}$)	5.30E-01
Porosity, Air-Filled ($cm^3\ cm^{-3}$)	2.00E-01
Porosity, Water-Filled ($cm^3\ cm^{-3}$)	3.30E-01
Residual soil water content ($cm^3\ cm^{-3}$)	1.20E-01
Saturated hydraulic conductivity ($cm\ s^{-1}$)	3.56E-03
van Genuchten shape parameter *m* (dimensionless)	3.20E-01
Bulk density ($g\ cm^{-3}$)	1.21E+00
Threshold value of wind speed at 10m ($m\ s^{-1}$)	7.20E+00
Empirical function (F_x) for dust model (dimensionless)	1.22E+00
Ambient soil temperature (K)	2.83E+02
Soil pH	7.00E+00
Soil Organic Matter content (%)	1.00E+00
Fraction of organic carbon ($g\ g^{-1}$)	5.80E-03
Effective total fluid saturation (unitless)	5.12E-01
Intrinsic soil permeability (cm^2)	4.75E-08
Relative soil air permeability (unitless)	6.42E-01
Effective air permeability (cm^2)	3.05E-08

Environment Agency

Soil - Vapour Model

Depth to top of source (no building) (cm)	0
Depth to top of source (beneath building) (cm)	55
Default soil gas ingress rate?	No
Soil gas ingress rate ($cm^3\ s^{-1}$)	1.36E+01
Building ventilation rate ($cm^3\ s^{-1}$)	2.33E+04
Averaging time surface emissions (yr)	65
Finite vapour source model?	Yes
Thickness of contaminated layer (cm)	200

Air Dispersion Model

Mean annual windspeed at 10m ($m\ s^{-1}$)	5.00
Air dispersion factor at height of 0.8m *	140.00
Air dispersion factor at height of 1.6m *	0.12
Fraction of site cover ($m^2\ m^{-2}$)	0.5

* Air dispersion factor in $g\ m^{-2}\ s^{-1}$ per $kg\ m^{-3}$

Soil - Plant Model

	Dry weight conversion factor	Homegrown fraction Average	Homegrown fraction High	Soil loading factor	Preparation correction factor
	$g\ DW\ g^{-1}\ FW$	dimensionless		$g\ g^{-1}\ DW$	dimensionless
Green vegetables	0.096	0.05	0.33	1.00E-03	2.00E-01
Root vegetables	0.103	0.06	0.40	1.00E-03	1.00E+00
Tuber vegetables	0.210	0.02	0.13	1.00E-03	1.00E+00
Herbaceous fruit	0.058	0.06	0.40	1.00E-03	6.00E-01
Shrub fruit	0.166	0.09	0.60	1.00E-03	6.00E-01
Tree fruit	0.157	0.04	0.27	1.00E-03	6.00E-01

Gardener type High

Appendix D: Communities Oil Spill Incidents Distribution and Risk Index Score.

S/N	Name	LGA	Spill Period					Distance (km)			Freq.	score	Quantity	Pop	Sex	
			85-90	91-96	97-02	03-08	Sabotage	River	Spill	Pipe					Male	Female
1	RUSSIA	AKUKU-TORU	7	21	13	18	26	0.42	0.67	0.88	59	4	23219	1307	590	717
2	ONONGISUO	AKUKU-TORU	2	13	21	9	7	0.50	2.25	4.37	45	4	12399	2508	1132	1376
3	IJAWKIRI	BRASS	x	11	1	12	8	0.16	1.89	1.46	24	4	10067	1376	621	755
4	GOGOBOKIRI	DEGEMA	5	12	6	4	5	0.17	2.72	0.85	27	4	8531	2019	911	1108
5	ADERIKIRI	DEGEMA	2	9	10	11	8	0.15	1.62	1.37	32	4	6812	3313	1495	1818
6	EGOROBITI	BRASS	1	10	9	3	8	1.41	1.57	2.56	23	4	8740	1906	860	1046
7	FESTUSKIRI	BRASS	2	12	5	8	12	0.50	6.45	0.38	27	4	6740	840	379	461
8	IMEPELEHOKE	DEGEMA	x	x	1	3	2	0.91	4.77	5.87	4	2	5418	1279	577	702
9	DAOJUKIRI/ABABO	BRASS	3	4	5	2	5	0.01	1.07	0.29	14	4	5021	9775	4411	5364
10	DAWARI	DEGEMA	4	2	2	x	1	0.20	9.62	6.19	8	3	2856	1519	686	833
11	ABABOKMO	BRASS	x	4	5	3	4	0.37	2.04	3.30	12	3	1432	2567	1158	1409
12	IDO	ASARI-TORU	1	x	1	2	3	0.51	6.01	0.40	4	3	3994	651	294	357
13	BANKIRI	DEGEMA	x	1	1	5	3	0.80	1.58	2.03	7	3	2648	2186	987	1199
14	OKPO	DEGEMA	x	x	x	7	2	0.67	5.94	1.34	7	1	2261	2668	1204	1464
15	KILLYKIRI	DEGEMA	3	2	1	x	1	0.09	13.37	0.31	6	3	1831	1043	471	572
16	OPOMAKIRI	DEGEMA	1	4	3	x	4	0.14	0.34	2.44	8	3	1666	664	300	364
17	OMEKWE-TARI-AMA	ASARI-TORU	x	x	x	6	1	0.14	0.99	3.26	6	1	1451	1000	451	549
18	ASUMEBUAMA	OKRIKA	5	2	1	x	1	1.31	1.49	5.06	8	3	1001	649	293	356
19	ELEM-KRAKAMA	DEGEMA	1	1	1	1	1	1.77	4.87	1.60	4	3	1869	632	285	347

S/N	Name	LGA	Spill Period					Distance (km)			Freq.	score	Quantity	Pop	Sex	
			85-90	91-96	97-02	03-08	Sabotage	River	Spill	Pipe					Male	Female
20	OBENIBOKIRI	DEGEMA	1	2	x	x	1	0.32	13.08	8.45	3	2	2357	2085	941	1144
21	ISAKA	P-HARCOURT	x	x	1	3	1	1.53	2.49	3.69	4	2	2215	3733	1685	2048
22	MONEY KIRI	DEGEMA	x	1	1	3	1	0.17	4.09	0.89	5	3	1207	938	423	515
23	KRIKAMA	DEGEMA	x	2	2	1	1	0.05	4.39	3.23	5	3	1582	747	337	410
24	SANDVILLAGE	BRASS	x	x	1	2	1	0.07	1.13	0.96	3	2	2089	3009	1358	1651
25	OLDSANGAMA	BRASS	x	x	x	2	2	0.40	7.10	0.13	2	1	1390	5685	2566	3119
26	OKIKIRI	DEGEMA	x	1	2	4	2	0.06	13.98	0.02	7	3	416	1184	534	650
27	ABABOKO	BRASS	x	1	2	2	1	0.17	0.32	1.06	5	3	442	675	305	370
28	ETAM KALBAN	DEGEMA	x	x	x	6	2	0.91	7.23	0.06	6	1	365	1270	573	697
29	OBONOMA	ASARI-TORU	x	2	x	5	6	0.77	1.35	0.68	7	2	430	4039	1823	2216
30	EKEMA	DEGEMA	1	x	x	x	1	1.01	6.97	5.60	1	1	1720	1654	746	908
31	OKOROBAKO	AKUKU-TORU	x	1	1	x	1	0.93	5.17	5.99	2	2	451	1249	564	685
32	KEBOKO	AKUKU-TORU	x	x	x	1		0.78	1.14	1.42	1	1	1200	1153	520	633
33	NDUKIRI	BRASS	x	x	x	4	2	0.01	1.31	3.98	4	1	292	665	300	365
34	OPU-ONONG	AKUKU-TORU	x	1	x	4	2	0.00	2.64	0.24	5	2	554	1192	538	654
35	ETUKUKIRI	BRASS	x	2	1	x	1	1.61	9.71	5.13	3	2	511	904	408	496
36	BEKIRIKIRI	DEGEMA	2	2	x	x	1	0.18	7.67	3.57	4	2	323	4089	1845	2244
37	KOKOONONA	AKUKU-TORU	x	x	1	x	1	0.06	5.40	2.54	1	1	400	1048	473	575
38	ORUKALAMA	ASARI-TORU	x	x	1	1	2	0.27	8.40	0.46	2	2	720	1319	595	724
39	IMOTANJIKIRI	DEGEMA	x	3	1	x	2	0.13	1.95	0.44	4	2	194	3979	1796	2183
40	TEMAKIRI	DEGEMA	x	1	1	x	x	0.16	12.93	3.89	2	2	194	7791	3516	4275

S/N	Name	LGA	Spill Period					Distance (km)			Freq.	score	Quantity	Pop	Sex	
			85-90	91-96	97-02	03-08	Sabotage	River	Spill	Pipe					Male	Female
41	OPAPUNGIA	BRASS	x	2	1	x	1	0.40	2.63	1.35	3	2	143	2429	1096	1333
42	IWAKIRI	DEGEMA	x	x	x	2	x	0.36	5.11	1.54	2	1	276	1282	579	703
43	FENIPANGA	DEGEMA	x	1	4	1	2	0.06	9.12	2.59	6	3	102	4036	1821	2215
44	NTUISANGHA	DEGEMA	x	1	x	x	x	0.61	0.54	2.65	1	1	500	2155	973	1182
45	BAKANA	P-HARCOURT	x	x	x	1	1	0.24	11.77	653	1	1	235	27675	12490	15185
46	IWOAMA	DEGEMA	1	2	x	x	x	0.62	3.19	2.28	3	2	211	9043	4081	4962
47	ANGULAMA	ASARI-TORU	x	x	1	2	3	0.58	0.86	0.63	3	2	153	6497	2932	3565
48	OKRIKOKIRI	BRASS	x	2	x	1	1	0.74	3.62	4.20	3	2	245	1770	799	971
49	ELEM-KALABARI	DEGEMA	x	1	1	x	x	0.01	6.46	0.53	2	2	116	1328	599	729
50	BILLE	DEGEMA	x	x	x	1	x	0.25	4.79	0.23	1	1	214	6285	2836	3449
51	BIKKIRI	BRASS	x	1	x	1	1	0.05	1.17	2.44	2	2	80	1086	490	596
52	OGOLOGOKIRI	DEGEMA	2	x	1	x	x	0.88	7.27	3.33	3	2	73	2577	1163	1414
53	AWOLAKAKIRI	DEGEMA	x	x	x	1	1	1.61	0.90	1.39	1	1	50	3458	1561	1897
54	OMEKWEREKO	DEGEMA	x	2	1	x	1	0.77	16.17	0.36	3	2	50	5087	2296	2791
55	AKUKUAMA	DEGEMA	x	x	x	1	x	0.00	0.30	2.03	1	1	30	2669	1205	1464
56	OMUNGUKIRI	DEGEMA	x	x	1	x	x	0.51	15.92	5.76	1	1	27	2021	912	1109
57	APARAKIRI	AKUKU-TORU	x	1	x	1	x	0.21	4.12	0.59	2	2	25	624	282	342
58	DOKUBOKIRI	AKUKU-TORU	x	1	1	x	x	0.14	4.17	0.43	2	2	25	1462	660	802
59	OLD-SANGA	BRASS	x	x	1	1	1	0.37	2.74	0.81	2	1	15	953	430	523
		Total	**44**	**141**	**113**	**145**	**140**				**443**		**129578**	**168747**	**76156**	**92591**

APPENDIX D-2: Toxicity Weighting Procedure for Mapping Oil Spills (≥100bbl) in ArcGIS.

Column Guide

$\mathrm{STD1} = S_y - S_{\min(y)}$; $\mathrm{STD2} = S_{\max(y)} - S_{\min(y)}$; $\mathrm{STDYEAR} = \frac{STD1}{STD2}$; $\mathrm{NORM(Y \times Q)} = STDYEAR \times QUANTITY$;

$\mathrm{NORM1} = TU_{sy} - TU_{\min(sy)}$; $\mathrm{NORM2} = TU_{\max(sy)} - TU_{\min(sy)}$ $\mathrm{TOXNORM} = \frac{NORM1}{NORM2}$; $\mathrm{TOXUNIT} = TOXNORM \times 10$

SNO.	CAUSE	YEAR	QUANT	STAGE 1: NORMALISATION			NORM(YXQ)	STAGE 2: NORMALISATION			TOXUNIT
				STD1	STD2	STDYEAR		NORM1	NORM2	TOXNORM	
1	Production Error	1986	128	1	23	0.0435	5.5652	0.0030	2875.4783	0.0000	0.0
2	Sabotage	1986	232	1	23	0.0435	10.0870	4.5248	2875.4783	0.0016	0.0
3	Other	1986	2578	1	23	0.0435	112.0870	106.5248	2875.4783	0.0370	0.4
4	Production Error	1986	269	1	23	0.0435	11.6957	6.1335	2875.4783	0.0021	0.0
5	Other	1986	1720	1	23	0.0435	74.7826	69.2204	2875.4783	0.0241	0.2
6	Other	1987	782	2	23	0.0870	68.0000	62.4378	2875.4783	0.0217	0.2
7	Production Error	1987	230	2	23	0.0870	20.0000	14.4378	2875.4783	0.0050	0.1
8	Production Error	1987	204	2	23	0.0870	17.7391	12.1770	2875.4783	0.0042	0.0
9	Production Error	1987	215	2	23	0.0870	18.6957	13.1335	2875.4783	0.0046	0.0
10	Sabotage	1988	1027	3	23	0.1304	133.9565	128.3944	2875.4783	0.0447	0.4
11	Production Error	1988	179	3	23	0.1304	23.3478	17.7857	2875.4783	0.0062	0.1
12	Corrosion	1988	120	3	23	0.1304	15.6522	10.0900	2875.4783	0.0035	0.0
13	Production Error	1989	107	4	23	0.1739	18.6087	13.0465	2875.4783	0.0045	0.0
14	Production Error	1989	317	4	23	0.1739	55.1304	49.5683	2875.4783	0.0172	0.2
15	Production Error	1989	121	4	23	0.1739	21.0435	15.4813	2875.4783	0.0054	0.1
16	Other	1990	1095	5	23	0.2174	238.0435	232.4813	2875.4783	0.0809	0.8
17	Production Error	1990	100	5	23	0.2174	21.7391	16.1770	2875.4783	0.0056	0.1
18	Production Error	1990	207	5	23	0.2174	45.0000	39.4378	2875.4783	0.0137	0.1

SNO.	CAUSE	YEAR	QUANT	STAGE 1: NORMALISATION			NORM(YXQ)	STAGE 2: NORMALISATION			TOXUNIT
				STD1	STD2	STDYEAR		NORM1	NORM2	TOXNORM	
19	Production Error	1990	712	5	23	0.2174	154.7826	149.2204	2875.4783	0.0519	0.5
20	Other	1990	807	5	23	0.2174	175.4348	169.8726	2875.4783	0.0591	0.6
21	Sabotage	1990	137	5	23	0.2174	29.7826	24.2204	2875.4783	0.0084	0.1
22	Corrosion	1990	201	5	23	0.2174	43.6957	38.1335	2875.4783	0.0133	0.1
23	Sabotage	1990	1094	5	23	0.2174	237.8261	232.2639	2875.4783	0.0808	0.8
24	Sabotage	1991	1074	6	23	0.2609	280.1739	274.6117	2875.4783	0.0955	1.0
25	Sabotage	1991	1273	6	23	0.2609	332.0870	326.5248	2875.4783	0.1136	1.1
26	Corrosion	1991	106	6	23	0.2609	27.6522	22.0900	2875.4783	0.0077	0.1
27	Sabotage	1991	1932	6	23	0.2609	504.0000	498.4378	2875.4783	0.1733	1.7
28	Sabotage	1991	2016	6	23	0.2609	525.9130	520.3509	2875.4783	0.1810	1.8
29	Corrosion	1991	173	6	23	0.2609	45.1304	39.5683	2875.4783	0.0138	0.1
30	Production Error	1991	326	6	23	0.2609	85.0435	79.4813	2875.4783	0.0276	0.3
31	Production Error	1991	296	6	23	0.2609	77.2174	71.6552	2875.4783	0.0249	0.2
32	Corrosion	1991	102	6	23	0.2609	26.6087	21.0465	2875.4783	0.0073	0.1
33	Production Error	1991	231	6	23	0.2609	60.2609	54.6987	2875.4783	0.0190	0.2
34	Sabotage	1991	146	6	23	0.2609	38.0870	32.5248	2875.4783	0.0113	0.1
35	Sabotage	1991	105	6	23	0.2609	27.3913	21.8291	2875.4783	0.0076	0.1
36	Other	1991	1092	6	23	0.2609	284.8696	279.3074	2875.4783	0.0971	1.0
37	Production Error	1992	2134	7	23	0.3043	649.4783	643.9161	2875.4783	0.2239	2.2
38	Production Error	1992	1352	7	23	0.3043	411.4783	405.9161	2875.4783	0.1412	1.4
39	Production Error	1992	113	7	23	0.3043	34.3913	28.8291	2875.4783	0.0100	0.1
40	Production Error	1992	152	7	23	0.3043	46.2609	40.6987	2875.4783	0.0142	0.1
41	Sabotage	1992	1032	7	23	0.3043	314.0870	308.5248	2875.4783	0.1073	1.1
42	Production Error	1992	1024	7	23	0.3043	311.6522	306.0900	2875.4783	0.1064	1.1

SNO.	CAUSE	YEAR	QUANT	STAGE 1: NORMALISATION			NORM(YXQ)	STAGE 2: NORMALISATION			TOXUNIT
				STD1	STD2	STDYEAR		NORM1	NORM2	TOXNORM	
43	Production Error	1992	750	7	23	0.3043	228.2609	222.6987	2875.4783	0.0774	0.8
44	Sabotage	1992	1352	7	23	0.3043	411.4783	405.9161	2875.4783	0.1412	1.4
45	Sabotage	1993	407	8	23	0.3478	141.5652	136.0030	2875.4783	0.0473	0.5
46	Sabotage	1993	231	8	23	0.3478	80.3478	74.7857	2875.4783	0.0260	0.3
47	Sabotage	1993	105	8	23	0.3478	36.5217	30.9596	2875.4783	0.0108	0.1
48	Sabotage	1993	783	8	23	0.3478	272.3478	266.7857	2875.4783	0.0928	0.9
49	Sabotage	1993	1052	8	23	0.3478	365.9130	360.3509	2875.4783	0.1253	1.3
50	Production Error	1993	732	8	23	0.3478	254.6087	249.0465	2875.4783	0.0866	0.9
51	Production Error	1993	108	8	23	0.3478	37.5652	32.0030	2875.4783	0.0111	0.1
52	Production Error	1993	124	8	23	0.3478	43.1304	37.5683	2875.4783	0.0131	0.1
53	Sabotage	1993	371	8	23	0.3478	129.0435	123.4813	2875.4783	0.0429	0.4
54	Sabotage	1993	2043	8	23	0.3478	710.6087	705.0465	2875.4783	0.2452	2.5
55	Sabotage	1993	132	8	23	0.3478	45.9130	40.3509	2875.4783	0.0140	0.1
56	Sabotage	1993	114	8	23	0.3478	39.6522	34.0900	2875.4783	0.0119	0.1
57	Production Error	1993	2013	8	23	0.3478	700.1739	694.6117	2875.4783	0.2416	2.4
58	Corrosion	1994	725	9	23	0.3913	283.6957	278.1335	2875.4783	0.0967	1.0
59	Corrosion	1994	620	9	23	0.3913	242.6087	237.0465	2875.4783	0.0824	0.8
60	Sabotage	1994	1078	9	23	0.3913	421.8261	416.2639	2875.4783	0.1448	1.4
61	Sabotage	1994	308	9	23	0.3913	120.5217	114.9596	2875.4783	0.0400	0.4
62	Corrosion	1994	407	9	23	0.3913	159.2609	153.6987	2875.4783	0.0535	0.5
63	Production Error	1995	100	10	23	0.4348	43.4783	37.9161	2875.4783	0.0132	0.1
64	Production Error	1995	100	10	23	0.4348	43.4783	37.9161	2875.4783	0.0132	0.1
65	Production Error	1995	102	10	23	0.4348	44.3478	38.7857	2875.4783	0.0135	0.1
66	Sabotage	1995	785	10	23	0.4348	341.3043	335.7422	2875.4783	0.1168	1.2

SNO.	CAUSE	YEAR	QUANT	STAGE 1: NORMALISATION			NORM(YXQ)	STAGE 2: NORMALISATION			TOXUNIT
				STD1	STD2	STDYEAR		NORM1	NORM2	TOXNORM	
67	Corrosion	1995	973	10	23	0.4348	423.0435	417.4813	2875.4783	0.1452	1.5
68	Sabotage	1995	843	10	23	0.4348	366.5217	360.9596	2875.4783	0.1255	1.3
69	Production Error	1995	1500	10	23	0.4348	652.1739	646.6117	2875.4783	0.2249	2.2
70	Production Error	1995	164	10	23	0.4348	71.3043	65.7422	2875.4783	0.0229	0.2
71	Corrosion	1996	196	11	23	0.4783	93.7391	88.1770	2875.4783	0.0307	0.3
72	Corrosion	1996	500	11	23	0.4783	239.1304	233.5683	2875.4783	0.0812	0.8
73	Corrosion	1996	557	11	23	0.4783	266.3913	260.8291	2875.4783	0.0907	0.9
74	Corrosion	1996	589	11	23	0.4783	281.6957	276.1335	2875.4783	0.0960	1.0
75	Production Error	1996	205	11	23	0.4783	98.0435	92.4813	2875.4783	0.0322	0.3
76	Sabotage	1996	436	11	23	0.4783	208.5217	202.9596	2875.4783	0.0706	0.7
77	Production Error	1996	105	11	23	0.4783	50.2174	44.6552	2875.4783	0.0155	0.2
78	Corrosion	1996	533	11	23	0.4783	254.9130	249.3509	2875.4783	0.0867	0.9
79	Production Error	1996	201	11	23	0.4783	96.1304	90.5683	2875.4783	0.0315	0.3
80	Production Error	1996	163	11	23	0.4783	77.9565	72.3944	2875.4783	0.0252	0.3
81	Other	1997	207	12	23	0.5217	108.0000	102.4378	2875.4783	0.0356	0.4
82	Sabotage	1997	100	12	23	0.5217	52.1739	46.6117	2875.4783	0.0162	0.2
83	Sabotage	1997	179	12	23	0.5217	93.3913	87.8291	2875.4783	0.0305	0.3
84	Sabotage	1997	1079	12	23	0.5217	562.9565	557.3944	2875.4783	0.1938	1.9
85	Sabotage	1997	2000	12	23	0.5217	1043.4783	1037.9161	2875.4783	0.3610	3.6
86	Corrosion	1997	380	12	23	0.5217	198.2609	192.6987	2875.4783	0.0670	0.7
87	Corrosion	1997	250	12	23	0.5217	130.4348	124.8726	2875.4783	0.0434	0.4
88	Sabotage	1998	507	13	23	0.5652	286.5652	281.0030	2875.4783	0.0977	1.0
89	Sabotage	1998	108	13	23	0.5652	61.0435	55.4813	2875.4783	0.0193	0.2
90	Sabotage	1998	358	13	23	0.5652	202.3478	196.7857	2875.4783	0.0684	0.7

SNO.	CAUSE	YEAR	QUANT	STAGE 1: NORMALISATION			NORM(YXQ)	STAGE 2: NORMALISATION			TOXUNIT
				STD1	STD2	STDYEAR		NORM1	NORM2	TOXNORM	
91	Corrosion	1998	379	13	23	0.5652	214.2174	208.6552	2875.4783	0.0726	0.7
92	Corrosion	1998	1505	13	23	0.5652	850.6522	845.0900	2875.4783	0.2939	2.9
93	Corrosion	1998	785	13	23	0.5652	443.6957	438.1335	2875.4783	0.1524	1.5
94	Sabotage	1998	109	13	23	0.5652	61.6087	56.0465	2875.4783	0.0195	0.2
95	Sabotage	1998	408	13	23	0.5652	230.6087	225.0465	2875.4783	0.0783	0.8
96	Sabotage	1999	184	14	23	0.6087	112.0000	106.4378	2875.4783	0.0370	0.4
97	Sabotage	1999	259	14	23	0.6087	157.6522	152.0900	2875.4783	0.0529	0.5
98	Sabotage	1999	468	14	23	0.6087	284.8696	279.3074	2875.4783	0.0971	1.0
99	Corrosion	1999	125	14	23	0.6087	76.0870	70.5248	2875.4783	0.0245	0.2
100	Sabotage	1999	374	14	23	0.6087	227.6522	222.0900	2875.4783	0.0772	0.8
101	Sabotage	1999	807	14	23	0.6087	491.2174	485.6552	2875.4783	0.1689	1.7
102	Sabotage	1999	1000	14	23	0.6087	608.6957	603.1335	2875.4783	0.2098	2.1
103	Production Error	1999	231	14	23	0.6087	140.6087	135.0465	2875.4783	0.0470	0.5
104	Sabotage	2000	558	15	23	0.6522	363.9130	358.3509	2875.4783	0.1246	1.2
105	Other	2000	117	15	23	0.6522	76.3043	70.7422	2875.4783	0.0246	0.2
106	Other	2000	400	15	23	0.6522	260.8696	255.3074	2875.4783	0.0888	0.9
107	Sabotage	2000	500	15	23	0.6522	326.0870	320.5248	2875.4783	0.1115	1.1
108	Sabotage	2000	200	15	23	0.6522	130.4348	124.8726	2875.4783	0.0434	0.4
109	Corrosion	2000	625	15	23	0.6522	407.6087	402.0465	2875.4783	0.1398	1.4
110	Sabotage	2000	285	15	23	0.6522	185.8696	180.3074	2875.4783	0.0627	0.6
111	Sabotage	2001	100	16	23	0.6957	69.5652	64.0030	2875.4783	0.0223	0.2
112	Production Error	2001	100	16	23	0.6957	69.5652	64.0030	2875.4783	0.0223	0.2
113	Production Error	2001	258	16	23	0.6957	179.4783	173.9161	2875.4783	0.0605	0.6
114	Production Error	2001	260	16	23	0.6957	180.8696	175.3074	2875.4783	0.0610	0.6

SNO.	CAUSE	YEAR	QUANT	STAGE 1: NORMALISATION			NORM(YXQ)	STAGE 2: NORMALISATION			TOXUNIT
				STD1	STD2	STDYEAR		NORM1	NORM2	TOXNORM	
115	Corrosion	2001	1000	16	23	0.6957	695.6522	690.0900	2875.4783	0.2400	2.4
116	Corrosion	2001	200	16	23	0.6957	139.1304	133.5683	2875.4783	0.0465	0.5
117	Sabotage	2001	320	16	23	0.6957	222.6087	217.0465	2875.4783	0.0755	0.8
118	Corrosion	2001	117	16	23	0.6957	81.3913	75.8291	2875.4783	0.0264	0.3
119	Sabotage	2002	1069	17	23	0.7391	790.1304	784.5683	2875.4783	0.2728	2.7
120	Sabotage	2002	3500	17	23	0.7391	2586.9565	2581.3944	2875.4783	0.8977	9.0
121	Production Error	2002	346	17	23	0.7391	255.7391	250.1770	2875.4783	0.0870	0.9
122	Sabotage	2002	230	17	23	0.7391	170.0000	164.4378	2875.4783	0.0572	0.6
123	Sabotage	2002	122	17	23	0.7391	90.1739	84.6117	2875.4783	0.0294	0.3
124	Corrosion	2002	276	17	23	0.7391	204.0000	198.4378	2875.4783	0.0690	0.7
125	Production Error	2002	304	17	23	0.7391	224.6957	219.1335	2875.4783	0.0762	0.8
126	Sabotage	2003	500	18	23	0.7826	391.3043	385.7422	2875.4783	0.1341	1.3
127	Ytd	2003	150	18	23	0.7826	117.3913	111.8291	2875.4783	0.0389	0.4
128	Sabotage	2003	915	18	23	0.7826	716.0870	710.5248	2875.4783	0.2471	2.5
129	Sabotage	2004	1078	19	23	0.8261	890.5217	884.9596	2875.4783	0.3078	3.1
130	Sabotage	2004	2573	19	23	0.8261	2125.5217	2119.9596	2875.4783	0.7373	7.4
131	Ytd	2004	252	19	23	0.8261	208.1739	202.6117	2875.4783	0.0705	0.7
132	Production Error	2004	221	19	23	0.8261	182.5652	177.0030	2875.4783	0.0616	0.6
133	Sabotage	2004	318	19	23	0.8261	262.6957	257.1335	2875.4783	0.0894	0.9
134	Sabotage	2005	1593	20	23	0.8696	1385.2174	1379.6552	2875.4783	0.4798	4.8
135	Sabotage	2005	100	20	23	0.8696	86.9565	81.3944	2875.4783	0.0283	0.3
136	Sabotage	2005	212	20	23	0.8696	184.3478	178.7857	2875.4783	0.0622	0.6
137	Sabotage	2005	241	20	23	0.8696	209.5652	204.0030	2875.4783	0.0709	0.7
138	Sabotage	2005	107	20	23	0.8696	93.0435	87.4813	2875.4783	0.0304	0.3

SNO.	CAUSE	YEAR	QUANT	STAGE 1: NORMALISATION			NORM(YXQ)	STAGE 2: NORMALISATION			TOXUNIT
				STD1	STD2	STDYEAR		NORM1	NORM2	TOXNORM	
139	Sabotage	2005	214	20	23	0.8696	186.0870	180.5248	2875.4783	0.0628	0.6
140	Ytd	2005	121	20	23	0.8696	105.2174	99.6552	2875.4783	0.0347	0.3
141	Sabotage	2005	307	20	23	0.8696	266.9565	261.3944	2875.4783	0.0909	0.9
142	Sabotage	2005	515	20	23	0.8696	447.8261	442.2639	2875.4783	0.1538	1.5
143	Sabotage	2005	521	20	23	0.8696	453.0435	447.4813	2875.4783	0.1556	1.6
144	Sabotage	2006	1213	21	23	0.9130	1107.5217	1101.9596	2875.4783	0.3832	3.8
145	Sabotage	2006	1012	21	23	0.9130	924.0000	918.4378	2875.4783	0.3194	3.2
146	Sabotage	2006	514	21	23	0.9130	469.3043	463.7422	2875.4783	0.1613	1.6
147	Sabotage	2006	602	21	23	0.9130	549.6522	544.0900	2875.4783	0.1892	1.9
148	Corrosion	2006	119	21	23	0.9130	108.6522	103.0900	2875.4783	0.0359	0.4
149	Sabotage	2006	126	21	23	0.9130	115.0435	109.4813	2875.4783	0.0381	0.4
150	Sabotage	2006	203	21	23	0.9130	185.3478	179.7857	2875.4783	0.0625	0.6
151	Sabotage	2006	141	21	23	0.9130	128.7391	123.1770	2875.4783	0.0428	0.4
152	Sabotage	2006	2213	21	23	0.9130	2020.5652	2015.0030	2875.4783	0.7008	7.0
153	Sabotage	2006	210	21	23	0.9130	191.7391	186.1770	2875.4783	0.0647	0.6
154	Production Error	2006	700	21	23	0.9130	639.1304	633.5683	2875.4783	0.2203	2.2
155	Sabotage	2006	150	21	23	0.9130	136.9565	131.3944	2875.4783	0.0457	0.5
156	Sabotage	2006	1042	21	23	0.9130	951.3913	945.8291	2875.4783	0.3289	3.3
157	Sabotage	2006	167	21	23	0.9130	152.4783	146.9161	2875.4783	0.0511	0.5
158	Sabotage	2006	1734	21	23	0.9130	1583.2174	1577.6552	2875.4783	0.5487	5.5
159	Sabotage	2006	1215	21	23	0.9130	1109.3478	1103.7857	2875.4783	0.3839	3.8
160	Sabotage	2006	155	21	23	0.9130	141.5217	135.9596	2875.4783	0.0473	0.5
161	Corrosion	2006	352	21	23	0.9130	321.3913	315.8291	2875.4783	0.1098	1.1
162	Sabotage	2006	180	21	23	0.9130	164.3478	158.7857	2875.4783	0.0552	0.6

SNO.	CAUSE	YEAR	QUANT	STAGE 1: NORMALISATION			NORM(YXQ)	STAGE 2: NORMALISATION			TOXUNIT
				STD1	STD2	STDYEAR		NORM1	NORM2	TOXNORM	
163	Sabotage	2006	521	21	23	0.9130	475.6957	470.1335	2875.4783	0.1635	1.6
164	Sabotage	2006	284	21	23	0.9130	259.3043	253.7422	2875.4783	0.0882	0.9
165	Sabotage	2007	514	22	23	0.9565	491.6522	486.0900	2875.4783	0.1690	1.7
166	Sabotage	2007	813	22	23	0.9565	777.6522	772.0900	2875.4783	0.2685	2.7
167	Sabotage	2007	201	22	23	0.9565	192.2609	186.6987	2875.4783	0.0649	0.6
168	Production Error	2007	200	22	23	0.9565	191.3043	185.7422	2875.4783	0.0646	0.6
169	Sabotage	2007	1320	22	23	0.9565	1262.6087	1257.0465	2875.4783	0.4372	4.4
170	Sabotage	2007	204	22	23	0.9565	195.1304	189.5683	2875.4783	0.0659	0.7
171	Sabotage	2007	2000	22	23	0.9565	1913.0435	1907.4813	2875.4783	0.6634	6.6
172	Sabotage	2007	2451	22	23	0.9565	2344.4348	2338.8726	2875.4783	0.8134	8.1
173	Sabotage	2007	116	22	23	0.9565	110.9565	105.3944	2875.4783	0.0367	0.4
174	Sabotage	2007	213	22	23	0.9565	203.7391	198.1770	2875.4783	0.0689	0.7
175	Sabotage	2007	242	22	23	0.9565	231.4783	225.9161	2875.4783	0.0786	0.8
176	Sabotage	2007	201	22	23	0.9565	192.2609	186.6987	2875.4783	0.0649	0.6
177	Sabotage	2007	211	22	23	0.9565	201.8261	196.2639	2875.4783	0.0683	0.7
178	Sabotage	2007	351	22	23	0.9565	335.7391	330.1770	2875.4783	0.1148	1.1
179	Sabotage	2007	135	22	23	0.9565	129.1304	123.5683	2875.4783	0.0430	0.4
180	Sabotage	2007	214	22	23	0.9565	204.6957	199.1335	2875.4783	0.0693	0.7
181	Sabotage	2007	100	22	23	0.9565	95.6522	90.0900	2875.4783	0.0313	0.3
182	Sabotage	2007	2064	22	23	0.9565	1974.2609	1968.6987	2875.4783	0.6847	6.8
183	Sabotage	2007	629	22	23	0.9565	601.6522	596.0900	2875.4783	0.2073	2.1
184	Corrosion	2007	101	22	23	0.9565	96.6087	91.0465	2875.4783	0.0317	0.3
185	Corrosion	2007	608	22	23	0.9565	581.5652	576.0030	2875.4783	0.2003	2.0
186	Sabotage	2007	100	22	23	0.9565	95.6522	90.0900	2875.4783	0.0313	0.3

SNO.	CAUSE	YEAR	QUANT	STAGE 1: NORMALISATION			NORM(YXQ)	STAGE 2: NORMALISATION			TOXUNIT
				STD1	STD2	STDYEAR		NORM1	NORM2	TOXNORM	
187	Sabotage	2007	100	22	23	0.9565	95.6522	90.0900	2875.4783	0.0313	0.3
188	Sabotage	2007	720	22	23	0.9565	688.6957	683.1335	2875.4783	0.2376	2.4
189	Sabotage	2007	375	22	23	0.9565	358.6957	353.1335	2875.4783	0.1228	1.2
190	Sabotage	2007	801	22	23	0.9565	766.1739	760.6117	2875.4783	0.2645	2.6
191	Sabotage	2007	3012	22	23	0.9565	2881.0435	2875.4813	2875.4783	1.0000	10.0
192	Corrosion	2008	202	23	23	1.0000	202.0000	196.4378	2875.4783	0.0683	0.7
193	Corrosion	2008	116	23	23	1.0000	116.0000	110.4378	2875.4783	0.0384	0.4
194	Corrosion	2008	1200	23	23	1.0000	1200.0000	1194.4378	2875.4783	0.4154	4.2
195	Sabotage	2008	1023	23	23	1.0000	1023.0000	1017.4378	2875.4783	0.3538	3.5
196	Sabotage	2008	512	23	23	1.0000	512.0000	506.4378	2875.4783	0.1761	1.8
197	Sabotage	2008	504	23	23	1.0000	504.0000	498.4378	2875.4783	0.1733	1.7
198	Corrosion	2008	120	23	23	1.0000	120.0000	114.4378	2875.4783	0.0398	0.4
199	Other	2008	196	23	23	1.0000	196.0000	190.4378	2875.4783	0.0662	0.7
200	Sabotage	2008	412	23	23	1.0000	412.0000	406.4378	2875.4783	0.1413	1.4
201	Production Error	2008	532	23	23	1.0000	532.0000	526.4378	2875.4783	0.1831	1.8
202	Sabotage	2008	120	23	23	1.0000	120.0000	114.4378	2875.4783	0.0398	0.4

Appendix E: Registry of High Consequence Settlements (Database).

SNO.	NAME	LOCAL GOVT.	POP	MALES	FEMALES	0_14 Years	Approx. no. Household
1	ABABOKMO	BRASS	2567	1158.49	1408.51	942.09	320.88
2	ABABOKO	BRASS	675	304.63	370.37	247.73	84.38
3	ABALAKIRI	DEGEMA	3933	1774.96	2158.04	1443.41	491.63
4	ABALAMA	ASARI-TORU	11164	5038.31	6125.69	4097.19	1395.50
5	ABELKIRI	DEGEMA	2144	967.59	1176.41	786.85	268.00
6	ABOKIRI	ABUA/ODUAL	616	278.00	338.00	226.07	77.00
7	ABOLIKIRI	BRASS	1650	744.65	905.36	605.55	206.25
8	ABOLOKIRI	BRASS	3524	1590.38	1933.62	1293.31	440.50
9	ABONNEMA	DEGEMA	58791	26532.38	32258.62	21576.30	7348.88
10	ABONNEMA	DEGEMA	58791	26532.38	32258.62	21576.30	7348.88
11	ABUKIRI	BRASS	560	252.73	307.27	205.52	70.00
12	AFIKINSARI	AKUKU-TORU	1584	714.86	869.14	581.33	198.00
13	AFIKINSARI	AKUKU-TORU	1584	714.86	869.14	581.33	198.00
14	AGBAGBAKIRI	AKUKU-TORU	967	436.41	530.59	354.89	120.88
15	AGBARAKIRI-2	AKUKU-TORU	1362	614.67	747.33	499.85	170.25
16	AKASA	DEGEMA	7757	3500.73	4256.27	2846.82	969.63
17	AKASA	DEGEMA	7757	3500.73	4256.27	2846.82	969.63
18	AKIDY-AMA	DEGEMA	20962	9460.15	11501.85	7693.05	2620.25
19	AKOKOKIRI	ABUA/ODUAL	3421	1543.90	1877.10	1255.51	427.63
20	AKUKUAMA	DEGEMA	2669	1204.52	1464.48	979.52	333.63
21	ALISONKIRI	DEGEMA	616	278.00	338.00	226.07	77.00
22	AMANGA	DEGEMA	4614	2082.30	2531.70	1693.34	576.75
23	AMANGALAKIRI	DEGEMA	916	413.39	502.61	336.17	114.50
24	AMASUON	DEGEMA	2809	1267.70	1541.30	1030.90	351.13
25	AMBIEAME	DEGEMA	3028	1366.54	1661.46	1111.28	378.50
26	ANANGOLO	DEGEMA	4232	1909.90	2322.10	1553.14	529.00
27	ANGULAMA	ASARI-TORU	6497	2932.10	3564.90	2384.40	812.13
28	ANGULAMA	ASARI-TORU	6497	2932.10	3564.90	2384.40	812.13
29	ANU SETTLEMENT	ABUA/ODUAL	6844	3088.70	3755.30	2511.75	855.50
30	ASOBELEMA	DEGEMA	8994	4058.99	4935.01	3300.80	1124.25
31	ASUMEBUAMA	OKRIKA	649	292.89	356.11	238.18	81.13
32	ATUKA	EMUOHA	13413	6053.29	7359.71	4922.57	1676.63
33	ATUKAPERIWINKLE	EMUOHA	1639	739.68	899.32	601.51	204.88
34	AWOBA	DEGEMA	1273	574.50	698.50	467.19	159.13
35	BAKANA	PORTHARCOURT	27675	12489.73	15185.27	10156.73	3459.38
36	BANKIRI	DEGEMA	2186	986.54	1199.46	802.26	273.25
37	BEKINKIRI	DEGEMA	801	361.49	439.51	293.97	100.13
38	BEKIRIKIRI	DEGEMA	4089	1845.37	2243.63	1500.66	511.13
39	BIANU	ABUA/ODUAL	801	361.00	440.00	294.00	100.13
40	BIKKIRI	BRASS	1086	490.11	595.89	398.56	135.75
41	BILLE	DEGAMA	6285	2836.00	3449.00	2307.00	785.63

SNO.	NAME	LOCAL GOVT.	POP	MALES	FEMALES	0_14 Years	Approx. no. Household
42	BITEKIRI	DEGEMA	8217	3708.33	4508.67	3015.64	1027.13
43	BOKOBOKIRI	DEGEMA	5716	2579.63	3136.37	2097.77	714.50
44	BRICKFIELD	ASARI-TORU	3342	1508.24	1833.76	1226.51	417.75
45	BUGUMA	ASARI-TORU	8846	3992.20	4853.80	3246.48	1105.75
46	BUGUMA CREEK	DEGEMA	1350	609.26	740.75	495.45	168.75
47	BUKUMA	DEGEMA	9161	4134.36	5026.64	3362.09	1145.13
48	BUSH BAKANA	PORTHARCOURT	926	417.90	508.10	339.84	115.75
49	CANON	ASARI-TORU	513	231.52	281.48	188.27	64.13
50	DABARA	DEGEMA	1636	738.33	897.67	600.41	204.50
51	DAOJUKIRI/ABABO	BRASS	9775	4411.46	5363.54	3587.43	1221.88
52	DAWARI	DEGEMA	1519	685.52	833.48	557.47	189.88
53	DEGEMA	DEGEMA	21608	9751.69	11856.31	7930.14	2701.00
54	DEGEMA HULK	DEGEMA	21608	9751.69	11856.31	7930.14	2701.00
55	DEGEMATOWN	DEGEMA	27675	12489.73	15185.27	10156.73	3459.38
56	DERIFAKA	DEGEMA	1612	727.50	884.50	591.60	201.50
57	DIEPREYE	DEGEMA	938	423.32	514.68	344.25	117.25
58	DIMINABOKIRI	ASARI-TORU	2142	966.68	1175.32	786.11	267.75
59	EBU	DEGEMA	938	423.00	515.00	344.00	117.25
60	EBUYEDOKUBOKIRI	DEGEMA	2652	1196.85	1455.15	973.28	331.50
61	EDDYKIRI	DEGEMA	1096	494.62	601.38	402.23	137.00
62	EFEBIRI	ABUA/ODUAL	632	285.00	347.00	232.00	79.00
63	EFEREBOKIRI	ASARI-TORU	300	135.39	164.61	110.10	37.50
64	EKEME	DEGEMA	1654	746.45	907.55	607.02	206.75
65	EKULAMA	AKUKU-TORU	2727	1230.70	1496.30	1000.81	340.88
66	EKULAMA	AKUKU-TORU	2727	1230.70	1496.30	1000.81	340.88
67	EKWALEMA	AKUKU-TORU	438	198.00	240.00	161.00	54.75
68	ELEM KALABARI	DEGEMA	904	408.00	496.00	332.00	113.00
69	ELEM-BEKI	DEGEMA	1623	732.46	890.54	595.64	202.88
70	ELEM-KALABARI	DEGEMA	1328	599.33	728.67	487.38	166.00
71	ELEM-KRAKAMA	DEGEMA	632	285.22	346.78	231.94	79.00
72	ELEM-KRAKAMA	DEGEMA	632	285.22	346.78	231.94	79.00
73	ELOGH	ABUA/ODUAL	308	139.00	169.00	113.04	38.50
74	ELUGBE	DEGEMA	1724	778.04	945.96	632.71	215.50
75	ELUKU	ABUA/ODUAL	7837	3536.84	4300.16	2876.18	979.63
76	EMUAMA	BRASS	922	416.10	505.90	338.37	115.25
77	EPAIA	ABUA/ODUAL	1818	820.46	997.54	667.21	227.25
78	EREKWEREKA	DEGEMA	1301	587.14	713.86	477.47	162.63
79	EREMAOGBOGORO	OBIO-AKPOR	13111	5916.99	7194.01	4811.74	1638.88
80	ERISEKIRI	AKUKU-TORU	727	328.10	398.90	266.81	90.88
81	ETAM KALBAN	DEGEMA	1270	573.15	696.85	466.09	158.75
82	ETEBIRI	ABUA/ODUAL	3807	1718.10	2088.90	1397.17	475.88
83	ETIBILIGBOLOGBO	DEGEMA	420	189.55	230.45	154.14	52.50

SNO.	NAME	LOCAL GOVT.	POP	MALES	FEMALES	0_14 Years	Approx. no. Household
84	ETUBO	DEGEMA	1593	718.92	874.08	584.63	199.13
85	ETUKUKIRI	BRASS	904	407.98	496.02	331.77	113.00
86	EWON	ABUA/ODUAL	2548	1149.91	1398.09	935.12	318.50
87	FESTUSKIRI	BRASS	840	379.09	460.91	308.28	105.00
88	FREDKIRI	DEGEMA	8023	3620.78	4402.22	2944.44	1002.88
89	GALILEE	DEGEMA	4898	2210.47	2687.53	1797.57	612.25
90	GBOLAME	DEGEMA	2598	1172.48	1425.52	953.47	324.75
91	GOGOBOKIRI	DEGEMA	2019	911.17	1107.83	740.97	252.38
92	GOGOKIRI	DEGEMA	1672	754.57	917.43	613.62	209.00
93	GOLDCOAST	AKUKU-TORU	381	171.95	209.05	139.83	47.63
94	GOLDCOAST	AKUKU-TORU	381	171.95	209.05	139.83	47.63
95	HARRISONKIRI	DEGEMA	1544	696.81	847.19	566.65	193.00
96	HARRYS TOWN	EMUOHA	1239	559.16	679.84	454.71	154.88
97	HARRYSONKIRI	DEGEMA	381	172.00	209.00	140.00	47.63
98	IBIMABOKO	DEGEMA	3805	1717.20	2087.80	1396.44	475.63
99	IBUDOKUBOKIRI	DEGEMA	906	408.88	497.12	332.50	113.25
100	IDAMA	AKUKU-TORU	1249	563.67	685.33	458.38	156.13
101	IDAMA	AKUKU-TORU	1249	563.67	685.33	458.38	156.13
102	IDO	ASARI-TORU	651	293.80	357.20	238.92	81.38
103	IGHOM	ABUA/ODUAL	1587	716.21	870.79	582.43	198.38
104	IJAWKIRI	BRASS	1376	620.99	755.01	504.99	172.00
105	IKOT INYANG NUNG ITA	AKUKU-TORU	729	329.00	400.00	268.00	91.13
106	IKUKIRI	OBIO/AKPOR	542	244.60	297.40	198.91	67.75
107	ILELEMA	EMUOHA	716	323.13	392.87	262.77	89.50
108	IMEPELEHOKE	DEGEMA	1279	577.21	701.79	469.39	159.88
109	IMOKOBO	AKUKU-TORU	1989	897.64	1091.36	729.96	248.63
110	IMOPELEYEKIRI	DEGEMA	10773	4861.85	5911.15	3953.69	1346.63
111	ISAKA	PORTHARCOURT	3733	1684.70	2048.30	1370.01	466.63
112	ISAMGBOKIRI	OBIO-AKPO	9294	4194.38	5099.62	3410.90	1161.75
113	ISEREKIRI	BRASS	967	436.41	530.59	354.89	120.88
114	IWAFEAMAKGKIRI	OBOI/AKPOR	11672	5267.57	6404.43	4283.62	1459.00
115	IWAKIRI	DEGEMA	1282	578.57	703.43	470.49	160.25
116	IWOAMA	ASARI-TORU	9043	4081.11	4961.89	3318.78	1130.38
117	IYAKI	ABUA/ODUAL	2166	977.52	1188.48	794.92	270.75
118	JAMESKIRI	ASARI-TORU	719	324.48	394.52	263.87	89.88
119	JOJOKIRI	AKUKU-TORU	635	286.58	348.42	233.05	79.38
120	JOMYCAMP	ABUA/ODUAL	3031	1367.89	1663.11	1112.38	378.88
121	KALA KRAKRAMA	ASARI-TORU	755	340.73	414.27	277.09	94.38
122	KALA ONON	AKUKU-TORU	2374	1071.39	1302.61	871.26	296.75
123	KALA TUMA	DEGEMA	1360	613.77	746.23	499.12	170.00
124	KALABARISETTLEMENT	ASARI-TORU	6026	2719.53	3306.47	2211.54	753.25
125	KALADEGEMA	DEGEMA	1112	501.85	610.15	408.10	139.00

SNO.	NAME	LOCAL GOVT.	POP	MALES	FEMALES	0_14 Years	Approx. no. Household
126	KALAMA	ASARI-TORU	724	326.74	397.26	265.71	90.50
127	KEBOKO	AKUKU-TORU	1153	520.35	632.65	423.15	144.13
128	KEBOKO	AKUKU-TORU	1153	520.35	632.65	423.15	144.13
129	KENNYKIRI	EMUOHA	815	367.81	447.19	299.11	101.88
130	KIBIRI	DEGEMA	1573	709.89	863.11	577.29	196.63
131	KILLYKIRI	DEGEMA	1043	470.71	572.29	382.78	130.38
132	KRAKAMA	ABUA/ODUAL	1474	665.22	808.78	540.96	184.25
133	KRAKAMA	ABUA/ODUAL	1474	665.22	808.78	540.96	184.25
134	KRAKRAMA	DEGEMA	1324	597.52	726.48	485.91	165.50
135	KRIKAMA	DEGEMA	747	337.12	409.88	274.15	93.38
136	KUGBOCREE	BRASS	1220	550.59	669.41	447.74	152.50
137	KULA EKWEBUKO	DEGEMA	11549	5212.06	6336.94	4238.48	1443.63
138	KUMBULUBOKO II	DEGEMA	1248	563.22	684.78	458.02	156.00
139	KUMULUBOKOIII	DEGEMA	1603	723.43	879.57	588.30	200.38
140	LEKEMABOKO	DEGEMA	1614	728.40	885.60	592.34	201.75
141	MACJAJAKIRI	ASARI-TORU	11061	4991.83	6069.17	4059.39	1382.63
142	MBEEKIRI	OBOI/AKPOR	2268	1023.55	1244.45	832.36	283.50
143	MICHEALKIRI	AKUKU-TORU	1413	637.69	775.31	518.57	176.63
144	MONEY KIRI	DEGEMA	938	423.32	514.68	344.25	117.25
145	MUOJOKIRI	ASARI-TORU	312	140.81	171.19	114.50	39.00
146	NDUKIRI	BRASS	665	300.11	364.89	244.06	83.13
147	NEVALBASE	PORTHARCOURT	719	324.00	395.00	264.00	89.88
148	NGBAE	DEGEMA	1580	713.05	866.95	579.86	197.50
149	NKPOLUOROWORU	OBOI/AKPOR	5712	2577.83	3134.17	2096.30	714.00
150	NOJUAMA	DEGEMA	764	344.79	419.21	280.39	95.50
151	NTUISANGHA	DEGEMA	2155	972.55	1182.45	790.89	269.38
152	NUMBER1CAMP	ABUA/ODUAL	607	273.94	333.06	222.77	75.88
153	NUMBER2CAMP	ABUA/ODUAL	1778	802.41	975.59	652.53	222.25
154	OBENIBOKIRI	DEGEMA	2085	940.96	1144.04	765.20	260.63
155	OBOKOFINA	BRASS	1613	727.95	885.05	591.97	201.63
156	OBONOMA	ASARI-TORU	4039	1822.80	2216.20	1482.31	504.88
157	OBUAMA	EMUOHA	15048	6791.16	8256.84	5522.62	1881.00
158	OBUAMA	EMUOHA	15048	6791.16	8256.84	5522.62	1881.00
159	OBUKURU	OBIO/AKPOR	4289	1935.63	2353.37	1574.06	536.13
160	ODIGBO	AKUKU-TORU	1098	495.53	602.47	402.97	137.25
161	ODIGBO	AKUKU-TORU	1098	495.53	602.47	402.97	137.25
162	ODOANI	BRASS	2008	906.21	1101.79	736.94	251.00
163	ODOANI	BRASS	2008	906.21	1101.79	736.94	251.00
164	ODOROGU	PORTHARCOURT	729	329.00	400.00	268.00	91.13
165	ODOROGU	PORTHARCOURT	8636	3897.43	4738.57	3169.41	1079.50
166	ODUWIRI	ABUA/ODUAL	3324	1500.12	1823.88	1219.91	415.50
167	OGAJI-AMA	DEGEMA	988	446.00	542.00	363.00	123.50

SNO.	NAME	LOCAL GOVT.	POP	MALES	FEMALES	0_14 Years	Approx. no. Household
168	OGAJI-AMA	DEGEMA	3710	1674.32	2035.68	1361.57	463.75
169	OGBAKIRI	OBIO/AKPOR	13211	5962.12	7248.88	4848.44	1651.38
170	OGBEMA KOKU	ABUA/ODUAL	1643	741.49	901.51	602.98	205.38
171	OGBORTUBA	AKUKU-TORU	2066	932.39	1133.61	758.22	258.25
172	OGIDIKIRI	AKUKU-TORU	3743	1689.22	2053.78	1373.68	467.88
173	OGODOKIRI	AKUKU-TORU	911	411.00	500.00	334.00	113.88
174	OGOLOGOKIRI	DEGEMA	2577	1163.00	1414.00	945.76	322.13
175	OJIAMA	ASARI-TORU	316	142.61	173.39	115.97	39.50
176	OKEMINI	OBOI/AKPOR	1724	778.04	945.96	632.71	215.50
177	OKIOBOKO	DEGEMA	1958	883.65	1074.35	718.59	244.75
178	OKIRIKA	PORTHARCOURT	6055	2732.62	3322.38	2222.19	756.88
179	OKOKOBOKO	AKUKU-TORU	1352	610.16	741.84	496.18	169.00
180	OKOKOBOKO	AKUKU-TORU	1352	610.16	741.84	496.18	169.00
181	OKOROBAKO	AKUKU-TORU	1249	563.67	685.33	458.38	156.13
182	OKOROBAKO	AKUKU-TORU	1249	563.67	685.33	458.38	156.13
183	OKOROBOKO	AKUKU-TORU	2509	1132.31	1376.69	920.80	313.63
184	OKPARAKIRI	DEGEMA	6055	2732.62	3322.38	2222.19	756.88
185	OKPO	DEGEMA	2668	1204.07	1463.93	979.16	333.50
186	OKRIKOKIRI	BRASS	1770	798.80	971.20	649.59	221.25
187	OKULUTA	OBOI/AKPOR	2325	1049.27	1275.73	853.28	290.63
188	OKUNGBA	PORTHARCOURT	11424	5155.65	6268.35	4192.61	1428.00
189	OLAMO	ASARI-TORU	2891	1304.71	1586.29	1061.00	361.38
190	OLD-BAKAN	PORTHARCOURT	6285	2836.42	3448.58	2306.60	785.63
191	OLD-SANGA	BRASS	953	430.09	522.91	349.75	119.13
192	OLDSANGAMA	BRASS	5685	2565.64	3119.36	2086.40	710.63
193	OMEKUAMA	ASARI-TORU	631	284.77	346.23	231.58	78.88
194	OMUNGUKIRI	DEGEMA	2021	912.08	1108.92	741.71	252.63
195	ONONGISUO	AKUKU-TORU	2508	1131.86	1376.14	920.44	313.50
196	ONWUMA	DEGEMA	1892	853.86	1038.14	694.36	236.50
197	OPAPUNGIA	BRASS	2429	1096.21	1332.79	891.44	303.63
198	OPOMAKIRI	DEGEMA	664	299.66	364.34	243.69	83.00
199	OPU DABARA	DEGEMA	673	304.00	369.00	247.00	84.13
200	OPU-DABARA	DEGEMA	1394	629.11	764.89	511.60	174.25
201	OPU-OEGEH	DEGEMA	762	343.89	418.11	279.65	95.25
202	OPU-ONONG	AKUKU-TORU	1192	537.95	654.05	437.46	149.00
203	ORLUKIRI	EMUOHA	342	154.34	187.66	125.51	42.75
204	ORUKALAMA	ASARI-TORU	1319	595.26	723.74	484.07	164.88
205	ORUSANGAM	BRASS	26058	11759.98	14298.02	9563.29	3257.25
206	ORUSANGAMA	BRASS	632	285.00	347.00	232.00	79.00
207	OWINKIRI	DEGEMA	2210	997.37	1212.63	811.07	276.25
208	OWINKIRI KALAMA	ASARI-TORI	906	409.00	497.00	33.00	113.25
209	OWOKOKIRI	DEGEMA	2570	1159.84	1410.16	943.19	321.25

SNO.	NAME	LOCAL GOVT.	POP	MALES	FEMALES	0_14 Years	Approx. no. Household
210	OWUPOKOPU	DEGEMA	1072	483.79	588.21	393.42	134.00
211	OWUPOKUOBO	DEGEMA	2014	908.92	1105.08	739.14	251.75
212	PANPADUA	DEGEMA	1580	713.05	866.95	579.86	197.50
213	PEKOKIRI	BRASS	922	416.10	505.90	338.37	115.25
214	PROFITKIRI	AKUKU-TORU	1245	561.87	683.13	456.92	155.63
215	RUSSIA	AKUKU-TORU	1307	589.85	717.15	479.67	163.38
216	SAMKIRI	DEGEMA	468	211.21	256.79	171.76	58.50
217	SANDVILLAGE	BRASS	3009	1357.96	1651.04	1104.30	376.13
218	SANGAMA	ASARI-TORU	909	410.23	498.77	333.60	113.63
219	SHELLKIRI	BRASS	373	168.33	204.67	136.89	46.63
220	SHELLKIRI	BRASS	373	168.33	204.67	136.89	46.63
221	SIKAKAKIRI	DEGEMA	1128	509.07	618.93	413.98	141.00
222	TEMA	ASARI-TORU	1195	539.30	655.70	438.57	149.38
223	TEMAKIRI	DEGEMA	7791	3516.08	4274.92	2859.30	973.88
224	TOMBIA	EMUOHA	22284	10056.77	12227.23	8178.23	2785.50
225	TUMA	DEGEMA	2630	1186.92	1443.08	965.21	328.75
226	U.A.C	DEGEMA	5499	2481.70	3017.30	2018.13	687.38
227	UBAHA	DEGEMA	291	131.00	160.00	107.00	36.38
228	UDAMA	DEGEMA	6673	3011.52	3661.48	2448.99	834.13
229	WAKAMA	ASARI-TORU	1316	593.91	722.09	482.97	164.50
230	WILLIAMKIRI	DEGEMA	6317	2850.86	3466.14	2318.34	789.63
231	YAE	DEGEMA	967	436.41	530.59	354.89	120.88

Appendix F: General Recommendations for Returning Ogoniland to Pristine State (UNEP, 2011).

	Recommendation	Strategies	Remark
1	**Operational**		
	a) Maintenance of oilfield facilities	-Review assets and develop "Asset Integrity Management Plan." -Communicate plan to Ogoni people.	✓
	b) Decommissioning of oilfield facilities	-Decommission facilities no longer in use. -Communicate to the people.	
	c) Prevention of illegal activities	-Stakeholders campaign against bunkering and vandalising of oil facilities. -Introduce incentive to discourage public participation in the above.	✓
	d) Oil spill response	- Repose to spills within shortest possible time. -Create awareness on environmental consequences of delay. -Organise periodic drill exercise to ensure rapid oil spill response. -Communicate result to the people. -integrate people in spill response by providing training and assign roles to them.	✓
	d) On-going remediation of contaminated sites	-Discontinue remediation by enhances natural attenuation (RENA). -Heavily contaminated soil be excavated for treatment and disposal.	x
2	**Environmental restoration**		
	a) Clean-up of contaminated soil and sediments	- Clean-up should be on site-by-site risk assessment in consultation with communities and regulators. -Design different approach to suit particular hydrocarbons.	x
	b) Decontamination of Groundwater	-Use site-specific clean-up technology.	x
	c) Rehabilitation of mangroves	-End artisanal refining and commence rehabilitation. -Review state of degradation of various sections and prioritise areas for intervention. -Control and manage alien invasive species prior to intervention.	x
3	**Public health**		

	Recommendation	Strategies	Remark
	a) Communities exposed to petroleum hydrocarbons in their drinking water	-Identify exposed households and provided alternative source of safe clean water. -Government to identify polluted wells and provide medical care to exposed households. -Monitor wells until hydrocarbon contamination is eliminated. -Maintain database of households already exposed to hydrocarbon-contaminated water. -Conduct comprehensive and regular medical examination to track their health during their lifetime.	✓
	b) Communities living on rights of way	-Relocate people living on ROW. -Provide alternative location for housing.	✓
	c) People involved in bunkering and artisanal refining	- Organise Awareness campaign against such activities by showing long-term health consequences. -Create alternative employment opportunities for individual and broader community.	✓
4	**Follow-up monitoring**		
		Objectives are: 1) Monitor on-going pollution in all environmental segments. 2) Track health impact of communities exposed over many years. 3) Track clean-up progress and provide supportive documentation.	✓
	a) Preventive surveillance	-Organise weekly aerial surveillance to identify new incidents or illegal activities. -Organise weekly surveillance by boat to check the creeks for signs of on-going pollution or spill incidents. -Organise weekly inspection of oil installations and contaminated sites, to identify signs of new spills or encroachment on ROW and progress with remediation. -Preventive surveillance to be conducted in collaboration with industry reps, environmental agencies and local community reps. -Make information and report available to stakeholders including the communities.	✓
	b) Monitoring of groundwater	- Monthly Investigation of wells for hydrocarbon pollution in all communities and identify source. - Monitor contaminated sites monthly and provide early warnings of migration to groundwater.	✓

	Recommendation	Strategies	Remark
	c) Monitoring of water bodies, fish and aquatic sediments	-Zone and suspend areas of fishing and recreational activities if excessively polluted. -Track improvement in environmental quality as remediation is undertaken. -Monitoring of water should be done quarterly including sediments and benthic communities.	✓
	d) Monitoring of vegetation and fauna.	-Monitor vegetation recovery in the creeks and oil filed sites by transects method once a year. -Use satellite imagery to supplement field transects also once a year.	✓
	e) Air quality monitoring	-Monitor air quality and keep track of on-going pollution. -Establish guideline for protecting public health. -Track improvements at clean-up sites.	✓
	f) Public health monitoring	-Provide public health registry for tracking long term exposure to hydrocarbon pollution. -Establish cohort registry of already exposed individuals for health status assessment.	✓
5	**Changes to regulatory Framework**		
	a) Legislative matters.	-Transfer oversight of EGASPIN to the Federal Ministry of Environment and train staffs to handle EGASPIN requirement. -Make provision for social and health impact assessment an integral part of EIA relating with oil and gas projects. -Give clear guideline on remediation criteria and timeframe. -Clarify inconsistency between 'intervention value' and 'target value' -Guideline for decommissioning and environmental due diligence should be adhered to. -Establish new guideline for a) surface water quality management, b) ambient air quality, and c) mangroves and coastal vegetation. -Establish closure guideline for polluted water bodies where recreation and commercial fishery is conducted. -Establish guideline for closing down water bodies subjected to pollution but used for recreation, bathing, swimming etc.	x

	Recommendation	Strategies	Remark
		-Improve public access to non-classified information on EIAs, monitoring reports, spill reports, and remediation closure. -Increase access to environmental legislation by making them freely available on websites.	
	b) Institutional arrangement	-Institutions with conflicting or overlapping responsibilities should be straightened. -Clarify regulation and oversight on: a) water quality in the creeks, b) Set standard for the use of creeks i.e. recreation, fishing etc. c) Monitor public health d) restoration, management, and monitoring of mangroves. -Increase institutional human and material resources and technical skills of staffs in various agencies.	x
6	Follow-up	-Ensure on-going contamination from all possible sources is stopped. -Ensure individual sites do not become secondary source of on-going contamination. -Clean-up should be prioritised or run concurrently as soon as On-going pollution stops. -Priority 1. Communities already known to be at risk, treat contaminated drinking water sources, re-house families living on or adjacent contaminated oilfield facilities, well pads or ROW. -Priority 2. Where contamination could potentially affect/ impact community's groundwater, fishing grounds, or agricultural land. *Priority 3: condition where a community's livelihood support base is affected e.g. mangroves, swamps, surface water etc. *Priority 4: where there is no immediate risk to the community but there is non-compliance with the law.	x

Appendix G: Statistics

Table G1: TPC concentrations in soil for selected sites in Ogoniland (Source: UNEP Factsheet, 2011).

Site No.	Name	1st Spill	Last spill	no spills	Max. (mg/kg)	Min. mg/kg)
qc_001-004	Ebubu/Ejama/Agbeta	1989	1989	2	533	31.7
qc_008-001	Aabue-Korokoro	1986	1990	3	4370	60.7
qc_005-001	Okuluebu-Ogale	1989	1992	4	2950	160
qc_016-001	Kwawa	1992	1993	2	3070	1280
qc_015-001	Wiikayako-Kpean	1997	2001	2	4900	1830
qc_003-001	Nsioken-Akpajo	2006	2006	1	3680	674
qc_003-002	Aleto	1988	2007	2	13400	3030
qc_001-002	Obollo	1993	2008	4	15300	674

Table G2: Proportion of respondents' involvement in more than one activity.

Parameters		Pearson Chi-Square	Sig. (2-sided)	P Value	Yates	Asymp. Sig (2-sided)	Phi
Farming	Gathering	11.71	0.001	<0.001	10.44	0.001	-0.22
	Fishing	0.02	1.000		0.00	1.000	-0.01
	Hunting	2.02	0.176		1.56	0.211	-0.09
Fishing	Gathering	14.44	0.000	<0.001	13.27	0.000	0.24
	Hunting	53.04	0.000	<0.001	51.01	0.000	0.46
	Farming	0.02	1.000		0.00	1.000	-0.01
Hunting	Gathering	75.84	0.000	<0.001	72.9	0.000	0.55
	Fishing	53.04	0.000	<0.001	51.01	0.000	0.46
	Farming	2.017	0.176		1.56	0.211	-0.09
Gathering	Farming	11.71	0.001	<0.001	10.44	0.001	-0.22
	Fishing	14.44	0.000	<0.001	13.27	0.000	0.24
	Hunting	75.84	0.000	<0.001	72.9	0.000	0.55

Table G2a: Correlations between age, Protective clothing, and exposed body.

		Age	Protective Clothing	Body Exposed
Age	Pearson Correlation	1	.020	.161*
	Sig. (2-tailed)		.751	.011
	N	250	250	250
Protective Clothing	Pearson Correlation	.020	1	.258**
	Sig. (2-tailed)	.751		.000
	N	250	250	250
Body Exposed	Pearson Correlation	.161*	.258**	1
	Sig. (2-tailed)	.011	.000	
	N	250	250	250

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

Table G2b: Hunting * Gathering

Hunting * Gathering Crosstabulation

			Gathering		Total
			yes	no	
Hunting	yes	Count	163	11	174
		% within Hunting	93.7%	6.3%	100.0%
		% within Gathering	82.7%	20.8%	69.6%
		% of Total	65.2%	4.4%	69.6%
	no	Count	34	42	76
		% within Hunting	44.7%	55.3%	100.0%
		% within Gathering	17.3%	79.2%	30.4%
		% of Total	13.6%	16.8%	30.4%
Total		Count	197	53	250
		% within Hunting	78.8%	21.2%	100.0%
		% within Gathering	100.0%	100.0%	100.0%
		% of Total	78.8%	21.2%	100.0%

Hunting * Gathering Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	75.842[a]	1	.000		
Continuity Correction[b]	72.941	1	.000		
Likelihood Ratio	71.748	1	.000		
Fisher's Exact Test				.000	.000
Linear-by-Linear Association	75.539	1	.000		
N of Valid Cases	250				

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 16.11.

b. Computed only for a 2x2 table

Hunting and Gathering Symmetric Measures

		Value	Approx. Sig.
Nominal by Nominal	Phi	.551	.000
	Cramer's V	.551	.000
N of Valid Cases		250	

Table G2c: Farming * Fishing

Farming * Fishing Crosstabulation

			Fishing		Total
			yes	no	
Farming	No	Count	31	21	52
		% within Farming	59.6%	40.4%	100.0%
		% within Fishing	20.5%	21.2%	20.8%
		% of Total	12.4%	8.4%	20.8%
	Yes	Count	120	78	198
		% within Farming	60.6%	39.4%	100.0%
		% within Fishing	79.5%	78.8%	79.2%
		% of Total	48.0%	31.2%	79.2%
Total		Count	151	99	250
		% within Farming	60.4%	39.6%	100.0%
		% within Fishing	100.0%	100.0%	100.0%
		% of Total	60.4%	39.6%	100.0%

Farming * Fishing Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.017[a]	1	.897		
Continuity Correction[b]	.000	1	1.000		
Likelihood Ratio	.017	1	.897		
Fisher's Exact Test				1.000	.509
Linear-by-Linear Association	.017	1	.897		
N of Valid Cases	250				

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 20.59.
b. Computed only for a 2x2 table

Farming * Fishing Symmetric Measures

		Value	Approx. Sig.
Nominal by Nominal	Phi	-.008	.897
	Cramer's V	.008	.897
N of Valid Cases		250	

Table G2d: Farming * Hunting

Farming * Hunting Crosstabulation

			Hunting		Total
			yes	no	
Farming	No	Count	32	20	52
		% within Farming	61.5%	38.5%	100.0%
		% within Hunting	18.4%	26.3%	20.8%
		% of Total	12.8%	8.0%	20.8%
	Yes	Count	142	56	198
		% within Farming	71.7%	28.3%	100.0%
		% within Hunting	81.6%	73.7%	79.2%
		% of Total	56.8%	22.4%	79.2%
Total		Count	174	76	250
		% within Farming	69.6%	30.4%	100.0%
		% within Hunting	100.0%	100.0%	100.0%
		% of Total	69.6%	30.4%	100.0%

Farming * Hunting Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	2.017[a]	1	.156		
Continuity Correction[b]	1.564	1	.211		
Likelihood Ratio	1.955	1	.162		
Fisher's Exact Test				.176	.107
Linear-by-Linear Association	2.009	1	.156		
N of Valid Cases	250				

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 15.81.
b. Computed only for a 2x2 table

Farming * Hunting Symmetric Measures

		Value	Approx. Sig.
Nominal by Nominal	Phi	-.090	.156
	Cramer's V	.090	.156
N of Valid Cases		250	

Table G2e: **Hunting * Fishing**

Hunting * Fishing Cross tabulation

			Fishing		Total
			yes	no	
Hunting	yes	Count	131	43	174
		Expected Count	105.1	68.9	174.0
		% within Hunting	75.3%	24.7%	100.0%
		% within Fishing	86.8%	43.4%	69.6%
		% of Total	52.4%	17.2%	69.6%
		Std. Residual	2.5	-3.1	
	no	Count	20	56	76
		Expected Count	45.9	30.1	76.0
		% within Hunting	26.3%	73.7%	100.0%
		% within Fishing	13.2%	56.6%	30.4%
		% of Total	8.0%	22.4%	30.4%
		Std. Residual	-3.8	4.7	
Total		Count	151	99	250
		Expected Count	151.0	99.0	250.0
		% within Hunting	60.4%	39.6%	100.0%
		% within Fishing	100.0%	100.0%	100.0%
		% of Total	60.4%	39.6%	100.0%

Hunting * Fishing Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	53.037[a]	1	.000		
Continuity Correction[b]	51.009	1	.000		
Likelihood Ratio	53.489	1	.000		
Fisher's Exact Test				.000	.000
Linear-by-Linear Association	52.825	1	.000		
N of Valid Cases	250				

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 30.10.
b. Computed only for a 2x2 table

Hunting * Fishing Symmetric Measures

		Value	Approx. Sig.
Nominal by Nominal	Phi	.461	.000
	Cramer's V	.461	.000
N of Valid Cases		250	

Table G2f: Gathering * Fishing

Gathering * Fishing Cross tabulation

			Fishing		Total
			yes	no	
Gathering	yes	Count	131	66	197
		Expected Count	119.0	78.0	197.0
		% within Gathering	66.5%	33.5%	100.0%
		% within Fishing	86.8%	66.7%	78.8%
		% of Total	52.4%	26.4%	78.8%
		Std. Residual	1.1	-1.4	
	no	Count	20	33	53
		Expected Count	32.0	21.0	53.0
		% within Gathering	37.7%	62.3%	100.0%
		% within Fishing	13.2%	33.3%	21.2%
		% of Total	8.0%	13.2%	21.2%
		Std. Residual	-2.1	2.6	
Total		Count	151	99	250
		Expected Count	151.0	99.0	250.0
		% within Gathering	60.4%	39.6%	100.0%
		% within Fishing	100.0%	100.0%	100.0%
		% of Total	60.4%	39.6%	100.0%

Gathering * Fishing Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	14.444[a]	1	.000		
Continuity Correction[b]	13.267	1	.000		
Likelihood Ratio	14.180	1	.000		
Fisher's Exact Test				.000	.000
Linear-by-Linear Association	14.387	1	.000		
N of Valid Cases	250				

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 20.99.
b. Computed only for a 2x2 table

Gathering * Fishing Symmetric Measures

		Value	Approx. Sig.
Nominal by Nominal	Phi	.240	.000
	Cramer's V	.240	.000
N of Valid Cases		250	

Table G2g: Farming * Gathering

Farming * Gathering Crosstabulation

			Gathering		Total
			yes	no	
Farming	No	Count	32	20	52
		% within Farming	61.5%	38.5%	100.0%
		% within Gathering	16.2%	37.7%	20.8%
		% of Total	12.8%	8.0%	20.8%
	Yes	Count	165	33	198
		% within Farming	83.3%	16.7%	100.0%
		% within Gathering	83.8%	62.3%	79.2%
		% of Total	66.0%	13.2%	79.2%
Total		Count	197	53	250
		% within Farming	78.8%	21.2%	100.0%
		% within Gathering	100.0%	100.0%	100.0%
		% of Total	78.8%	21.2%	100.0%

Farming * Gathering Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	11.710[a]	1	.001		
Continuity Correction[b]	10.442	1	.001		
Likelihood Ratio	10.582	1	.001		
Fisher's Exact Test				.001	.001
Linear-by-Linear Association	11.664	1	.001		
N of Valid Cases	250				

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 11.02.
b. Computed only for a 2x2 table

Farming * Gathering Symmetric Measures

		Value	Approx. Sig.
Nominal by Nominal	Phi	-.216	.001
	Cramer's V	.216	.001
N of Valid Cases		250	

Table G3: Correlation between cause and quantity.

		Quantity	Cause
Quantity	Pearson Correlation	1	.142*
	Sig. (2-tailed)		.044
	N	201	201
Cause	Pearson Correlation	.142*	1
	Sig. (2-tailed)	.044	
	N	201	201

*. Correlation is significant at the 0.05 level (2-tailed).

Table G4: Correlation between frequency and quantity.

		Frequency	Quantity
Frequency	Pearson Correlation	1	.701**
	Sig. (2-tailed)		.000
	N	24	24
Quantity	Pearson Correlation	.701**	1
	Sig. (2-tailed)	.000	
	N	24	24

**. Correlation is significant at the 0.01 level (2-tailed).

Table G5: Body Part Exposed

		Frequency	per cent	Valid per cent	Cumulative per cent
Valid	no	14	5.6	5.6	5.6
	yes	236	94.4	94.4	100.0
	Total	250	100.0	100.0	

Table G6:Farming

		Frequency	per cent	Valid per cent	Cumulative per cent
Valid	No	52	20.8	20.8	20.8
	Yes	198	79.2	79.2	100.0
	Total	250	100.0	100.0	

Table G7: Fishing

		Frequency	Per cent	Valid per cent	Cumulative per cent
Valid	yes	151	60.4	60.4	60.4
	no	99	39.6	39.6	100.0
	Total	250	100.0	100.0	

Table G8: Hunting

		Frequency	per cent	Valid per cent	Cumulative Per cent
Valid	yes	174	69.6	69.6	69.6
	no	76	30.4	30.4	100.0
	Total	250	100.0	100.0	

Table G9: Gathering

		Frequency	Per cent	Valid Per cent	Cumulative Per cent
Valid	yes	197	78.8	78.8	78.8
	no	53	21.2	21.2	100.0
	Total	250	100.0	100.0	

Table G10: Distance

		Frequency	Per cent	Valid Per cent	Cumulative Per cent
Valid	< 1km	18	7.2	7.2	7.2
	1 -2km	59	23.6	23.6	30.8
	2 - 3km	79	31.6	31.6	62.4
	> 3km	94	37.6	37.6	100.0
	Total	250	100.0	100.0	

Table G11: Number of Days worked in a Week

		Frequency	Per cent	Valid Per cent	Cumulative Per cent
Valid	7days	39	15.6	15.6	15.6
	5days	94	37.6	37.6	53.2
	3days	21	8.4	8.4	61.6
	< 3days	96	38.4	38.4	100.0
	Total	250	100.0	100.0	

Table G12: Hours Worked a day

		Frequency	Per cent	Valid Per cent	Cumulative Per cent
Valid	< 3hrs	12	4.8	4.8	4.8
	3-4hrs	13	5.2	5.2	10.0
	4-5hrs	115	46.0	46.0	56.0
	>5hrs	110	44.0	44.0	100.0
	Total	250	100.0	100.0	

Table G13: Family Labour

		Frequency	Per cent	Valid Per cent	Cumulative Per cent
Valid	No	88	35.2	35.2	35.2
	Yes	162	64.8	64.8	100.0
	Total	250	100.0	100.0	

Table G14: Protective Clothing

		Frequency	Per cent	Valid Per cent	Cumulative Per cent
Valid	Yes	43	17.2	17.2	17.2
	No	207	82.8	82.8	100.0
	Total	250	100.0	100.0	

Table G15: Lower limb

		Frequency	Per cent	Valid Per cent	Cumulative Per cent
Valid	yes	223	89.2	89.2	89.2
	no	27	10.8	10.8	100.0
	Total	250	100.0	100.0	

Table G16: Hands elbow down

		Frequency	Per cent	Valid Per cent	Cumulative Per cent
Valid	yes	200	80.0	80.0	80.0
	no	50	20.0	20.0	100.0
	Total	250	100.0	100.0	

Table G17: Torso

		Frequency	Per cent	Valid Per cent	Cumulative Per cent
Valid	yes	238	95.2	95.2	95.2
	no	12	4.8	4.8	100.0
	Total	250	100.0	100.0	

Table G18: Intensity of labour

		Frequency	Per cent	Valid Per cent	Cumulative Per cent
Valid	Not Intensive	32	12.8	12.8	12.8
	Less Intensive	67	26.8	26.8	39.6
	Very Intensive	151	60.4	60.4	100.0
	Total	250	100.0	100.0	

Table G19: Hands, Legs and Torso area

		Frequency	Per cent	Valid Per cent	Cumulative Per cent
Valid	No	70	28.0	28.0	28.0
	Yes	180	72.0	72.0	100.0
	Total	250	100.0	100.0	

Table G20: Gender

		Frequency	per cent	Valid per cent	Cumulative per cent
Valid	Male	199	79.6	79.6	79.6
	Female	51	20.4	20.4	100.0
	Total	250	100.0	100.0	

Table G21: Age

		Frequency	per cent	Valid per cent	Cumulative per cent
Valid	16 - 22	56	22.4	22.4	22.4
	23 - 29	105	42.0	42.0	64.4
	30 - 36	47	18.8	18.8	83.2
	37 - 43	42	16.8	16.8	100.0
	Total	250	100.0	100.0	

Table G22: Pearson Correlation matrix for Toxic Units, Quantity, and Year of spills.

		Year	Quantity	Toxic Unit
Year of Spill	Pearson Correlation	1	-.027	.366**
	Sig. (2-tailed)		.706	.000
	N	202	202	202
Quantity of Spill	Pearson Correlation	-.027	1	.823**
	Sig. (2-tailed)	.706		.000
	N	202	202	202
Toxic Unit	Pearson Correlation	.366**	.823**	1
	Sig. (2-tailed)	.000	.000	
	N	202	202	202

**. Correlation is significant at the 0.01 level (2-tailed).

Appendix H: Oil Production Data

Table H1: Oil and Non-Oil contributions to government revenue 1981-2012 (Millions of Naira).

	Revenue			Percentage Revenue	
Year	Oil	Non-Oil	Total	Oil	Non-Oil
1981	8,564.40	4,726.10	13,290.50	64.4	35.6
1982	7,814.90	3,618.80	11,433.70	68.3	31.7
1983	7,253.00	3,255.70	10,508.70	69.0	31.0
1984	8,269.20	2,984.10	11,253.30	73.5	26.5
1985	10,923.70	4,126.70	15,050.40	72.6	27.4
1986	8,107.30	4,488.50	12,595.80	64.4	35.6
1987	19,027.00	6,353.60	25,380.60	75.0	25.0
1988	19,831.70	7,765.00	27,596.70	71.9	28.1
1989	39,130.50	14,739.90	53,870.40	72.6	27.4
1990	71,887.10	26,215.30	98,102.40	73.3	26.7
1991	82,666.40	18,325.20	100,991.60	81.9	18.1
1992	164,078.10	26,375.10	190,453.20	86.2	13.8
1993	162,102.40	30,667.00	192,769.40	84.1	15.9
1994	160,192.40	41,718.40	201,910.80	79.3	20.7
1995	324,547.60	135,439.70	459,987.30	70.6	29.4
1996	408,783.00	114,814.00	523,597.00	78.1	21.9
1997	416,811.10	166,000.00	582,811.10	71.5	28.5
1998	324,311.20	139,297.60	463,608.80	70.0	30.0
1999	724,422.50	224,765.40	949,187.90	76.3	23.7
2000	1,591,675.80	314,483.90	1,906,159.70	83.5	16.5
2001	1,707,562.80	903,462.30	2,611,025.10	65.4	34.6
2002	1,230,851.20	500,986.30	1,731,837.50	71.1	28.9
2003	2,074,280.60	500,815.30	2,575,095.90	80.6	19.4
2004	3,354,800.00	565,700.00	3,920,500.00	85.6	14.4
2005	4,762,400.00	785,100.00	5,547,500.00	85.8	14.2
2006	5,287,566.90	677,535.00	5,965,101.90	88.6	11.4
2007	4,462,910.00	1,200,800.00	5,663,710.00	78.8	21.2
2008	6,530,600.00	1,336,000.00	7,866,600.00	83.0	17.0
2009	3,191,900.00	1,652,700.00	4,844,600.00	65.9	34.1
2010	5,396,100.00	1,907,600.00	7,303,700.00	73.9	26.1
2011	8,879,000.00	2,237,900.00	11,116,900.00	79.9	20.1
2012	8,025,953.48	2,628,771.39	10,654,724.87	75.3	24.7
Average % contribution to government revenue				**75.6**	**24.4**

Source: (Central Bank of Nigeria, 2012)

Table H2: Crude Oil Production By Different Contract Regime from 2003-2012. (Source: Nigerian National Petroleum Corporation, 2012)

Crude Oil Production By Contract Regime (Barrels)								**Percentage (%)**					
YEAR	Barrels (Total)	Joint Ventures (JV)	JV/AF/ CARRY	Production Sharing Contract (PSC)	Service Contract Companies (SCC)	Sole Risk Independent Companies (SRIC)	Marginal Field (MF)	Joint Ventures (JV)	JV/AF/ CARRY	Production Sharing Contract (PSC)	Service Contract Companies (SCC)	Sole Risk Independent Companies (SRIC)	Marginal Field (MF)
2003	**844,150,929**	719,153,258	72,074,662	16,718,964	3,483,966	32,720,079	0	85.19	8.54	1.98	0.41	3.88	0.00
2004	**910,156,486**	722,797,515	121,973,001	24,399,567	3,886,392	37,100,014	141,028	79.41	13.40	2.68	0.43	4.08	0.02
2005	**918,660,619**	689,111,525	141,514,419	36,711,219	4,317,081	47,171,464	784,278	75.01	15.40	4.00	0.47	5.13	0.09
2006	**869,196,506**	518,184,570	144,307,081	162,532,458	4,013,954	39,374,165	431,608	59.62	16.60	18.70	0.46	4.53	0.05
2007	**803,000,708**	462,888,989	118,579,072	192,621,306	3,932,714	24,547,019	2,847,994	57.64	14.77	23.99	0.49	3.06	0.35
2008	**768,745,932**	471,900,351	70,235,646	195,127,693	3,361,078	25,273,170	3,878,439	61.39	9.14	25.38	0.44	3.29	0.50
2009	**780,347,940**	331,554,144	131,497,197	268,792,256	3,237,284	41,388,620	3,878,439	42.49	16.85	34.45	0.41	5.30	0.50
2010	**896,043,406**	364,717,172	165,986,773	316,887,117	2,711,402	41,937,495	3,803,447	40.70	18.52	35.37	0.30	4.68	0.42
2011	**866,245,232**	348,509,885	173,007,467	289,333,720	2,802,031	44,511,369	8,080,760	40.23	19.97	33.40	0.32	5.14	0.93
2012	**852,776,653**	314,740,436	150,238,893	320,434,163	3,056,412	46,245,470	18,061,279	36.91	17.62	37.58	0.36	5.42	2.12
Total (bbl)	**8,509,324,411**	**4,943,557,845**	**1,289,414,211**	**1,823,558,463**	**34,802,314**	**380,268,865**	**41,907,272**						
Average	850,932,441	494,355,785	128,941,421	182,355,846	3,480,231	38,026,887	4,190,727	57.86	15.08	21.75	0.41	4.45	0.50

Appendix I: Data Request Letters

I-1: The DPR introduction letter to Shell Petroleum Development Company

MINISTRY OF PETROLEUM RESOURCES

DEPARTMENT OF PETROLEUM RESOURCES

7 KOFO ABAYOMI STREET, VICTORIA ISLAND LAGOS

P.M.B. No: 12560
Telephone: 2715730, 4611777
Website: www.dprnigeria.com

Ref. No: PI/SE/7118/Vol.7/185
Date: 18th May, 2010

SNEPCO
18 MA 2010
Sign
RE EIVED

The Managing Director
Shell Petroleum Development Company
Of Nigeria Limited
Freeman House, 21/22 Marina
Lagos

Dear Sir,

LETTER OF INTRODUCTION OF SHITTU WHANDA JA'AFARU

The bearer, Mr. Shittu Whanda Ja'afaru is a PhD student of the Department of Geography at the University of Nottingham, United Kingdom.

He is currently carrying out research on "Mapping Petroleum Risk to Human Health and the Environment using the Niger Delta as a Case Study" – and requires the following to enable him complete his research:

i. Current data/statistics on oil spill incidents including spill location, cause of spill as well as spill quantity.

ii. Pipeline network map and GPS locations of selected oil wells.

iii. Relevant literature on the oil spill management philosophy of your company as well as the opportunity to interact with some of your key staff involved in oil spill and other risks management.

Kindly afford him all the necessary assistance to enable him carry out the research.

Yours faithfully,

Onyeri I. C. (Mrs)
for: Director of Petroleum Resources.

I-2: The DPR introduction letter to Chevron Nigeria Limited

MINISTRY OF PETROLEUM RESOURCES

DEPARTMENT OF PETROLEUM RESOURCES

7 KOFO ABAYOMI STREET, VICTORIA ISLAND LAGOS

P.M.B. No: **12560**

Telephone: **2715730, 4611777**

Website: www.dprnigeria.com

Ref. No: **PI/SE/7118/Vol.7/184**

Date: **18th May, 2010**

The Managing Director
Chevron Nigeria Limited
2 Chevron Drive
Lekki Peninsula
Lagos.

CHEVRON NIGERIA LIMITED
RECEIVED
13.20pm
18/5/2010

Dear Sir,

LETTER OF INTRODUCTION OF SHITTU WHANDA JA'AFARU

The bearer, Mr. Shittu Whanda Ja'afaru is a PhD student of the Department of Geography at the University of Nottingham, United Kingdom.

He is currently carrying out research on "Mapping Petroleum Risk to Human Health and the Environment using the Niger Delta as a Case Study" – and requires the following to enable him complete his research.

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ii. Pipeline network map and GPS locations of selected oil wells.

iii. Relevant literature on the oil spill management philosophy of your company as well as the opportunity to interact with some of your key staff involved in oil spill and other risks management.

Kindly afford him all the necessary assistance to enable him carry out the research.

Yours faithfully,

Onyeri I. C. (Mrs)
for: Director of Petroleum Resources.

I-3: The DPR introduction letter to Nigeria Agip Oil Company

MINISTRY OF PETROLEUM RESOURCES

DEPARTMENT OF PETROLEUM RESOURCES

7 KOFO ABAYOMI STREET, VICTORIA ISLAND LAGOS

P.M.B. No: 12560
Telephone: 2715730, 4611777
Website: www.dprnigeria.com

Ref. No: PI/SE/7118/Vol.7/186
Date: 18th May, 2010

The Managing Director
Nigeria Agip Oil Company
Plot PC 23 Engineering Close
Victoria Island
Lagos.

Dear Sir,

LETTER OF INTRODUCTION OF SHITTU WHANDA JA'AFARU

The bearer, Mr. Shittu Whanda Ja'afaru is a PhD student of the Department of Geography at the University of Nottingham, United Kingdom.

He is currently carrying out research on "Mapping Petroleum Risk to Human Health and the Environment using the Niger Delta as a Case Study" and requires the following to enable him complete his research:

i. Current data/statistics on oil spill incidents including spill location, cause of spill as well as spill quantity.

ii. Pipeline network map and GPS locations of selected oil wells.

iii. Relevant literature on the oil spill management philosophy of your company as well as the opportunity to interact with some of your key staff involved in oil spill and other risks management.

Kindly afford him all the necessary assistance to enable him carry out the research.

Yours faithfully,

Onyeri I/C. (Mrs)
for: Director of Petroleum Resources

18/05/2010
Tel: 01-2621600-9

I-4: SPDC Internal Memo

NOTE

DATE 2 June 2010 FROM EPG-TDGX

TO Manager, HSE Environment UIG/S/HE (Attn: OKORO, I. Charles)

SUBJECT **Data Assistance & Support For University Research Student**

A data request from the bearer **Mr. SHITTU, Whanda J.** student of the School of Geography, The University of Nottingham, Nottingham has been approved by DPR. A copy of DPR letter, referenced PI/SE/7118/Vol.7/185 is attached.

In line with SPDC's Corporate University Liaison Policy, we require your team to kindly provide Mr. Shittu assistance on his project titled:

'Mapping petroleum risk to human health and the environment using the Niger delta as a case study'

The scope of assistance should cover the following:

- Having a one-on-one discussion with the bearer, to establish data needs for the project, in line with his research objectives.
- Provision of required data for the project. In so doing, please ensure that any specific reference to field/location/well names is deleted from the provided data to ensure confidentiality.

Your co-operation is highly appreciated.

OGUNKOYA, Olayinka O.
University Liaison (UIG/T/DGX)

cc: UIG/T/DGX file

Appendix J: Model Scripts

J-1: Model Python Script for MCDM-AHP Model

```
# ----------------------------------------------------------------------------
# MCE-AHP ModelScipt.py
# Created on: 2013-11-22 14:26:06.00000
#   (generated by ArcGIS/ModelBuilder)
# Description:
# THE MODEL IDENTIFY AREAS WHERE LAND USE ACTIVITIES CAN BE POTENTIALLY UNSAFE
FOR HUMANS BASED ON PROXIMITY TO PETROLEUM HYDROCARBON DISCHARGE SOURCES LIVE
PIPELINE, DOWNSTREAM EFFECT OF RIVER-PIPELINE INTERSECTIONS.THE MCE-AHP PROVIDES
A BUFFER CORRIDOR OF POTENTIAL PIPELINE IMPACT RADIUS (PPIR) AND IDENTIFY
SETTLEMENTS, RIVERS AND LAND COVER WITHIN THE PPIR FOR DESIGNATION AS HIGH
CONSEQUENCE AREAS (HCAs)
# ----------------------------------------------------------------------------
# Import arcpy module
import arcpy
# Check out any necessary licenses
arcpy.CheckOutExtension("spatial")
# Set Geoprocessing environments
arcpy.env.scratchWorkspace = "G:\\SWJ_PhDMODEL\\SWJ_2013PhD_Thesis\\2013
PERMS_Model.gdb"
arcpy.env.cellSize = "5"
arcpy.env.mask = ""
arcpy.env.workspace = "G:\\SWJ_PhDMODEL\\SWJ_2013PhD_Thesis\\2013 PERMS_Model.gdb"
# Local variables:
Settlements_Pt =
"G:\\SWJ_PhDMODEL\\SWJ_2013PhD_Thesis\\Degena_ModelData.gdb\\Settlements_Pt"
LandCover_Ras =
"G:\\SWJ_PhDMODEL\\SWJ_2013PhD_Thesis\\Degena_ModelData.gdb\\LandCover_Ras"
Pipeline_Network =
"G:\\SWJ_PhDMODEL\\SWJ_2013PhD_Thesis\\Degena_ModelData.gdb\\Pipeline_Network"
River_System =
"G:\\SWJ_PhDMODEL\\SWJ_2013PhD_Thesis\\Degena_ModelData.gdb\\River_System"
TrimeEdge = "G:\\SWJ_PhDMODEL\\SWJ_2013PhD_Thesis\\Degena_ModelData.gdb\\TrimeEdge"
River_System__2_ =
"G:\\SWJ_PhDMODEL\\SWJ_2013PhD_Thesis\\Degena_ModelData.gdb\\River_System"
Settlements__2_ =
"G:\\SWJ_PhDMODEL\\SWJ_2013PhD_Thesis\\Degena_ModelData.gdb\\Settlements"
LandCover_2 =
"G:\\SWJ_PhDMODEL\\SWJ_2013PhD_Thesis\\Degena_ModelData.gdb\\LandCover_2"
Population_Sqkm = "G:\\SWJ_PhDMODEL\\SWJ_2013PhD_Thesis\\2013
PERMS_Model.gdb\\KernelD_Set%n%1"
Potential_Hazard_Areas = "G:\\SWJ_PhDMODEL\\SWJ_2013PhD_Thesis\\2013
PERMS_Model.gdb\\Potential_Hazard_Areas%n%"
```

```
POPULATION-DENSITY = "G:\\SWJ_PhDMODEL\\SWJ_2013PhD_Thesis\\2013
PERMS_Model.gdb\\Population_Density%n%"
LANDCOVER = "G:\\SWJ_PhDMODEL\\SWJ_2013PhD_Thesis\\2013
PERMS_Model.gdb\\LandCover%n%"
EucDist_oilp1 = "G:\\SWJ_PhDMODEL\\SWJ_2013PhD_Thesis\\2013
PERMS_Model.gdb\\EucDist_Pipe1"
Output_direction_raster = ""
EucDist_Rive2 = "G:\\SWJ_PhDMODEL\\SWJ_2013PhD_Thesis\\2013
PERMS_Model.gdb\\EucDist_Rive1"
Output_direction_raster__2_ = ""
PROXIMITY_RIVER = "G:\\SWJ_PhDMODEL\\SWJ_2013PhD_Thesis\\2013
PERMS_Model.gdb\\Proxi_River%n%"
PROXIMITY_PIPELINES = "G:\\SWJ_PhDMODEL\\SWJ_2013PhD_Thesis\\2013
PERMS_Model.gdb\\Proxi_Pipeline%n%"
PHA = "G:\\SWJ_PhDMODEL\\SWJ_2013PhD_Thesis\\2013 PERMS_Model.gdb\\PHA"
PHA_Area = "G:\\SWJ_PhDMODEL\\SWJ_2013PhD_Thesis\\2013
PERMS_Model.gdb\\RasterT_PHA1"
PHA_Zones = "G:\\SWJ_PhDMODEL\\SWJ_2013PhD_Thesis\\2013
PERMS_Model.gdb\\PHA_Zones"
Pipeline_Potential_Impact_Radius__PPIR_ = "PPIR%n%"
Output_Layer = "Settlements_Layer"
River_System_Clip_Dissolve_shp = "G:\\SWJ_PhDMODEL\\SWJ_2013PhD_Thesis\\2013
PERMS_Model.gdb\\River_System_Clip_Dissolve"
HCA_River_Creeks = "HCA_River_Creeks"
Settlements = "Settlements_Layer"
HCA_Settlements = "HCA_Settlements"
River_System_Clip_shp = "G:\\SWJ_PhDMODEL\\SWJ_2013PhD_Thesis\\2013
PERMS_Model.gdb\\River_System_Clip"
HCA_LandCover = "G:\\SWJ_PhDMODEL\\SWJ_2013PhD_Thesis\\2013
PERMS_Model.gdb\\LandCover_2_Clip"
# Process: Euclidean Distance
arcpy.gp.EucDistance_sa(Pipeline_Network, EucDist_oilp1, "", "5", Output_direction_raster)
# Process: Reclassify (6)
arcpy.gp.Reclassify_sa(EucDist_oilp1, "Value", "0 500 10;500 1000 9;1000 1500 8;1500 2000
7;2000 2500 6;2500 3000 5;3000 3500 4;3500 4000 3;4000 4500 2;4500 9208.2099609375 1",
PROXIMITY_PIPELINES, "DATA")
# Process: Euclidean Distance (2)
arcpy.gp.EucDistance_sa(River_System, EucDist_Rive2, "", "5", Output_direction_raster__2_)
# Process: Reclassify (5)
arcpy.gp.Reclassify_sa(EucDist_Rive2, "Value", "0 500 10;500 1000 9;1000 1500 8;1500 2000
7;2000 2500 6;2500 3000 5;3000 3500 4;3500 4000 3;4000 4500 2;4500 5740.7861328125 1",
PROXIMITY_RIVER, "DATA")
# Process: Kernel Density
arcpy.gp.KernelDensity_sa(Settlements_Pt, "Proj_2002", Population_Sqkm, "5",
"1160.93060333331", "SQUARE_KILOMETERS")
# Process: Reclassify (3)
```

```
arcpy.gp.Reclassify_sa(Population_Sqkm, "Value", "0 8825.5760253906192
1;8825.5760253906192 17651.152050781238 2;17651.152050781238 26476.728076171858
3;26476.728076171858 35302.304101562477 4;35302.304101562477 44127.880126953096
5;44127.880126953096 52953.456152343715 6", POPULATION-DENSITY, "DATA")
# Process: Reclassify (4)
arcpy.gp.Reclassify_sa(LandCover_Ras, "DESC_1", "'Fadama Plantation' 1;'Freshwater Swamp'
2;'Grazing Field' 3;'Grazing Filed' 4;'Major River' 5;'Major Urban Centre' 6;'Mangrove Forest'
7;'Minor River' 8;'Minor Urban Settlements' 9;'Mix Cultivation' 10", LANDCOVER, "DATA")
# Process: Weighted Overlay
arcpy.gp.WeightedOverlay_sa("('G:\\SWJ_PhDMODEL\\SWJ_2013PhD_Thesis\\2013
PERMS_Model.gdb\\LandCover%n%' 12 'VALUE' (1 8; 2 7; 3 7; 4 7; 5 9; 6 4; 7 8; 8 9; 9 4; 10
8;NODATA Restricted); 'G:\\SWJ_PhDMODEL\\SWJ_2013PhD_Thesis\\2013
PERMS_Model.gdb\\Population_Density%n%' 5 'VALUE' (1 9; 2 9; 3 9; 4 6; 5 6; 6 6;NODATA
Restricted); 'G:\\SWJ_PhDMODEL\\SWJ_2013PhD_Thesis\\2013
PERMS_Model.gdb\\Proxi_River%n%' 25 'VALUE' (1 9; 2 8; 3 7; 4 6; 5 5; 6 4; 7 3; 8 2; 9 1; 10
1;NODATA Restricted); 'G:\\SWJ_PhDMODEL\\SWJ_2013PhD_Thesis\\2013
PERMS_Model.gdb\\Proxi_Pipeline%n%' 58 'VALUE' (1 9; 2 8; 3 7; 4 6; 5 5; 6 4; 7 3; 8 2; 9
Restricted; 10 Restricted;NODATA Restricted));1 9 1", Potential_Hazard_Areas)
# Process: Clip
arcpy.Clip_management(Potential_Hazard_Areas, "224388.150153848 497239.882539086
278950.038477774 531715.703795516", PHA, TrimeEdge, "", "NONE", "NO_MAINTAIN_EXTENT")
# Process: Raster to Polygon
arcpy.RasterToPolygon_conversion(PHA, PHA_Area, "SIMPLIFY", "Value")
# Process: Dissolve
arcpy.Dissolve_management(PHA_Area, PHA_Zones, "gridcode", "", "MULTI_PART",
"DISSOLVE_LINES")
# Process: Make Feature Layer
arcpy.MakeFeatureLayer_management(PHA_Zones, Pipeline_Potential_Impact_Radius__PPIR_,
"gridcode <= 3", "", "gridcode gridcode VISIBLE NONE")
# Process: Make Feature Layer (4)
arcpy.MakeFeatureLayer_management(Settlements__2_, Output_Layer, "", "", "OBJECTID
OBJECTID VISIBLE NONE;Shape Shape VISIBLE NONE;NAME_12 NAME_12 VISIBLE
NONE;LOCAL_GO_1 LOCAL_GO_1 VISIBLE NONE;STATE_12 STATE_12 VISIBLE
NONE;Proj__2004 Proj__2004 VISIBLE NONE;Male__2003 Male__2003 VISIBLE
NONE;Female_201 Female_201 VISIBLE NONE;Yrs0_14_15 Yrs0_14_15 VISIBLE
NONE;Shape_Length Shape_Length VISIBLE NONE;Shape_Area Shape_Area VISIBLE
NONE;Proj_Household Proj_Household VISIBLE NONE")
# Process: Select Layer By Location (2)
arcpy.SelectLayerByLocation_management(Output_Layer, "INTERSECT",
Pipeline_Potential_Impact_Radius__PPIR_, "", "NEW_SELECTION")
# Process: Make Feature Layer (3)
arcpy.MakeFeatureLayer_management(Settlements, HCA_Settlements, "", "", "OBJECTID
OBJECTID VISIBLE NONE;Shape Shape VISIBLE NONE;NAME_12 NAME_12 VISIBLE
NONE;LOCAL_GO_1 LOCAL_GO_1 VISIBLE NONE;STATE_12 STATE_12 VISIBLE
NONE;Proj__2004 Proj__2004 VISIBLE NONE;Male__2003 Male__2003 VISIBLE
NONE;Female_201 Female_201 VISIBLE NONE;Yrs0_14_15 Yrs0_14_15 VISIBLE
```

```
NONE;Shape_Length Shape_Length VISIBLE NONE;Shape_Area Shape_Area VISIBLE
NONE;Proj_Household Proj_Household VISIBLE NONE")
# Process: Clip (2)
arcpy.Clip_analysis(River_System__2_, Pipeline_Potential_Impact_Radius__PPIR_,
River_System_Clip_shp, "")
# Process: Dissolve (2)
arcpy.Dissolve_management(River_System_Clip_shp, River_System_Clip_Dissolve_shp,
"GM_LAYER", "", "MULTI_PART", "DISSOLVE_LINES")
# Process: Make Feature Layer (2)
arcpy.MakeFeatureLayer_management(River_System_Clip_Dissolve_shp, HCA_River_Creeks, "",
"", "GM_LAYER GM_LAYER VISIBLE NONE")
# Process: Clip (3)
arcpy.Clip_analysis(LandCover_2, Pipeline_Potential_Impact_Radius__PPIR_, HCA_LandCover, "")
```

J-2: Phyton Script for Ogoniland model

```
# -*- coding: utf-8 -*-
# ---------------------------------------------------------------------------
# OgoniScript.py
# Created on: 2013-11-24 00:21:05.00000
#   (generated by ArcGIS/ModelBuilder)
# Description:
# THE MODEL IDENTIFY AREAS WHERE LAND USE ACTIVITIES CAN BE POTENTIALLY UNSAFE
FOR HUMANS BASED ON PROXIMITY TO PETROLEUM HYDROCARBON DISCHARGE SOURCES LIKE
PIPELINE, DOWNSTREAM EFFECT OF RIVER-PIPELINE INTERSECTIONS.THE MCE-AHP
CONSTRUCT BUFFER CORRIDOR OF POTENTIAL PIPELINE IMPACT RADIUS (PPIR) AND IDENTIFY
SETTLEMENTS, RIVERS AND LAND COVER WITHIN THE PPIR FOR DESIGNATION AS HIGH
CONSEQUENCE AREAS (HCAs). THIS PARTICULAR MODEL IS TEST ON OGONILAND.
# ---------------------------------------------------------------------------

# Import arcpy module
import arcpy
# Check out any necessary licenses
arcpy.CheckOutExtension("spatial")
# Set Geoprocessing environments
arcpy.env.scratchWorkspace = "G:\\SWJ_PhDMODEL\\UNEP-North and
Easting\\OgoniDatasets.gdb"
arcpy.env.cellSize = "5"
arcpy.env.mask = ""
arcpy.env.workspace = "G:\\SWJ_PhDMODEL\\UNEP-North and Easting\\OgoniDatasets.gdb"
# Local variables:
OgoniPopulation = "G:\\SWJ_PhDMODEL\\UNEP-North and
Easting\\OgoniDatasets.gdb\\OgoniPopulation"
OgoniPipeline = "G:\\SWJ_PhDMODEL\\UNEP-North and
Easting\\OgoniDatasets.gdb\\OgoniPipeline"
OgoniRiver = "G:\\SWJ_PhDMODEL\\UNEP-North and Easting\\OgoniDatasets.gdb\\OgoniRiver"
```

```
OgoniStudyArea_shp = "G:\\SWJ_PhDMODEL\\UNEP-North and
Easting\\OgoniModelTest\\OgoniStudyArea.shp"
Rivers_Ogoni = "G:\\SWJ_PhDMODEL\\UNEP-North and
Easting\\OgoniDatasets.gdb\\Rivers_Ogoni"
OgoniSettlements = "G:\\SWJ_PhDMODEL\\UNEP-North and
Easting\\OgoniDatasets.gdb\\OgoniSettlements"
OgoniLandCover__2_ = "G:\\SWJ_PhDMODEL\\UNEP-North and
Easting\\OgoniDatasets.gdb\\OgoniLandCover"
OgoniLandCover = "G:\\SWJ_PhDMODEL\\UNEP-North and
Easting\\OgoniDatasets.gdb\\OgoniLandCover"
PopDens = "G:\\SWJ_PhDMODEL\\UNEP-North and
Easting\\OgoniModelTest\\OgoniModelling.gdb\\PopDens"
OgoLanCov = "G:\\SWJ_PhDMODEL\\UNEP-North and
Easting\\OgoniModelTest\\OgoniModelling.gdb\\OgoLanCov"
LANDCOVER = "G:\\SWJ_PhDMODEL\\UNEP-North and
Easting\\OgoniDatasets.gdb\\Reclass_OgoL3"
PipeProxi = "G:\\SWJ_PhDMODEL\\UNEP-North and
Easting\\OgoniModelTest\\OgoniModelling.gdb\\PipeProxi"
Output_direction_raster = ""
RiveProxi = "G:\\SWJ_PhDMODEL\\UNEP-North and
Easting\\OgoniModelTest\\OgoniModelling.gdb\\RiveProxi"
Output_direction_raster__2_ = ""
PROXIMITY_RIVER = "G:\\SWJ_PhDMODEL\\UNEP-North and
Easting\\OgoniDatasets.gdb\\Reclass_Rive3"
PROXIMITY_PIPELINES = "G:\\SWJ_PhDMODEL\\UNEP-North and
Easting\\OgoniDatasets.gdb\\Reclass_Pipe4"
Weighte_Ogon1 = "G:\\SWJ_PhDMODEL\\UNEP-North and
Easting\\OgoniModelTest\\OgoniModelling.gdb\\Weighte_Ogon1"
PHA = "G:\\SWJ_PhDMODEL\\UNEP-North and
Easting\\OgoniDatasets.gdb\\Weighte_Ogon1_Clip"
RasterT_PHA1 = "G:\\SWJ_PhDMODEL\\UNEP-North and
Easting\\OgoniModelTest\\OgoniModelling.gdb\\RasterT_PHA1"
PHA_Zones = "G:\\SWJ_PhDMODEL\\UNEP-North and
Easting\\OgoniModelTest\\OgoniModelling.gdb\\PHA_Zones"
Output_Layer = "OgoniSettlements_Layer"
PHA_Zones_Layer = "PHA_Zones_Layer"
River_System_Clip_Dissolve = "G:\\SWJ_PhDMODEL\\UNEP-North and
Easting\\OgoniModelTest\\OgoniModelling.gdb\\River_System_Clip_Dissolve"
HCA_River_Creeks = "HCA_River_Creeks"
Settlements = "OgoniSettlements_Layer"
HCA_Settlements = "HCA_Settlements"
River_Clip = "G:\\SWJ_PhDMODEL\\UNEP-North and
Easting\\OgoniModelTest\\OgoniModelling.gdb\\River_Clip"
HCA_LandCover = "G:\\SWJ_PhDMODEL\\UNEP-North and
Easting\\OgoniModelTest\\OgoniModelling.gdb\\HCA_LandCover"
OgoniPopDens = "G:\\SWJ_PhDMODEL\\UNEP-North and
Easting\\OgoniDatasets.gdb\\Reclass_PopD3"
```

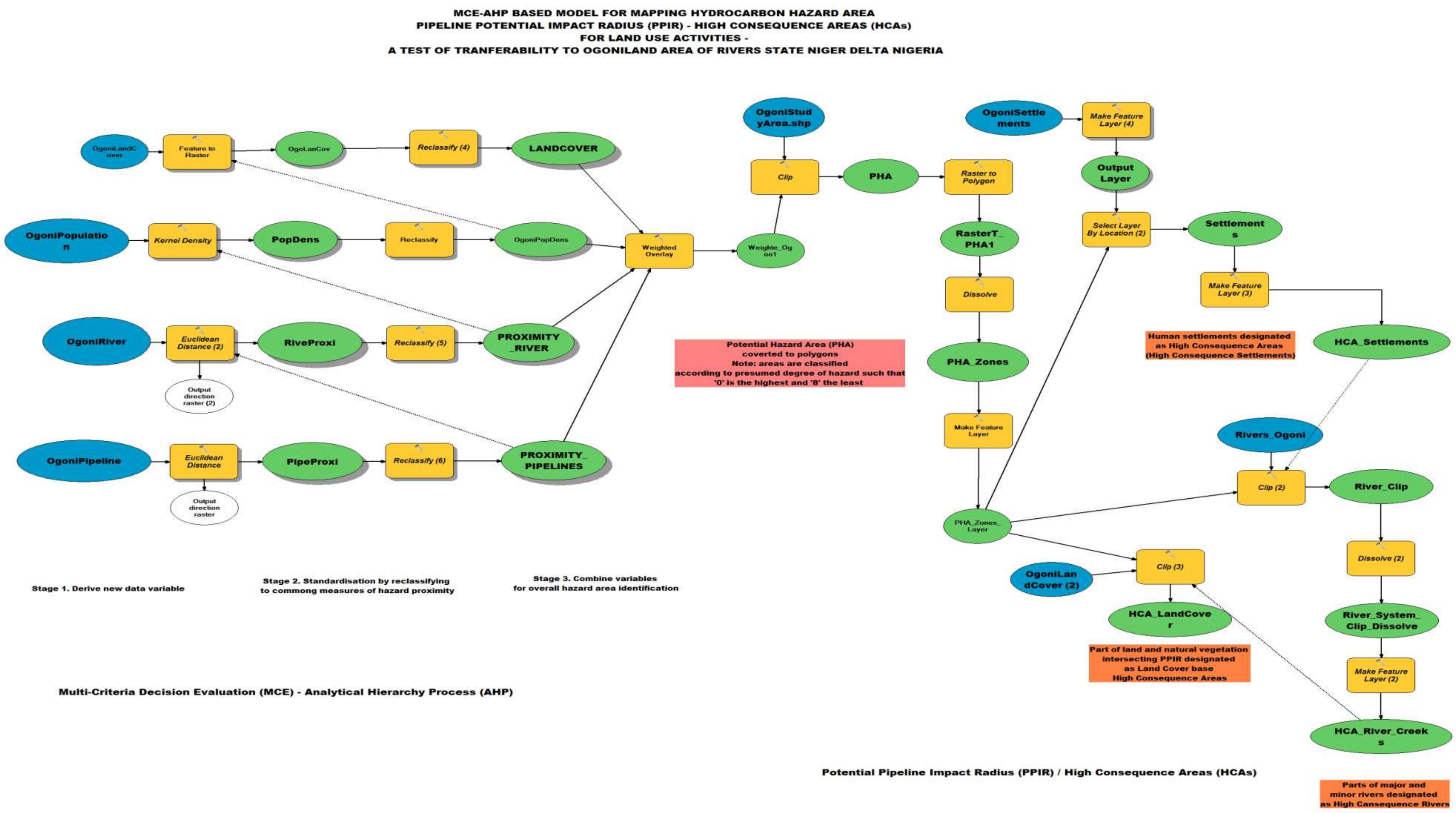
```
# Process: Euclidean Distance
arcpy.gp.EucDistance_sa(OgoniPipeline, PipeProxi, "", "5", Output_direction_raster)
# Process: Reclassify (6)
arcpy.gp.Reclassify_sa(PipeProxi, "Value", "0 500 9;500 1000 8;1000 1500 7;1500 2000 6;2000
2500 5;2500 3000 4;3000 3500 3;3500 4000 1;4000 4500 1", PROXIMITY_PIPELINES,
"NODATA")
# Process: Euclidean Distance (2)
arcpy.gp.EucDistance_sa(OgoniRiver, RiveProxi, "", "5", Output_direction_raster__2_)
# Process: Reclassify (5)
arcpy.gp.Reclassify_sa(RiveProxi, "Value", "0 500 1;500 1000 2;1000 1500 3;1500 2000 4;2000
2500 5;2500 3000 6;3000 3500 7;3500 4000 8;4000 7679.7603056066282
9;7679.7603056066282 9742.9794921875 10", PROXIMITY_RIVER, "NODATA")
# Process: Kernel Density
arcpy.gp.KernelDensity_sa(OgoniPopulation, "_Projection", PopDens, "5", "847.961893333339",
"SQUARE_KILOMETERS")

# Process: Reclassify
arcpy.gp.Reclassify_sa(PopDens, "Value", "0 0.0091147810453549027
1;0.0091147810453549027 0.018229562090709805 2;0.018229562090709805
0.027344343136064708 3;0.027344343136064708 0.036459124181419611
4;0.036459124181419611 0.045573905226774514 5;NODATA 6", OgoniPopDens, "DATA")
# Process: Feature to Raster
arcpy.FeatureToRaster_conversion(OgoniLandCover, "Descriptio", OgoLanCov, "5")
# Process: Reclassify (4)
arcpy.gp.Reclassify_sa(OgoLanCov, "Descriptio", "'River and Water Bodies' 3;'Mangrove Forest'
8;'SmallScale Agric' 7;Settlement 4;NODATA 0", LANDCOVER, "DATA")
# Process: Weighted Overlay
arcpy.gp.WeightedOverlay_sa("('G:\\SWJ_PhDMODEL\\UNEP-North and
Easting\\OgoniDatasets.gdb\\Reclass_OgoL3' 12 'Value' (0 3; 3 7; 4 7; 7 8; 8 9;NODATA
Restricted); 'G:\\SWJ_PhDMODEL\\UNEP-North and Easting\\OgoniDatasets.gdb\\Reclass_PopD3'
5 'Value' (1 9; 2 9; 3 9; 4 9; 5 9; 127 9;NODATA 4); 'G:\\SWJ_PhDMODEL\\UNEP-North and
Easting\\OgoniDatasets.gdb\\Reclass_Pipe4' 58 'Value' (1 1; 3 3; 4 4; 5 5; 6 6; 7 7; 8 8; 9
9;NODATA Restricted); 'G:\\SWJ_PhDMODEL\\UNEP-North and
Easting\\OgoniDatasets.gdb\\Reclass_Rive3' 25 'Value' (1 9; 2 8; 3 7; 4 6; 5 5; 6 4; 7 3; 8 2; 9
1; 10 1;NODATA Restricted));1 9 1", Weighte_Ogon1)
# Process: Clip
arcpy.Clip_management(Weighte_Ogon1, "288332.427000002 508148.212388106
313768.068200001 537925.132011896", PHA, OgoniStudyArea_shp, "", "NONE",
"NO_MAINTAIN_EXTENT")
# Process: Raster to Polygon
arcpy.RasterToPolygon_conversion(PHA, RasterT_PHA1, "SIMPLIFY", "Value")
# Process: Dissolve
arcpy.Dissolve_management(RasterT_PHA1, PHA_Zones, "grid_code", "", "MULTI_PART",
"DISSOLVE_LINES")
# Process: Make Feature Layer
arcpy.MakeFeatureLayer_management(PHA_Zones, PHA_Zones_Layer, "\"grid_code\" >= 7", "",
"grid_code grid_code VISIBLE NONE")
```

```
# Process: Make Feature Layer (4)
arcpy.MakeFeatureLayer_management(OgoniSettlements, Output_Layer, "", "", "OBJECTID
OBJECTID VISIBLE NONE;Shape Shape VISIBLE NONE;STATE STATE VISIBLE NONE;TAG TAG
VISIBLE NONE;X_Coord X_Coord VISIBLE NONE;Y_Coord Y_Coord VISIBLE NONE;Shape_Length
Shape_Length VISIBLE NONE;Shape_Area Shape_Area VISIBLE NONE;Settlements Settlements
VISIBLE NONE")
# Process: Select Layer By Location (2)
arcpy.SelectLayerByLocation_management(Output_Layer, "INTERSECT", PHA_Zones_Layer, "",
"NEW_SELECTION")
# Process: Make Feature Layer (3)
arcpy.MakeFeatureLayer_management(Settlements, HCA_Settlements, "", "", "OBJECTID
OBJECTID VISIBLE NONE;Shape Shape VISIBLE NONE;STATE STATE VISIBLE NONE;TAG TAG
VISIBLE NONE;X_Coord X_Coord VISIBLE NONE;Y_Coord Y_Coord VISIBLE NONE;Shape_Length
Shape_Length VISIBLE NONE;Shape_Area Shape_Area VISIBLE NONE;Settlements Settlements
VISIBLE NONE")

# Process: Clip (2)
arcpy.Clip_analysis(Rivers_Ogoni, PHA_Zones_Layer, River_Clip, "")
# Process: Dissolve (2)
arcpy.Dissolve_management(River_Clip, River_System_Clip_Dissolve, "River", "", "MULTI_PART",
"DISSOLVE_LINES")
# Process: Make Feature Layer (2)
arcpy.MakeFeatureLayer_management(River_System_Clip_Dissolve, HCA_River_Creeks, "", "",
"River River VISIBLE NONE")
# Process: Clip (3)
arcpy.Clip_analysis(OgoniLandCover__2_, PHA_Zones_Layer, HCA_LandCover, "")
```

J-3: Model structure for Ogoniland.



Appendix K: Site Inspection Report

K-1: Site No.1

Site No. 1 Report

Introduction

The purpose of the field inspection was to build on knowledge database of land use characteristics and physical condition of oil-polluted sites in the area. In addition to determining existence of pollutant linkages and the efficacy of clean-up method used by contractors.

Site description

The site is located about 50 metres from a community along old Port Harcourt road, in Port Harcourt Local Government Area. The pipeline runs through from Bonny Terminal to the old Port Harcourt refinery. There is no sign or fence-restricting access to the area neither was there evidence of any form of security along the pipeline rights of way. The pipeline rights of way buffer is less than the required 30 metres and adjourned by thick vegetation and tall trees, farther down south along the pipeline tract (approximately 50-metre) there is evidence of farming activities.

Land Use

Adjourning the area (spill site) is a forest used for farming cassava and yam, there is also palm trees scattered around the area.

Spill history

According to the site contractor, the spill was caused by leakage from corrosion in which an estimated 126 barrels of crude oil was discharged. There was no information on the date of spill, and time taken to stop the discharge. However, evidence of weathered crude oil suggests there has been previous oil spill on or close to the same site.

Site observations

The estimated area of impact is over 1,000 square metres (contractor), the area is devoid of healthy vegetation, and there is evidence of ongoing crust formation around the area, which is an indication that the product discharged was crude oil. The soil is made of alluvium deposits and clay loamy subsoil indicating fluvial activities (inundation) in the rainy session, the soil is hydrophobic which makes it difficult for water to penetrate when it rains.

The potential pathway is through run-off to nearby streams and subsoil percolation, which could contaminate both surface and underground water. Exposure to humans is negligible; however, people using the site as footpath or farmers down gradient of the site could be exposed through dermal and inhalation pathways.

Remediation strategy

The remediation method adopted by the contractor is "remediation by enhanced natural attenuation" (RENA). In this method, the top soil is ploughed over to increase aeration, fertilizer is then added to provide nutrient requirement for bacteria to break down hydrocarbon compounds. The ploughed soil is then piled into "windrows" and turned over periodically while samples are taken quarterly for analysis. When the 5,000mg/kg EGASPIN specification is reached, "the windrows are levelled" (UNEP, 2011).

Comment

The clean-up procedure is not suitable for the area. Firstly contaminants are removed by digging and disposed-off in a borrow pitch somewhere, which simply means transferring the contaminant to another place. Secondly, because of lack of containment, contaminants can migrate easily to surrounding areas through surface and subsurface processes especially during rainy session when the site is inundated. The use of this method must be discontinued in order not to encourage spread of contaminants around the site being remediated and borrow pit sites.

Finally the inconsistencies for remediation closure in EGASPIN should be addressed i.e. the target value of 50 mg/kg is the desired end point for restoration but the use of 5,000 mg/kg (which is the intervention value) for closure, is conflicting.

Field Assessment sheet for Site No.1

CRITERIA FOR ASSESSING AND PRIORITISING OIL SPILL SITES					
Name of Site: Industrial layout area **(along Oil Port Harcourt road)**			Site No.: 1		
Location: South of Port Harcourt		GPS:	North		East
Assessor: Author			N/A		N/A
Date of Assessment: 4/07/2010		Comment: *Oil pipeline spill caused by corrosion, leakage was slow steady discharge. Remediation by enhanced natural attenuation. (RENA). Recent alluvium and clay loamy subsoil. Green vegetation on both edges of ROW. ROW show tendency to waterlog and no evidence of containment. Fresh and weathered spill, an indication of previous spill without clean-up.*			
Type of Product Spilt: Crude oil					
Quantity Spilt: 126 barrels					
Land Use: farmland adjacent ROW					
Proximity to Dwellings: approx. **50 metres**					
Surface water Exposure Assessment			Score		
			High (7-10)	Medium (4-6)	Low (0-3)
Hazard	Toxicity		10		
	Extent			6	
	Quantity		10		
	Mobility after discharge			6	
Pathway	Containment		10		
	Flood Potential		10		
	Pooling Potential		7		
Receptor	Water Use			5	
Groundwater Exposure Assessment					
Hazard	Toxicity		10		
	Extent			5	
	Quantity			6	
	Mobility after discharge		9		
Pathway	Containment		10		
	Permeability				3
	Distance to water Table		8		
Receptor	Water Use			4	
Direct contact Exposure Assessment					
Hazard	Toxicity		10		
	Extent				3
	Quantity			6	
	Mobility when discharged		7		
Pathway	Containment		10		
	Surface Cover			5	
	Soil Permeability		8		
	Distance To Hazard		10		
Receptor	Land Use			6	
			129/14 = 9.2	49/9 = 5.4	6/2 = 3
Ranking = High (5.9)			(9.2 + 5.4 + 3) / 3 = 5.9		
Very Low Priority = 0-1, Low Priority = 2-3, Medium Priority =4-5, High Priority = 6-7, Very High Priority = 8-10					

Designed by author for research fieldwork 2010 only

K-2: Site No.2

Site No. 2 Report

Introduction

The purpose of the visit is in conformity with "Site No.1" (see report)

Site description

The site is located in Isaka Town in the outskirt of Port Harcourt. The pipeline conveys crude oil from a separation facility to the new Port Harcourt refinery. The site is surrounded with farms, immediately to the north (about 100 metres) is a river already overflowing its banks. What seems like a pipeline rights of way, has been converted to road (untarred) leading in and out of the Isaka town. Also like in the previous site, there is no security or access restriction. There is green vegetation on and around the epicentre of the spill although most are coated with mixture of mud and oil.

Land use

The immediate surrounding land uses include farming and residential, the river is used for transportation, fishing and as source of domestic water for the community.

Spill history

The oil spill was caused by interdiction (vandalism) and quantity discharge is unknown. That was the first incident within that particular area.

Site observation

At the time of the visit, vegetation on the site was green with the exception of the "marshy muddy" road and coated vegetation. There was no sign of stress on the undisturbed vegetation, except on specific locations used to carry out repair works and places trampled on by foot. The place is water logged and stagnant, while the hydrocarbon plume on most parts is partially covered by tall grasses.

Comment

The site share similar characteristic with the previous inspected site (see report on site no 1) and the same method of remediation was proposed by the contractor; however a lot of vegetation removal has been proposed in order to reach the topsoil. Dig and dump is not recommended for this particular site, because the site would be flooded by the nearby river if depressions were created. Another site-specific remediation method apart from dig and dump and RENA should be considered. Considering the inherent exposure partway on and around the site, a short period remediation method is recommended e.g. barrier erection, pump, and treat.

Field Assessment sheet for Site No.2

CRITERIA FOR ASSESSING AND PRIORITISING OIL SPILL SITES					
Name of Site: Isaka Town			**Site No.**: 2		
Location: South of Port Harcourt		**GPS:**	**North**		**East**
Assessor: Author			unknown		unknown
Date of Assessment: 4/07/2010		**Comment**: *Oil pipeline spill caused by interdiction, strong gushing discharge. Remediation options by contractor dig and dump and remediation by enhanced natural attenuation. (RENA). Geology is alluvium with clay sandy loamy soils. Green vegetation on and around facility. Area waterlog and no indication of any containment measures. Fresh spills which are easily washes ashore to river nearby.*			
Type of Product Spilt: Crude oil					
Quantity Spilt: unknown					
Land Use: Residential, farmland, waterway					
Proximity to Dwellings: less than 10 metres					
Surface water Exposure Assessment			**Score**		
			High	**Medium**	**Low**
Hazard	Toxicity		10		
	Extent		10		
	Quantity		8		
	Mobility after discharge		10		
Pathway	Containment		10		
	Flood Potential			6	
	Pooling Potential				
Receptor	Water Use			6	
Groundwater Exposure Assessment					
Hazard	Toxicity		10		
	Extent			6	
	Quantity			6	
	Mobility after discharge		8		
Pathway	Containment		10		
	Permeability		8		
	Distance to water Table		10		
Receptor	Water Use			6	
Direct contact Exposure Assessment					
Hazard	Toxicity		10		
	Extent			5	
	Quantity		8		
	Mobility when discharged		8		
Pathway	Containment		10		
	Surface Cover			5	
	Soil Permeability		7		
	Distance To Hazard		10		
Receptor	Land Use		10		
			167/18 = 9.3	40/7 = 5.7	
Ranking = Very High (7.5)			9.3 + 5.7 / 2 = 7.5		
Very Low Priority = 0-1, Low Priority = 2-3, Medium Priority =4-5, High Priority = 6-7, Very High Priority = 8-10					

Designed by author for research fieldwork 2010 only

Appendix L: Online Media Reports and Documentaries on Oil Thefts and Pollution in the Niger Delta Nigeria.

No.	Date	Organisation	Title	Medium	Reporter	Date Accessed
1	3/8/12	Aljazeera	The looting and 'cooking' of Nigeria's crude.	Video	Mohammed Adow	5/8/12
	http://www.aljazeera.com/indepth/features/2012/08/20128312530927823.html					
2	4/8/12	Aljazeera	Fallout from Nigerian oil spill haunts locals	Video	Mohammed Adow	4/8/12
	http://www.aljazeera.com/video/africa/2012/08/2012848394975693.html					
3	12/7/12	Aljazeera	Scores killed in massive Nigeria tanker blaze	Video	Mohammed Adow	14/7/12
	http://www.aljazeera.com/news/africa/2012/07/2012712112748208838.html					
4	26/7/12	BBC News	Nigeria's booming illegal oil refineries	Video	Will Rose	30/7/12
	http://www.bbc.co.uk/news/world-africa-18973637					
5	2/8/12	BBC News	Rare look at an illegal oil refinery	Video	Will Rose	5/8/12
	http://www.bbc.co.uk/news/world-africa-19082609					
6	24/4/12	BBC News	How oil spills have affected Nigeria	Video	Mark Doyle	28/4/12
	http://www.bbc.co.uk/news/world-africa-17793234					
7	15/6/12	BBC News	How oil spills have affected Nigeria	Video	Caroline Duffield	28/4/12
	http://www.bbc.co.uk/news/10315550					
8	4/8/11	BBC Radio4	Shell oil spill 'devastates' Nigerians	Radio	Martyn Day	28/4/12
	http://news.bbc.co.uk/today/hi/today/newsid_9555000/9555791.stm					
9	16/10/13	The Guardian	DIY illegal oil refinery in the Niger Delta	Video	John Vidal	18/10/13
	http://www.theguardian.com/global-development/video/2013/oct/16/illegal-oil-refinery-niger-delta-video					
10	7/10/12	The Guardian	Niger Delta oil spills: the real cost of crude	Video	John Vidal	18/10/13
	http://www.theguardian.com/global-development/video/2013/oct/07/niger-delta-nigeria-oil-spill-cost-crude-video					
11	8/11/12	Aljazeera	Shell denies lying about Nigeria oil spills	Video		8/11/13
	http://www.aljazeera.com/video/africa/2013/11/shell-denies-lying-about-nigeria-oil-spills-201311853724945877.html					

Appendix M: Land Use Act 1978

Part II

Principles of Land Tenure, Powers of Governor and Local Governments, and Rights of Occupiers

5. (1) It shall be lawful for the Governor in respect of land, whether or not in an urban areas:-

(a) to grant statutory rights of occupancy to any person for all purposes;

(b) to grant easements appurtenant to statutory rights occupancy;

(c) to demand rental for any such land granted to any person.

(d) to revise the said rental -

(i) *at such intervals as may be specified in the certificate of occupancy; or*

(ii) where no intervals are specified in the certificate or occupancy at any time during the term of the statutory rights of occupancy;

(e) to impose a penal rent for a breach of any covenant in a certificate of occupancy requiring the holder to develop or effect improvements on the land the subject of the certificate of occupancy and to revise such penal rent as provided in section 19 of this Act

(f) to impose a penal rent for a breach of any condition, express or implied, which precludes the holder of a statutory right of occupancy from alienating the right of or any part thereof by sale, mortgage, transfer or possession, sub-lease or request or otherwise howsoever without the prior consent of the Governor;

(g) to waive. Wholly or partially, except as otherwise prescribed; all or any of the covenant or conditions of which a statutory right of occupancy is subject where, owing to special circumstances, compliance therewith would be impossible or great hardship would be imposed upon the holder;

(h) to extend except as otherwise prescribed, the time to the holder of a statutory right of occupancy for performing any of the conditions of the right of occupancy upon such terms and conditions as he may thing fit.

(2) Upon the grant of a statutory right of occupancy under the provisions of subsection (1) of this section all existing rights to the use and occupation of the land which is the subject of the statutory right of occupancy shall be extinguished.