THE IMPACT OF OIL EXPLORATION, EXTRACTION AND TRANSPORT ON MANGROVE VEGETATION AND CARBON STOCKS IN NIGERIA

BIOMASS RESEARCH REPORT 1401

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Study executed at the request of Milieudefensie (Friends of the Earth Netherlands), Amsterdam, the Netherlands

Milieudefensie has commissioned this study with the financial assistance of the European Union. The contents of this document are the sole responsibility of Biomass Research and can under no circumstances be regarded as reflecting the position of the European Union.

Biomass Research, Wageningen, February 2014

Publications available from www.biomassresearch.eu

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PREFACE

Mangrove forests are distributed in tropical and subtropical regions between approximately latitude 30° N and 30° S. One third of mangroves were lost between 1980 to 2000, the forests declining at a faster rate than other tropical forests or coral reefs. Mangrove forests are home to a large variety of fish, crab, shrimp, and mollusc species. They form an essential source of food for thousands of coastal communities around the world. The forests serve as nurseries for many fish species, including coral reef fish, while the dense root systems of mangrove forests trap sediments flowing down rivers and off the land. In this way, they help stabilize the coastline and prevent erosion from waves and storms.

The Niger Delta, located in the southernmost part of Nigeria, is the largest river delta in Africa and, in hydrological terms, the third largest in the world. From a coastal belt of swamps, stretching northwards the land becomes a continuous rainforest gradually merging with woodland and savannah grasslands. It is host to petroleum production activities which have brought an economic boom, but not without problems. Exploration, drilling, extraction, transportation and refining of oil have gone hand in hand with clearing of vegetation, while waste discharge, accidental spills and operational failures, in combination with sabotage, pipeline bunkering and artisanal refining, all contribute to serious environmental pollution.

The result is substantial damage to surface water, drinking water, fish and other fauna as well as other parts of the mangrove ecosystems which make up most of the environment in the Niger Delta zone. While there have been many reports on the environmental and social implications of oil production in Nigeria, carbon releases related to oil production so far seem to have received little attention. This report aims to fill that gap.

Fossil fuels are considered as the primary source of increasing atmospheric CO_2 and therefore the main contributor to carbon dioxide concentrations, together with emissions related to land use change. While deforestation and, more recently, crop production have been identified as major causes of carbon releases through changes in land cover, the debate on the contribution of fossil fuel production to land-based emissions is still on-going.

This report determines the impact of oil production activities on mangroves in the Niger Delta by generating the best available estimates of oil discharge, and by assessing its impact on mangrove vegetation. The report was commissioned by Milieudefensie (Friends of the Earth Netherlands). It is co-authored by Hans Langeveld (Biomass Research) and Simon Delany (Delany Environmental).

Hans Langeveld has a background in agronomic and economic research and has worked on agricultural land use management in many countries including Nigeria. The main focus of his work is on sustainable biomass production for food and energy. In the past, he worked as a Senior Research scientist at Wageningen University and Research Centre and as Research scientist at the Centre for World Food Studies in Amsterdam, where he worked on land use, nutrient management and greenhouse gas (GHG) emissions. His track record includes work on sustainable land use systems in Europe, Asia, Africa and Latin America.

Simon Delany, a geographer by training, an ornithologist by inclination, and all-round environmental services professional, has worked for over 10 years as a Senior Technical Officer at Wetlands International before he established an independent environmental consultancy in Wageningen (the Netherlands). He has published over 120 reports, book chapters and articles.

Wageningen, February 2014

Hans Langeveld
Director

EXECUTIVE SUMMARY

This report aims to determine the impact of oil production activities on mangroves in the Niger Delta of Nigeria. It generates the best available estimate of oil discharge, and develops and applies an evaluation method for assessing impact on mangrove vegetation including the levels of carbon releases that have been caused by loss of previously vital vegetation.

A considerable amount of oil is discharged into sensitive coastal environments. In Nigeria, exploration, extraction, transportation and refining of oil have gone hand in hand with clearing of vegetation, while waste discharge, accidental spills, failures, sabotage, pipeline bunkering and artisanal refining are contributing to environmental pollution with petroleum hydrocarbons. The result is considerable damage to surface water, drinking water, fish and other fauna as well as other parts of the mangrove ecosystems.

Mangroves are highly sensitive to contamination with oil and industrial waste. Damage includes acute toxic impact of chemicals and physical damage which may occur later but which persists for longer. Following an estimate by the Nigerian Federal Ministry of Environment, a total of 13 million barrels of oil has been lost in more than 10,000 incidents since the start of oil production in 1958. The number of incidents is increasing; the former long term annual average (220 to 250 spills per year), has recently accelerated to numbers exceeding 500 spills per year.

Large accidents involving oil spills to the environment have sparked research efforts, and a considerable number of studies describing leakages now are available. Very rarely, however, do they include a quantified assessment of damage to mangroves. This study used observed damage following two spills – one tank rupture, and one tanker collision – to estimate and quantify damage.

A major distinction must be made between onshore and offshore spills where the former – being much closer to the vegetation – cause more acute chemical damage while offshore spills lose a considerable part of the (more toxic) lighter compounds through evaporation as they move towards the coast. Both can cause considerable damage via deposition of heavier compounds which can be washed into the vegetation.

Under low tidal activity, toxic compounds can settle firmly in sediments, causing damage for very long periods of time. Toxic effects have been reported to persist for 20 years or more (occasionally exceeding 40 years). Furthermore, under conditions of frequent spills, physical damage (smothering of plant roots) is likely to accumulate and worsen.

Given the long history of oil spills, the wide distribution of installations and the huge amount of oil lost, it must be assumed that most of Nigeria's mangroves have been affected. Pristine mangrove forests will be very rarely found, with the possible exceptions of the far west and extreme east of the country.

It is remarkable (and unfortunate) that so few studies provide a quantified assessment of oil spill impacts. Mangroves in Nigeria are bound to suffer more strongly than those elsewhere given (i) the large number (high frequency) of spills reported, (ii) the dense and evenly distributed network of wells, tanks and transport units, (iii) the large amount of oil lost, (iv) the poor maintenance and advanced age of the transport network, and (v) the combination of onshore and offshore spills, probably affecting overlapping areas.

A model was developed to assess mangrove mortality following Niger Delta oil spills. It has been applied in three scenarios providing low, probable and high estimates of damage caused. The scenarios provide estimations of vegetation clearance on behalf of the oil industry, impacts of industrial waste, and replacement of vegetation by invasive species due to disturbance of soils and water flows.

The total area of dead mangrove forests has been estimated at 25,000, 80,000 and 190,000 ha, for the Low, Probable and High Damage scenarios, respectively. Thus, up to 40% of the mangrove vegetation has died since 1958. As recovery takes many years and probably decades, at any given time, a considerable part of the mangrove area will be seriously affected. This has been confirmed by the literature and by feedback provided by local and international experts.

The total amount of carbon released since oil production started in 1958 according to the three scenarios is 96, 315 and 748 million tonnes of CO_2, representing 120%, 400% and 950% of the reported annual emission levels for Nigeria in 2010. Average annual emission levels amount to 1.8, 5.7 and 13.6 million tonnes of CO_2 per year under the Low, Probable and High Damage scenarios, respectively, which is equivalent to the national GHG emission levels of countries such as Guyana, Ivory Coast or Lithuania.

The uncertainty of damage assessments remains high, especially the impact of chronic contamination caused by high frequency spill incidents. The extent of the damage may, therefore, be much higher.

Carbon emissions released may exceed those from land disturbed during production of other fuels such as crude oil or in situ oil sands production in North America as calculated by Yeh et al. (2010). The impact of carbon releases in the Niger Delta (0.6, 1.8 and 4.3 g CO_2eq/MJ, for the Low, Probable and High Damage scenarios, respectively) on top of a base emission level of 105 g CO_2eq/MJ suggests that Nigerian crude is likely to be among the oils with the highest land use carbon impacts.

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ABBREVIATIONS

GHG	Greenhouse Gas
IUCN	International Union for the Conservation of Nature
LGA	Local Government Area
NPC	National Petroleum Corporation
PAHs	Polynuclear Aromatic Hydrocarbons
SOM	Soil Organic Matter
SPDC	Shell Petroleum Development Company of Nigeria
UNEP	United Nations Environment Programme
VOC	Volatile organic compounds

1. INTRODUCTION

Since experts recognized that petroleum pollutants were being discharged into marine waters via oil spills, vessel operations, and land-based sources in the early 1970’s, public attention to oil spills has forced improvements in practice. A considerable amount of oil is still discharged every year into sensitive coastal environments. Despite recent and substantive decreases in the size and frequency of petroleum spills from tankers, the potential for a large spill remains significant, especially in regions without stringent safety procedures and maritime inspection practices.

Nigeria is one of the largest, and the most populous country in Africa. It covers an area of 923,768 km^2 and has an estimated 4,049 km of land boundaries (shared with Cameroon, the Republic of Niger, Chad and Benin). In the south, it has an 853-km long coastline on the Atlantic Ocean. Nigeria is endowed with diverse mineral and natural resources among which is petroleum

In the past five decades, petroleum exploration and production activities have brought an economic boom, but not without problems. Petroleum exploration, construction of oil production units, transportation and refining facilities, have gone hand in hand with clearing of vegetation while waste discharge, accidental spills and operational failures, in combination with sabotage, pipeline bunkering and artisanal refining all contribute to a heavy load of environmental pollution with petroleum hydrocarbons.

The result is substantial damage to surface water, drinking water, fish and other fauna as well as other parts of the mangrove ecosystems which make up most of the environment in the Niger Delta zone: nine oil-producing states (Abia, Akwa Ibom, Bayelsa, Cross River, Delta, Edo, Imo, Ondo and Rivers states (Figure 1.1).

Figure 1.1 Niger Delta

In Nigeria, about 20 million people (23 per cent of the country’s population) live along the coastal zone, and an additional 13 million people live in the coastal capital of Lagos which is also the centre for 85 per cent of the country’s industrial activity (UNEP, 2013).

Housing and urban infrastructure, industrial sites, ports, agricultural activities and hotel and leisure facilities have all also developed and have brought with them activities such as extraction of sand, limestone and coral to provide building materials. These pressures have combined to destabilize Africa's coastal zone, increase erosion, smother habitats, deplete resources, pollute ecosystems, and reduce biodiversity (UNEP, 2013).

The Upper Guinea Forest (Figure 1.2), a strip of tropical moist forest that runs parallel to the coast from Guinea to Cameroon is one of the world's 25 biodiversity hotspots. It is estimated that only 20 per cent of the original extent still remains and this is highly fragmented. Several initiatives are under way to manage the forest and protect endangered species (UNEP, 2013).

Figure 1.2. Forest area in South of Nigeria
Source: UNEP (2013)

The coast is composed of four distinct geomorphological units namely the Barrier-Lagoon Complex; the Mud Coast; the Arcuate Niger Delta and the Strand Coast. The coastal area is low lying with altitudes reaching no more than 3.0 m above sea level and is generally covered by fresh water swamp, mangrove swamp, lagoonal mashes, tidal channels, beach ridges and sand bars (Nwilo and Badejo, 2007).

The Niger Delta consists of three major sections: the upper riverine floodplain, the lower tidal floodplain, and an outer chain of coastal barrier islands. The upper riverine floodplain stretches for 168 km from the head of the delta at Onitsha to the lower tidal floodplain. The Niger begins to separate into the Forcados and the Nun Rivers in the upper riverine floodplain, where seasonal and permanent freshwater swamps occur. Seasonal swamp forest is inundated during the wet season. Permanent swamp forests are inundated year-round (Brown and Thieme, 2013).

Nigeria's total land and water area is 92 million ha (Nwoli and Badejo, 2007). Vegetation in the Niger River Delta (with a total land area of 7.5 million ha) consists of extensive mangrove forests, brackish swamp forests, and rainforests. The large expanses of mangrove forests are estimated to cover approximately 500,000 to 860,000 ha of land. According to FAO (2007), mangrove surface in Nigeria is higher (nearly 1 million ha). Using satellite images, Giri et al. (2010), however, estimated the area of mangroves at 654,000 ha.

Over 80% of the delta floods seasonally, with swamps and pools remaining when floodwaters subside. In addition to precipitation, tidal movements and the Niger River flood determine the hydrological regime. The flood begins toward the end of the rainy season in August, peaks in October, and tapers off in December. The delta experiences a strong tidal influence with sea water penetrating as far inland as the riverine floodplain of the Nun River (Brown and Thieme, 2013).

Swamp forests of the upper riverine floodplain grade into mangrove forests on the lower tidal floodplain. This ecoregion is delineated based on the extent of the Niger Delta and is distinguished by a rich freshwater fauna. The Benin River and the Imo River mouths delimit the western and eastern boundaries of the ecoregion (Brown and Thieme, 2013)

Some mangrove area loss has occurred over the last two decades mainly caused by coastal erosion and deforestation. Nowadays, mangroves face serious threats such as oil pollution and uncontrolled exploitation of wood. Nigeria is the eighth largest oil exporter in the world. Development of the abundant oil and gas resources in the delta has created a host of environmental and social challenges.

In 1956, Shell discovered crude oil; commercial production began in 1958 (Nwilo and Badejo, 2007). Today, there are 606 oil fields in the Niger Delta, of which 360 are on-shore and 246 off-shore. Nigeria is the largest oil producer in Africa and the sixth largest in the world, averaging 2.2 million barrels per day (Pieprzyk et al., 2009). Nigeria's economy is heavily dependent on earnings from the oil sector, which provides 20% of GDP, 95% of foreign exchange earnings, and about 65% of budgetary revenues (Nwilo and Badejo, 2011).

Petroleum exploration and production and export of oil and gas resources have improved the economy but progress has not been as fast as one might have expected. Nigeria, and other African states, is still showing relatively low levels of development. Developing nations in other regions such as Latin America show relatively high life expectancy, at considerably lower oil production levels (Figure 1.3).

Activities associated with petroleum exploration, development and production have had detrimental impacts on the soils and sediments, surface and groundwater, marine environment, terrestrial and aquatic ecosystems in the Niger Delta. Discharges of petroleum hydrocarbons and petroleum–derived waste streams have caused environmental pollution, adverse human health effects, socio–economic problems and widespread environmental degradation (Ite et al., 2013).

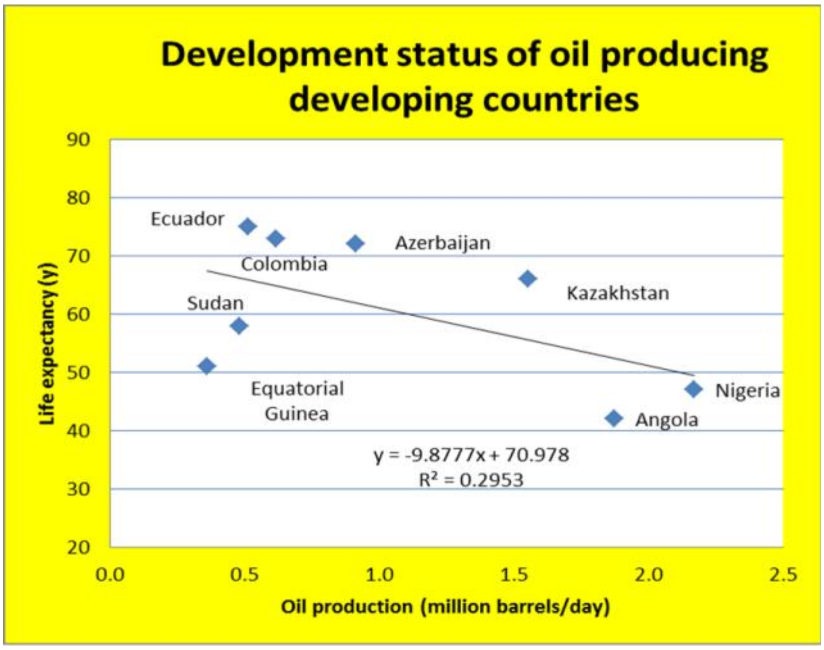

Figure 1.3. Life expectancy of oil exporting developing countries
Source: Pieprzyk etal (2009)

Offshore oil drilling activities are major sources of oil pollution, mainly because of leaking pipes, accidents, ballast water discharges, and production-water discharges. Drilling also involves the use of heavy metals such as vanadium and nickel, and contamination of seawater with these metals is known to affect plants and animals. Oil pollution damages coastal resources and habitats, as well as fisheries, reducing catches and incomes (UNEP, 2013). This increases poverty among indigenous populations and may leave them no choice but to take up livelihoods which are environmentally unsustainable.

Oil and gas installations are spread throughout the central and western parts of the Niger Delta and there are four tanker ports at the delta face. The Nigerian Oil Industry is located mostly in the mangrove forests. The activities of the numerous oil exploration companies have led to fragmentation, deforestation and degradation of the mangrove forest ecosystem.

This report aims to determine the impact of oil production activities on mangroves in the Niger Delta. It generates the best available estimate of oil discharge, and develops and applies an evaluation method for assessing impact on mangrove vegetation including the levels of carbon releases that have been caused by loss of previously vital vegetation. The report makes further recommendations for better monitoring of spills in order to facilitate improved assessment of carbon releases.

The report is organized as follows: Chapter 2 summarizes the impact oil can have on mangrove vegetation; Chapter 3 describes the methodology that is used in the analysis. This is followed by an overview of the results in Chapter 4, a brief discussion (Chapter 5), and a concluding chapter which also provides some recommendations.

2. THE IMPACT OF OIL

Oil drilling in or near mangrove shorelines has significant adverse impacts (US Fish and Wildlife Services, 2013). Oil spills can cause a variety of damage to marsh vegetation as they may reduce growth, photosynthetic rate, stem height, density, and above ground biomass, eventually leading to plant death (Onwurah et al., 2007).

Mangrove-related biological resources at risk in a spill situation can be affected in at least two principal ways: firstly, from physical effects; secondly, from the true toxicological effects of petroleum (Hoff, 2010). Introduction of significant quantities of crude oil into the aquatic ecosystem will cause increases in biochemical oxygen demand, reduction in dissolved oxygen concentration,and increased temperature and pH of the water body.

Field and laboratory studies show that in many circumstances, oil harms or kills mangroves, but it remains unclear how the harm is done and what mechanism toxicity is using. While there is consensus that oil causes physical suffocation and toxicological/physiological damage, researchers disagree as to the relative contributions of each mechanism which may vary with type of oil and time since the spill (Hoff, 2010).

Oil spilt on water spreads immediately. The gaseous and liquid components evaporate. Some become dissolved in water and may oxidize, and some undergo bacterial changes and eventually sink to the bottom. The soil is then contaminated, and this has a gross effect upon terrestrial and aquatic life. As the evaporation of volatile lower molecular weight components affect aerial life, so the dissolution of the less volatile components with the resulting emulsified water, affects aquatic life (Badejo and Nwilo, 2004).

In the 1986 Bahía las Minas (Panama) spill, scientists monitoring the effects of the oil on mangroves recorded a band of dead and dying trees where oil had washed ashore five months previously. A year and a half after the spill, dead mangroves were found along 27 km of the coast (Duke et al. 2004).

Researchers who compared oil spill impacts elsewhere found similar effects, but differences in the magnitude of the effect. The degree of impact appeared to be related to the physical factors that control oil persistence on the shoreline and exposure to waves and currents (Hoff, 2010). In Australia, Melville et al. (2009) reported little immediate impact of a spill, but significantly higher seedling mortality and defoliation after six months particularly in the upper intertidal zone.

An area of mangroves that has been destroyed by petroleum is susceptible to other problems. These areas may not be suitable for any native plant, at least for a while. As the soils become too toxic, a non-native invasive species of palm, Nypa fruticans, replaces original mangrove species. This invasive species has a shallow root system that destabilizes the banks along the waterways, further impacting sediment distribution lower in the delta system.

Mangroves have evolved a complex series of physiological mechanisms to enable them to survive in a low-oxygen, high-salinity world. Many, if not most, of these adaptations depend on unimpeded exchange with either water or air. Pneumatophores and their lenticels tend to be located in the same portions of intertidal areas most heavily impacted by stranded oil. While coatings of oil can also interfere with salt exchange, the leaves and submerged roots of the mangrove responsible for mediation of salts are often located away from the tidally influenced (and most likely to be oiled) portions of the plant (Hoff, 2010).

Oil spills in the Niger Delta have been a regular occurrence, and the resultant degradation of the surrounding environment has caused significant tension amongst the people living in the region. Environmental groups, the Federal Government, and the foreign oil companies operating in the Niger Delta only recently, began to take steps to mitigate these impacts. Large areas of the mangrove ecosystem have also been destroyed. The mangrove forest is in some places no longer in a healthy enough state to sustain wood extraction (Nwilo and Badejo, 2007).

The severity of these frequent and collectively massive spills is amplified by other environmental problems in the region. In particular, the region is plagued with seasonal floods and has a shortage of land for development. This means that contaminated water and sediment is washed extensively over the communities, roads, and farmlands which become partially or totally submerged by these floods (UNDP, 2006).

2.1. CHEMICAL DAMAGE

Crude oil is acutely toxic to mangroves, as has been shown in laboratory and field experiments and was observed after actual spills. Seedlings and saplings, in particular, are susceptible to oil exposure: in field studies, more than 96% of seedlings exposed to weathered crude oil died. Other studies found that mangrove seedlings could survive in oiled sediments but only up to the point where their food reserves were exhausted (Hoff, 2010).

Fresh crude oil is more toxic than weathered crude. From another set of studies investigating the toxicity of two oil types (a light crude and a heavy Bunker C) to mature mangroves over a period of two years. It was found that most tree deaths occurred during the first six months after treatment (Hoff, 2010).

Crude oil is associated with toxic heavy metals most of which contaminate the soil through underground deposits, especially lead and chromium. Iron is present in great abundance in tropical and subtropical aquifers and is also associated with crude oil deposits (Enujiugha and Nwanna, 2004).

The term Polycyclic Aromatic Hydrocarbons (PAHs) refers to a group of chemically-related, environmentally persistent organic compounds of various structure and varied toxicity. They affect organisms by interfering with cellular membranes and associated enzyme systems. PAHs have been shown to cause carcinogenic and mutagenic effects and are potent immunosuppressants (Toxipedia, 2013).

Crude oil contains hydrocarbon compounds and nonhydrocarbon compounds including porphyrins and their derivatives. Priority contaminants found in petroleum hydrocarbons and crude oil include benzene, heptanes, hexane, isobutene, isopentane as well as PAHs such as benzo[a] anthracene, benzo[b] pyrene etc. (Onwurah et al., 2007).

PAHs have been found in Nigerian waterways originating from industrial effluents and petrochemical products. Pollution may arise from oil well drilling production operations, transportation and storage, and refining. Some non-combusted hydrocarbons escape into the environment during the process of gas flaring (Onwurah et al., 2007).

Toxicity of PAHs in aquatic environments has been extensively assessed. Pampanin and Sydnes (2013) provide an overview of damage, mostly focussing on fish species. Crude oil toxicity is mainly explained by the presence of PAHs, which leads to the disruption of the development, immunity, reproduction, growth and survival of aquatic organisms (Onwurah et al., 2007).

Research has linked the presence of PAHs in soil to increased incidence of chlorophyll damage. There is a strong correlation between PAH concentration in sediments and loss of leaf pigments (Hoff, 2010). Plants can absorb PAHs from soils through their roots and translocate them to other plant parts (Toxipedia, 2013). Hydrocarbons can come into direct contact with vegetation in many ways: through spillage onto roots, stems or leaves; through spillage onto soil; through dissolved hydrocarbons in the groundwater in the root zone of the vegetation; or via air surrounding the vegetation.

Impacts on vegetation depend on the type and quantity of the chemicals involved, the development stage of the plants concerned, and the means through which the plants came into contact with the hydrocarbon. Different vegetation types also have varying sensitivity to hydrocarbons (UNEP, 2012). As the Niger Delta has high rainfall, any delay in cleaning up an oil spill leads to oil being washed away and almost always ending up in the creeks.

When oil reaches the root zone, crops and other plants experience stress and can die something which has been observed on a routine basis in Ogoniland. At one site, the research team of UNEP (2011) found heavy contamination present 40 years after an oil spill occurred, despite repeated clean-up attempts.

2.2. PHYSICAL DAMAGE

The physical effects of oiling (including covering or blocking of specialized tissues for respiration or salt management) can be as damaging to mangroves as the inherent toxicity of the oil. Many reviews indicate that physical mechanisms are the primary means by which oil adversely affects mangroves, but some species seem to be able to tolerate or accommodate exposure to moderate amounts of oil on breathing roots (Hoff, 2010).

Spilled petroleum hydrocarbons are drawn into the soil by gravity until an impervious horizon is met, for example bedrock, watertight clay or an aquifer. Poor miscibility of crude oil accounts for accumulation of free oil on the surface of ground water which may spread over a wide distance to pollute zones very far away from the point of pollution (Onwurah et al., 2007).

Many oil products are highly viscous and crude oils and heavy fuel oils can be deposited on shorelines in thick, sticky layers that may either disrupt or completely prevent normal biological processes of exchange with the environment. Even if a petroleum product is not especially toxic in its own right, when oil physically covers plants and animals, they may die from suffocation, starvation, or other physical interference with normal physiological function (Hoff, 2010).

Physical impacts of oil are linked to adaptive physiology of the mangrove plants, independent of any chemical toxicity in the oil. The additional impact from acute or chronic toxicity of the oil would exacerbate the influence of physical smothering. Some studies indicate that mangroves can tolerate some coating without apparent damage, but many others identify physical effects of oiling as the most serious (Hoff, 2010).

2.3. IMPACT ON VEGETATION

Oil drilling in or near mangrove shorelines has significant adverse impacts. Petroleum oils and their by-products can kill mangroves by coating aerial and submerged roots and from direct absorption. Some severe effects, including tree death, can take place months or years after a spill. Damage from the actions of mechanical abrasion, trampling, or compaction during clean-up can exacerbate negative environmental impacts (US Fish and Wildlife Service, 2013).

Mangrove communities are complex and, as might be expected, the impacts of oil on the associated plants and animals vary. The available information suggests that, while oil spills undoubtedly affect animal communities, these appear to recover more quickly than the mangroves themselves. Because of this, longer-term effects are likely to be related to death of the mangroves and loss of the habitat that supports and protects the community (Hoff, 2010).

Oil pollution, apart from causing depletion of oxygen and suffocation of aquatic species, affects plants and cultivated crops in lowland areas characterized by seasonal flooding. Soil pollution may cause oxygen depletion at the rhizosphere by hydrocarbon-degrading micro-organisms. This directly affects the overall physiology of the plant by reducing plant growth (Enujiugha and Nwanna, 2004).

Comparing spill impacts at several mangrove sites indicates that effects are related to geomorphology and hydrologic kinetics of the mangrove ecosystem that, in turn, control whether oil persists in the mangrove habitat. Oiled mangrove forests sheltered from wave and current exposure are likely to be more severely affected than well-exposed mangrove areas. The density of burrows from associated organisms such as crabs can increase the persistence of oil by allowing deep penetration into sediments (Hoff, 2010).

Kairo et al. (2005), studying damage of oil spills in Kenya, reported that the damage survey conducted one week after the spill recorded mangrove trees and saplings as most stressed (showing increased defoliation and yellowed leaf colour). The immediate response to the oil spill was the withering of the leaves and increased rate of defoliation. At the same time, mortality of mangrove saplings increased. The mortality of saplings continued for several months in highly impacted areas (Kairo et al., 2005).

Observed changes on the leaves of the affected mangroves were: increased defoliation, spots, perforations, yellowing, twisting and necrosis. The same symptoms have been reported in other mangrove areas of the world affected by oil (e.g. Burns et al., 1993). It is likely that a general reduction in leaf area, and hence loss of mangrove productivity, will occur in the affected area during the first 3 months after the spill (Kairo et al., 2005).

The effects of oil spills on the mangroves disrupt their structural development. Death of saplings and young trees is expected during the first year after the spill. Mangrove trees are slow-growing and take decades to be replaced by mature vegetation. The loss of a large number of trees may compromise the forest structure, making it unlikely to recover naturally. Natural recovery rates following damage vary from three years to several decades for badly damaged mangrove areas (Kairo et al., 2005).

A review article by Burns et al. (1993) summarized the results of a long term assessment of an oil spill into a coastal fringe mangrove ecosystem in Panama. The study, which combined chemical and biological assessment methods, demonstrated that a time period of up to 20 years or longer is required for deep mud coastal habitats to recover from the toxic impact of catastrophic oil spills. This is due to the long term persistence of oil trapped in anoxic sediments and subsequent release into the water column.

Burns et al. (1994) reported an unexpected persistence of aromatic hydrocarbon residues of the spilled crude oil in anoxic muds of coastal mangroves. Apparently, mangrove muds serve as long-term reservoirs for chronic contamination for over five years. Repeated pollution incidents lead to an increased proportion of dead mangrove roots in sediment cores. This was related to contaminant loading and was detectable for at least 20 years after major oil spills. The authors suggest this period is the minimum time-scale that is to be expected for the loss of toxicity of oil trapped in muddy coastal habitats impacted by catastrophic oil spills.

Another paper on the Panama spills is by Levings et al. (1994). The epibiota of fringing mangroves were examined in three habitats: (1) shoreward reef flats that fronted the open sea, (2) edges of channels and lagoons, and (3) banks of streams and man-made cuts that drained interior mangroves into lagoons. Each habitat was repeatedly oiled over a period of five years. The processes that released oil residues were at least partially independent and toxic hydrocarbons were likely to be released from sediments over the long term.

Prop roots that entered the water 15-18 months post-spill were more likely to die at oiled than unoiled sites in channels and streams, but not on the open coast. Five years after the spill, oiled sites were typified by persistent reductions in epibiota in two of the three habitats, and overall reductions in the surface area of submerged prop roots. Within Bahía las

Minas, it was estimated that the net result 5 years post-spill was a 33% reduction in the standing crop on the open coast (Levings et al., 1994).

Burns and Yelle-Simons (1994) showed that initial weathering removes most of the volatile hydrocarbons, and alkanes in oil adsorbed all sediments within 6 months after the spill. The initially rapid rate of degradation is however not maintained. Oil leaching out of heavily contaminated sediments was accumulated for at least 5 years, local organisms accumulating alkylated polynuclear aromatic hydrocarbons (PAHs) in the naphthalene through the benzoperylene elution range. A change in the composition of the accumulated aromatics indicated depletion of the most soluble and most acutely toxic hydrocarbons in the readily leachable reservoirs in year 5. The next five years will probably be the critical time frame when impacts grade from acutely lethal into sub lethal.

Different studies confirm the findings above. Burns et al. (2000) studied weathering and bioremediation of oil spills in Australian mangroves. They reported exponential decreases of hydrocarbons in mangroves, irrespective of initial oil concentrations, oil penetration depth, or oil dissipation or bioremediation. After 13 months, there were still n-alkanes in residual oils suggesting there was unlikely to be any change in the stable internal biomarkers of the oils over this time period.

In the case of Nigeria, where spillages are not immediately attended to, oil spills often lead to fires, causing total or partial destruction of vegetation. While such fires tend to be localized, more extensive fires, especially in forested regions, have the capacity to change species diversity over significant areas

Direct effects can occur at different points of the production cycle. Environmental hazards associated with drilling wastes include land, water and air pollution. Farming is the major land use system in Nigeria, especially in the Niger Delta region. The most significant in this aspect of environmental pollution in Nigeria is thus farmland pollution. Consequences include alteration in soil physical, biological and chemical properties, loss of soil fertility, stunted plant growth and reduced crop productivity (Hoff, 2010).

Poor miscibility of crude oil accounts for accumulation of free oil on the surface of ground water which may migrate over a wide distance to pollute zones very far away from the point of pollution. On land, crude oil spills have affected food productivity. A good percentage of oil spills that occurred on the dry land between 1978 and 1979, affected farm-lands. Crude oil affects germination and growth of plants, and may have an impact on soil fertility (Onwurah et al., 2007).

Severe crude oil spills in Cross-River state have forced farmers to migrate out of their traditional homes. Petroleum hydrocarbons ‘sterilize’ the soil and prevent crop growth and yield for a long period of time. The yield of yam tuber, for example, is adversely affected by some hydrocarbons. This is not the only food crop that suffers from oil contamination.

Oil spillages remain the major cause of depletion of vegetative cover and the mangrove ecosystem in the Niger Delta of Nigeria. Crude oil contamination of land affects soil mineral and organic matter content, cation exchange capacity, redox properties and pH values. It creates anaerobic conditions in the soil, which – coupled to waterlogging – may result in accumulation of toxic aluminium and manganese ions (Onwurah et al., 2007).

Large areas of the mangrove ecosystem have apparently been destroyed in the Nigerian coastal environment. The mangroves, once a source of both fuel wood for the indigenous people and a habitat for the area's biodiversity, is now unable to survive the oil toxicity of its habitat (Nwilo and Badejo, 2007). The potential impact of this on the carbon cycle is considerable.

Mangroves are 'among the most carbon-rich forests in the tropics', and have been reported to store over 1,000 tonnes of carbon per ha. Estimates for Asia vary between 566 and 1,259 tonnes per ha (Kauffmann and Donato, 2012). Data for Africa are lacking. A generic estimate provides an average of 1,031 tonnes of carbon for the Indo-Pacific region (Donato et al., 2011). Nearly 20% of this is stored in soils.

Affected mangroves suffer a reduction in levels of stored carbon. Yeh et al. (2010) assumed a 20-40% soil carbon loss from infrastructure activities in conventional oil and gas production as a result of scraping of surface soil for roads, drainage, drill pads, drilling wells, etc. Soil carbon loss from surface mining would be 70-90% due to higher disturbance in mining sites and other facilities.

These are long-term effects. Yeh et al. reported that most (84-100%) of total (above-ground and below ground) forest biomass still was missing 20 years after disturbance. This has been confirmed by other studies.

Different types of indirect effects have been reported:

- Loss of crop production capacity
- Loss of fish and shrimp production capacity
- Loss of livelihoods
- Accelerated mineralisation of Soil Organic Matter (SOM)
- Changes in food webs and ecosystem composition

Indirect impacts (of fossil oil production) on vegetation would include increased deposition of dust, spread of invasive and noxious weeds, and the increased potential for wildfires. Dust settling on vegetation may alter or limit plants' abilities to photosynthesize and/or reproduce (Wikipedia, 2013).

Chronic effects of oil spills can be measured over long time periods, potentially a decade or several decades. The experimental (i.e., intentional and controlled) 1984 TROPICS spill in Panama confirmed long-term impacts to oiled mangroves (termed "devastating" by the original researchers who returned to the study sites ten years later). They found a total mortality of nearly half of the affected trees and a significant subsidence of the underlying sediment. This was compared to 17-percent mortality at seven months post-oiling, a level that appeared to be stable after 20 months (Hoff, 2010).

Losses of mangroves or reduced mangrove vitality are bound to reduce their potential for carbon sequestration. Estimates for sequestration rates vary between 0.6 tonne/ha/y

(Chmura et al., 2003) to 18.0 tonne/ha/y (UNEP, 2011). Recent scientific papers (Alongi [2012]; Breithaupt et al., [2012]; Nelleman et al. [2011]) provide values around 1.5-1.7 tonne/ha/y. We follow Breithaupt et al. (1.63 tonne/ha/y).

2.4. RECOVERY

The time needed for full recovery after oil damage is variable. According to the National Research Council (2003), oil deposits in the substrate of mangrove environments not affected by tidal movements are likely to remain there ‘for years and possibly decades’. Santos et al. (2012) reported a recovery time for damaged mangroves in Brazil exceeding seven years, with recovered stands showing limited growth potential due to reduced structural development. This held especially for inland mangroves and regions with restricted water flow (Santos et al., 2012).

In Nigeria, the Independent IUCN Niger Delta Panel observed residues of so-called ‘Chemicals of Special Concern’ remaining for over 15 years, in spite of remediation efforts, natural degradation and significant flooding. The levels obtained were higher than international limits. In the view of the panel, these conditions were not conducive to ecosystem recovery (IUCN, 2013), which may be expected to require at least 20 years.

3. METHODOLOGY

3.1. DATA SOURCES

A large number of studies, reports, websites and other sources provide data on oil spills and their impact on Niger Delta. Most refer to a limited number of sources. The background of available sources of data and information is diverseand we identified the following categories:

- Category 1: scientific papers, published in refereed journals, book chapters
- Category 2: reports by international institutions including UN, conference papers
- Category 3: newspapers, and reports by NGOs, pressure groups, etc.
- Category 4: papers and reports by stakeholders that are directly involved in (damage from) oil production: oil companies, etc.

This report focuses mainly on scientific papers plus reports by independent international institutions. Major sources that have been used are presented in Table 3.1. These include reports by international organisations (UNDP, UNEP, Amnesty International), scientific papers by Nigerian or international experts (Nwilo and Badejo; Egberongbe et al.; Jernelöv, Galadima et al., Francis et al., Adekunle et al.). Data and conclusions have been compared to scientific journal papers reporting on spills in other parts of the world, such as the USA (for example, Hoff, 2010), Latin America (Duke et al., 1997; Santos et al., 2012), Asia, or Australia (Burns et al., 1993; Melville et al., 2009).

Table 3.1 Literature sources used

Source	Period covered	Region covered	Remarks
Nwilo and Badejo (2001)	1976-2001	Bayelsa state	Book chapter
UNDP (2006)	1976-2005	Niger Delta	International organisation
Egberongbe et al. (2006)	1976-2005	Bayelsa state	Conference paper
Obot et al. (2006)	2006	Niger Delta	International commission incl. Fed. Ministry of Environment
Amnesty International (2009)	1976-1996	Niger Delta	International organisation
Jernelöv (2010)	1970-2000	Niger Delta	Scientific journal
UNEP (2011)	Up to 2011	Ogoniland[1]	International organisation
Galadima et al. (2011)	1976-1996	Nigeria	Scientific journal
Francis et al. (2011)	2006-2010	Niger Delta	Intern. research centre
Amnesty International (2013)	2007-2012	Niger Delta	International organisation
Adekunle et al. (2013)	No data	Niger Delta	Book chapter
Lindén and Pålsson (2013)	No data	Ogoniland	Scientific journal

Source: compiled by the authors

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[1] Elme, Tai, Gokana and Khana LGA's in Cross River State

An overview of the most important sources used in this report is given in Annex 1.

3.2. THE OIL PRODUCTION PROCESS

Oil production is a complex process which involves a large number of activities which may impact the environment. As a first step, different phases of the oil production process are identified: (i) exploration, (ii) extraction, (iii) transport & storage, and (iv) post-extraction. Activities undertaken in each phase may affect mangrove vegetation in different ways. An overview of potential impacts is given in Table 3.2.

Table 3.2 Activities in fossil oil production and their impacts

Phase	Activities	Direct effects	Indirect effects	Impacts
Exploration	Road development	Clearing of vegetation	Invasion of exotic species	Direct carbon releases
Extraction	Housing	Soil dehydration	Soil acidification	Forgone carbon sequestration
Transport & storage	Research	Soil Compaction	Loss of crop productivity	
Post-extraction			Loss of carbon sequestration	

Note: impacts refer to all activities
Source: this study, Yeh et al. (2010)

Figure 3.1 provides an overview of activities and impacts of the first phase, exploration. In this phase, three activities can be identified. They often include clearing of vegetation and affecting of soil hydrology. Indirect effects are related to introduction of invasive species, and soil acidification. Final effects refer to direct carbon loss, and loss of production and of sequestration capacity which can be significant.

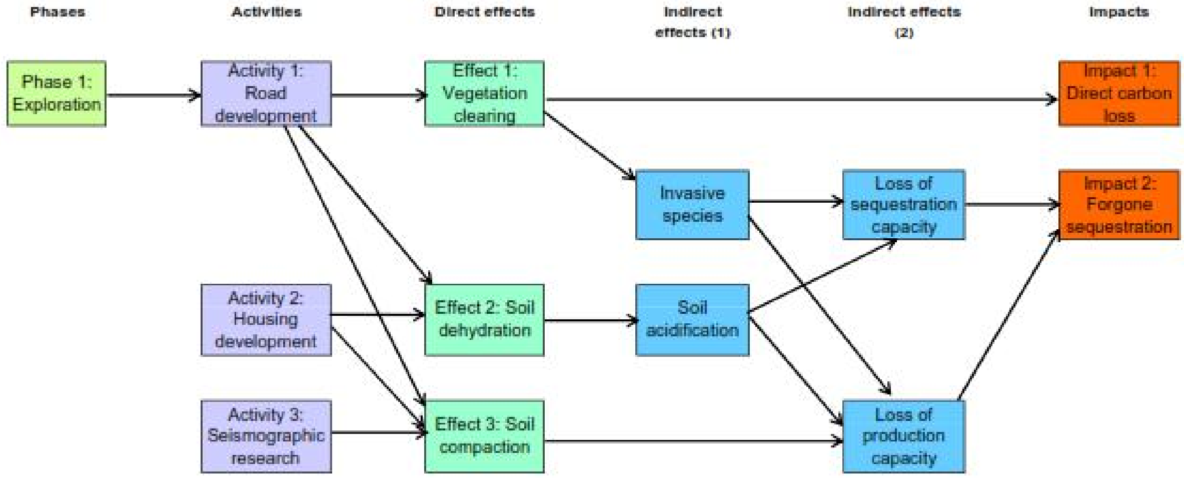

Figure 3.1. Activities, effects and carbon related impacts of the exploration phase
Source: this study

Drilling may lead to clearing of vegetation, and soil affecting, especially during the preparation. It is also associated with oil spills and flaring of natural gas. These activities may affect vegetation and soil productivity, and cause both direct carbon release and loss of sequestration capacity (Figure 3.2). Damage caused during drilling depends on the scale at which activities occur, and safety precautions. Risks are severely affected by use and discharge of potentially harmful substances including drilling muds which can be based on water or oil solutions (Adekunle et al., 2013).

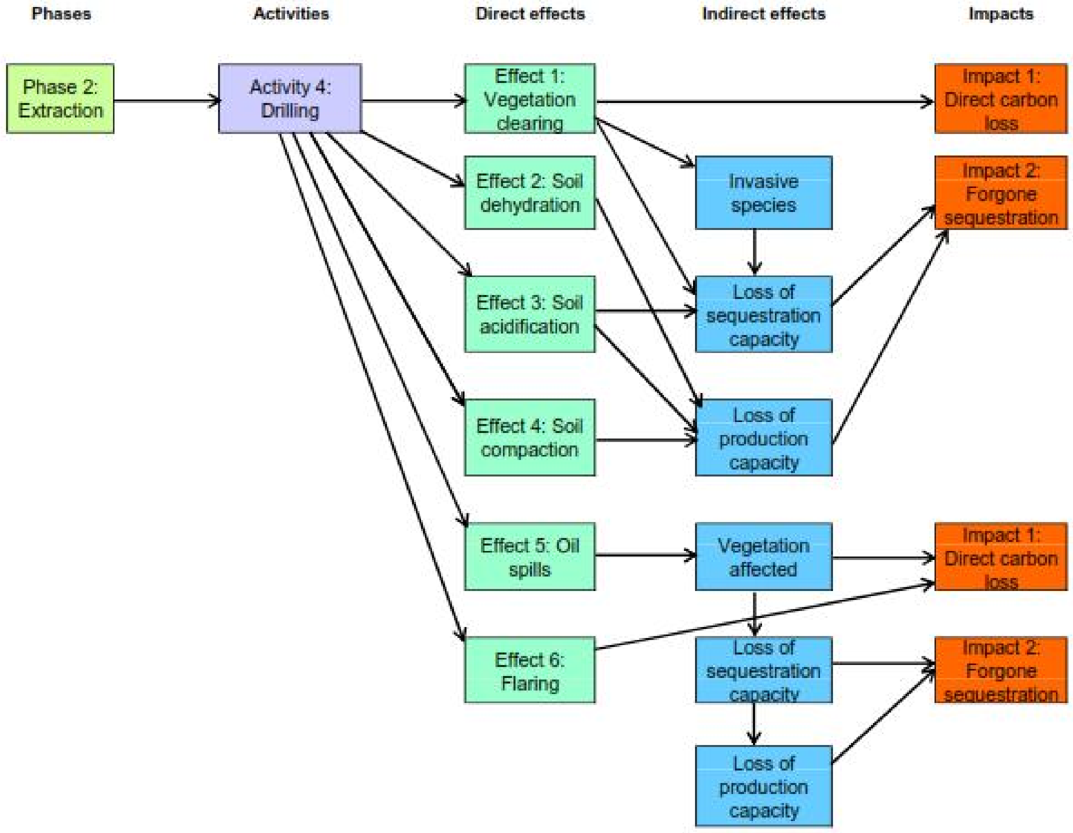

Figure 3.2. Activities, effects and carbon related impacts of the drilling phase
Source: this study

Oil extraction leads to many of the same effects as drilling, oil spills and flaring (Figure 3.3). According to the National Research Council (2003), releases from oil extraction can include accidental spills of crude oil from blow outs, surface spills of crude from platforms, or slow chronic releases associated with the disposal of water produced from oil or gas-bearing formations during extraction (referred to as produced water) or oil-bearing cuttings created during the drilling process. Volatile organic compounds (VOCs) associated with, or dissolved in, petroleum are released during extraction activities.

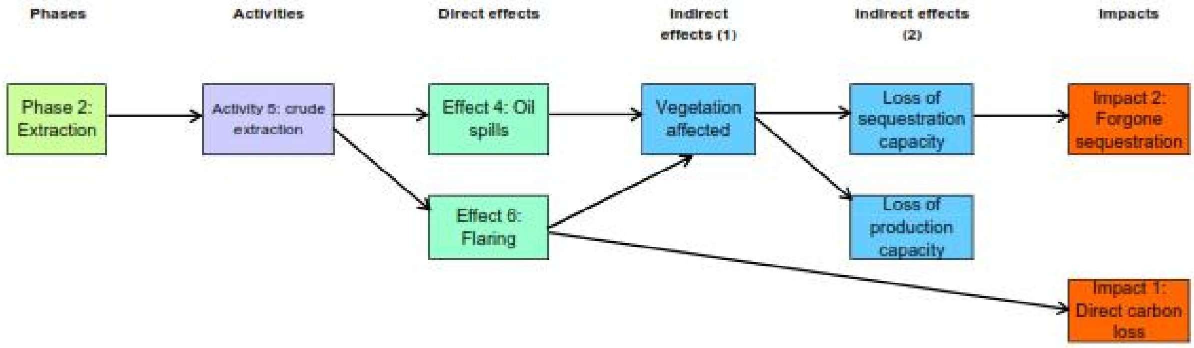

Figure 3.3. Activities, effects and carbon related impacts of oil extraction
Source: this study

Releases from extraction activities taking place near shore or even on shore can pose significant risks to sensitive coastal environments. They can occur as large spills or as slow, chronic releases concentrated in production fields (National Research Council, 2003).

Construction of pipelines basically has similar effects as (preparations of) drilling (Figure 3.4).

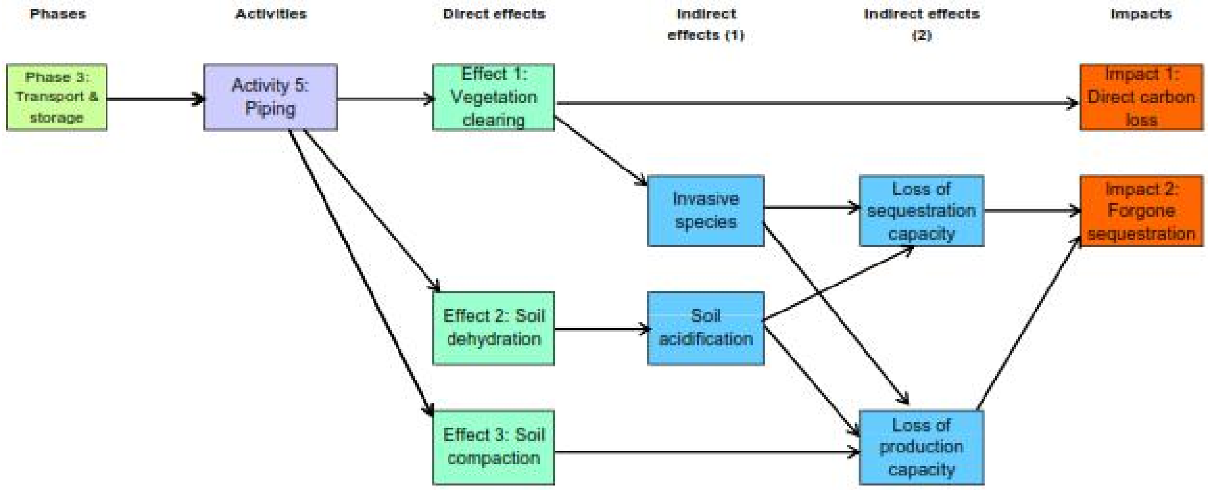

Figure 3.4. Activities, effects and carbon related impacts of piping
Source: this study

Transport is associated with oil spills which may have direct and indirect impacts. If it causes farmers to open new capacity where the old has been affected, this may lead to direct carbon loss (Figure 3.5). Spills from transportation_activities may release a wide variety of petroleum products, each of which behaves differently in the environment (for example light distillates tend to evaporate rapidly), or contain different concentrations of toxic compounds like PAH. VOC are also released from tankers underway or involved in loading and offloading activities. Again, these compounds evaporate rapidly into the atmosphere and thus appear to have a short residence time in marine waters. Despite recent and substantive decreases in the size and frequency of petroleum spills from tankers, the potential for a large spill is significant, especially in regions without stringent safety procedures and maritime inspection practices (National Research Council, 2003).

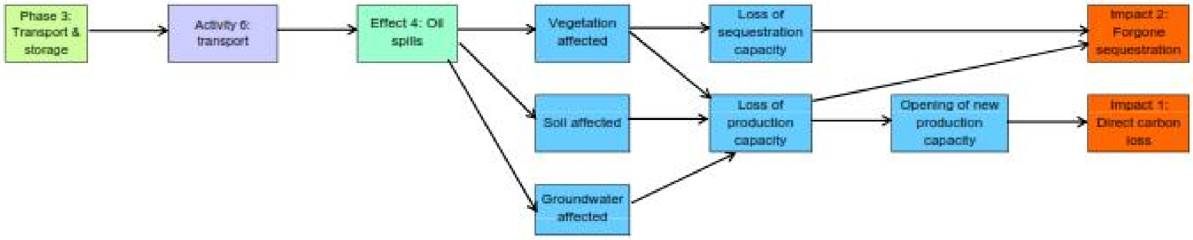

Figure 3.5. Activities, effects and carbon related impacts of transport. Source: this study

After ending the extraction and transport of oil, installations that have been used need to be cleaned and dismantled. If this is not done correctly, additional spills may occur during the post-production stage due to corrosion and erosion of installations (Figure 3.6).

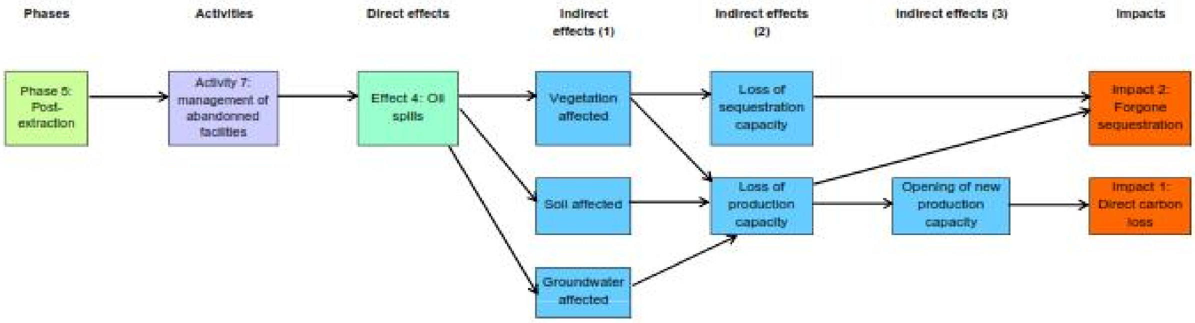

Figure 3.6. Potential consequences of incorrect cleaning and dismantling of installations that are no longer operational. Source: this study

3.3. DAMAGE ASSESSMENT

The type of damage that may be caused in the oil production process varies strongly. Some mostly occurs early in the process (for example, exploration, road construction, and drilling of wells). Not all activities equally affect the environment. This study focusses on the following types of damage:

- Clear-cutting of vegetation
- Replacement of vegetation by other plant species
- Damage to mangroves due to oil spills and toxic waste
- Loss of carbon sequestration capacity

Clearing of mangrove vegetation is done to prepare sites for prospecting, construction of drilling sites, housing, roads and pipelines, etc. Staff, equipment and installations have to be transported and each new drilling activity requires roads to be developed. Given the character of most of the mangrove soils, drainage may also be required. Alternatively, ‘right of way’ development may require digging new waterways for transportation of heavy machinery. According to UNEP (2011), such waterways may be up to 30m wide (Figure 3.7)

A right of way more than 30 metres wide cut through mangroves

Figure 3.7 ‘Right of way’ for transportation of installations in Ogoniland
Source: UNEP (2011)

Clearing vegetation for road, site or pipeline installations sometimes gives way to new vegetation. It has been reported that as much as 10% of mangrove trees have been replaced by invasive plant species (Nipa palm) in Ogoniland (UNEP, 2011). This phenomenon will also be found in other parts of the Delta as well. Sites that have been abandoned will be left to regrow.

Vegetation may also be affected by oil spills or disposal of toxic waste near production sites or transportation routes. With respect to the spills, incidental spills are considered as unique events. Each spill will affect a certain amount of land. the area of dead vegetation has been calculated following observations from the literature.

The impact of toxic waste is also expressed as area of dead mangrove vegetation.

Following land clearing or tree mortality caused by oil spills or chemical waste, it will take years before the vegetation recovers. During this period, carbon sequestration will be below the potential level. The amount lost will depend on the speed of recovery. Recovery following (serious) oil contamination incidents requires a great manjy years and possibly decades. We define the Recovery Period (RP) as the average time mangrove requires recover fully from a spill.

Literature reporting on impacts of chronic oil contamination is scarce. According to the US National Research Council, recent vegetation disturbance history is one of the factors determining the degree of impact and recovery from a spill (other factors being the geological structure of the shoreline, type of oil, weather conditions, thickness and lateral continuity of the slick, and time of year. Continuous or intermittent discharge of waste (produced water, drilling fluids, deck washings, etc.), or from repetitive, accidental spills (numerous small spills and/or a small number of major spills during the life of a field) may lead to chronic contamination (National Research Council, 2003).

Effects of chronic contamination have not been quantified. Experiments with realistic doses of PAH maintained these chemicals in the sediments to provide a chronic exposure regime. Damage was, however, only assessed for animal species.

High Frequency Effect (HFE) is the impact that frequent oil contamination incidents have on both the type and extent of the damage caused to mangrove vegetation. In the low damage scenario, no effect is assumed. The Probable Scenario assumes an additional damage of 50% of the level that has been observed for one-time incidents by Duke et al. (1997).

Indirect effects refer to compensation for crop or fish production capacity that has been lost by oil related damage. They are not considered in this study.

4. RESULTS

4.1. SPILLS

Oil production activities are more or less equally distributed over the Niger Delta (Figure 4.1). Exceptions are Ondo state in the north west and Cross River in the extreme north east. While the northern parts of these states (as well as Edo) are not affected by the oil industry, it must be assumed that the entire mangrove zone is impacted, either directly from losses and waste from onshore production activities, or indirectly from offshore oil spills, or losses related to oil transport (shipping or pipelines).

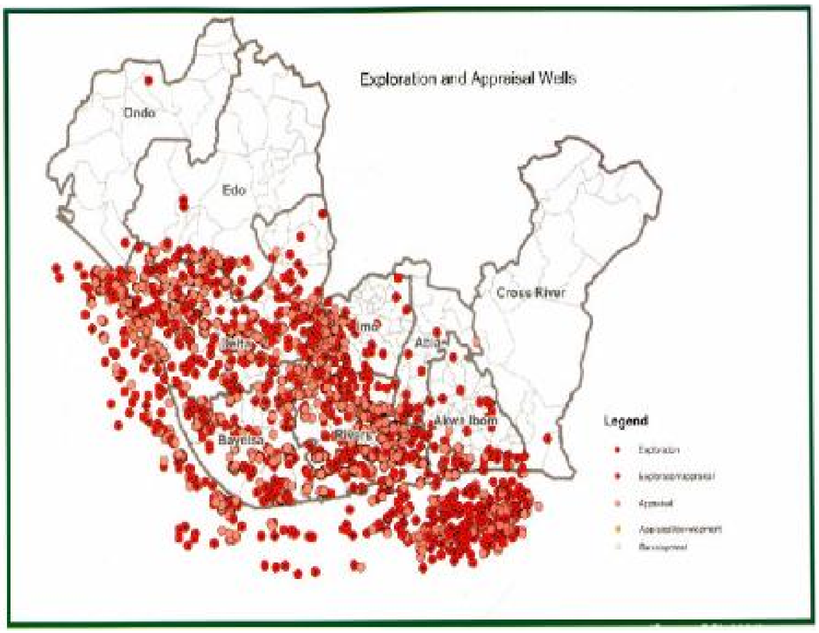

Figure 4.1 Onshore and offshore oil production activities in the Niger Delta
Cited by Achebe et al. (2012)

It is hard to obtain reliable statistics on oil spills in Nigeria. The system for reporting spills has been heavily criticised by local and international experts. Figures provided by the companies and reported by the Department of Petroleum Resources (DPR) are not expected to reflect the full scale of oil spillage. After comparing data formally reported by oil companies with alternative sources, Amnesty International (2013) concluded that the number of spills and the quantity of oil spilt are frequently underestimated.

This is confirmed by other sources. According to Ite et al. (2013), large numbers of spills go unreported; the volume of oil spilt has been estimated at ten times the officially reported figures. Underreporting has been related to guidelines issued by the Nigerian National Petroleum Corporation (NNPC), which only requires major spills to be reported.

In order to obtain a reliable assessment of oil spillage, our study focuses on quantitative studies by independent authors or institutions. Quantifications reported by oil companies, local stakeholders and newspapers have not been included. Data provided by DPR or other oil industry-related Government services were not included unless they had been scrutinised by authors presenting their work in scientific papers or reports by international institutions. In all cases, original sources have been included when available (Table 4.1).

A number of scientifically reviewed (Category 1) papers has been used. Papers published before 2000 were not included in the analysis which focusses on scientific papers (Nwilo & Badejo, Galadima et al.), plus major international reports by UNEP (2011) and Amnesty International (2009 and 2013). Scientific work (Category 2) further includes a conference paper (Egberongbe et al.) and a report by a US-based research centre (Francis et al.).

Table 4.1 Number of oil spills in the Niger delta

Source	Incidents	Period	Incidents per year	Remarks
Nwilo and Badejo (2001)	4,647	1976-1996	232	
Idem	2,097	1997-2001	419	
UNDP (2006)	6,817	1976-2005	273	
Egberongbe et al. (2006)	9,107	1976-2005	314	
Amnesty International (2009)	4,835	1976-1996	242	Citing DPR
Galadima et al. (2011)	4,647	1976-1996	221	Citing DPR
Francis et al. (2011)	2,405	2006-2010	534	
Amnesty International (2013)	3,291	2007-2012	549	Citing NOSDRA database

Source: compiled by the authors

All sources report several thousands of oil spills. Many papers cover two decades following 1976, listing nearly 5,000 incidents which is equivalent to 220-250 spills per year. More recent reports list larger numbers of incidents, especially after 1996. In one case, over 9,000 incidents were reported for 1976-2005. The total number of oil spills since 1976 must be well over 10,000. No reliable estimate can be given for spills in the early years (1959-1976).

The average annual number of spills since 1996 appears to be in the range of 420-530. According to Francis et al. (2011), the National Oil Spill Detection and Response Agency (NOSDRA) noted an increasing trend: 252 spills in 2006, 598 in 2007, 927 in 2008 and 628 in 2009. Numbers appear to have risen further in 2010. By combining the NOSDRA database with additional reports by major oil companies (Shell, Agip, Total), Amnesty International (2013) calculated 3,291 spills between 2007 and 2012 (an average of 549 per year).

It is mostly unclear whether the number of spills refers to on land incidents alone, or whether offshore spills are included as well. For obvious reasons, spills occurring on the land receive more attention (this is especially the case in studies on Ogoniland). Offshore spills are easily ignored, leading to an underestimation of the number of incidents and amount of oil that is lost. Data on distribution of spills are rare. According to Nwilo and

Badejo (2001), spills on land, mangroves and offshore amount to 6%, 25% and 69%, respectively[2].

Applying the ratio presented by Nwilo and Badejo to estimations presented by Amnesty International suggests that 4,770 spills occurred between 2007 and 2012, or an average annual number of 795 spills per year. This means that more than 15 spills occur each week.

UNDP (2006) estimated that between 1976 and 2001 there were approximately 6,800 spills totalling 3,000,000 barrels of oil. This value represents only the data that oil companies reported to DPR. It was discussed above that these data do not accurately represent the magnitude of the oil spillage.

In order to overcome this limitation, an independent group of experts on oil and the environment endeavoured to establish their own estimation of total oil spilled before 2007 (Jernelöv, 2010). Considering all sources of oil discharge into the environment, the group estimated a total discharge of between 9 and 13 million barrels since 1958. This roughly translates to 1.5 million tonnes, or one Exxon-Valdez spill annually for half a century. These results have been published by the Federal Ministry of Environment, in combination with, amongst others, WWF (Obot et al., 2006).

Most studies and many papers have reproduced data presented by the Ministry of Environment. For our analysis, we used the average of their estimate (hence, 11 million barrels), plus 2 million additional barrels to cover losses occurring during the period 2007-2013. Total crude lost due to oil spills in the Niger delta is therefore estimated at 13 million barrels.

4.2. CAUSES

Reasons for spills include corrosion of pipelines, poor maintenance of infrastructure, spills or leaks during processing at refineries, human error during oil extraction or transport, or following acts of vandalism or theft of oil (Amnesty International, 2009).

Information on the number of pipeline kilometres in Nigeria is conflicting. Many sources list a length of pipeline network of some 7000 km. After an analysis of many sources including remote sensing images, Achebe et al. (2012), however, calculated the length of the pipeline system in Nigeria at more than 80,000 kilometres. A large majority (90%) of these had a diameter of greater than 504 mm (20 inches). Some 76% (64,000 pipeline kilometres) were located in the Niger Delta States. The authors provided details of 22,000 km of pipelines.

The state of the pipeline system in Nigeria is generally rather poor. This is related to the high age of the pipes (Table 4.2), but also to poor maintenance, lack of protection and vandalism. Only 27% are less than 20 years old, while the lifetime of oil pipes is normally

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[2] These figures have been replicated in the 2006 Niger Delta Human Development Study (UNDP, 2006), but the original source remains unlisted.

set at 15 years (Achebe et al., 2012). Over 40% of the network is more than 30 years of age.

Table 4.2 Age and reliability of main oil pipelines (2000)

Age (years)	% reliability	% of total network length
< 20	46	27
20 - 30	29	32
> 30	25	41

Source: Achebe et al. (2012)

Following the poor state of the oil transport network, it comes as no surprise that most spills are caused by mechanic failures (Table 4.3). Sabotage apparently causes 20 to 25% of spills. Two thirds (over 70%) are related to poor maintenance or management.

Table 4.3 Causes of oil spills

Cause	Nwilo and Badejo (2001)	Achebe et al. (2012)	Remarks
Corrosion, lack of maintenance	50%	18%	
Operational incidents	22%	10%	
Mechanic induced failures		42%	
Sabotage	20%	24%	
Other, not specified	8%	6%	Including natural hazards

Source: compiled by the authors

4.3. IMPACT

Literature on the impact of oil spills includes the following types of sources (Table 4.4):

- Damage assessments of observed spills (Duke et al.; Burns et al.; Melville et al.; Hoff)
- Experimental and modelling studies (MacCay et al.; Egberongbe et al.; Grigalunas et al.)
- Literature reviews (Pezeshki et al., Hoff, ITOPF)
- Assessments of damage in Nigeria (UNEP; Lindén and Pålsson)

The majority of the studies presented below (Duke et al.; Burns et al.; Pezeshki et al., Melville et al.; MacCay et al.; Grigalunas et al.; Lindén and Pålsson) has been published in scientific journals; other were compiled by major international organisations (UNEP). The Hoff study was published by the USA National Oceanic and Atmospheric Administration, while the paper by Egberongbe et al. was presented at an international conference. ITOPF is a review prepared by the International Tanker Owners Pollution Federation.

Table 4.4 Oil spills and their impact on mangrove vegetation

Source	Type of damage	Remarks
Duke et al. (1997)	Oil spills in Panama	Using field observations and aerial photos. Partially affected areas are six times the size of full mortality zones.
Burns et al. (1993)	Idem	Up to 20 years or longer required for deep mud coastal habitats to recover from toxic impact of catastrophic oil spills, due to the long term persistence of oil trapped in anoxic sediments and subsequent release into the water column.
Pezeshki et al., (2000)	US Gulf Coast	Impact contamination depends on plant species, plant age, soil type, and season. Affected leaves show potential breakdown of photosynthesis. Physical damage if gas exchange is impacted. Impact of chronic contamination may be non-linear, depends on soil type. Indirect effect may be change in SOM contents.
Melville et al. (2009)	Oil spill in Australia	Six months after a heavy fuel spill PAH concentration had significantly decreased, suggesting evaporation, photoxidation and tidal flushing. Highest concentrations found inland areas.
Hoff (2010)	Niger Delta	Mangroves highly susceptible to oil. Acute damage: yellowing, defoliation, tree death. Physical effects (covering roots) can be as damaging. Spilled oil carried into mangroves by winds and currents. Light oils penetrate more deeply but are not persistent; crude oils and heavy refined products form highly resistant residues on sediments.
MacCay et al. (2004)	Components of fossil oil	Volatile components [(i) monoaromatic hydrocarbons , alkyl-substituted benzenes, (ii) two-ring Polynuclear Aromatic Hydrocarbons (PAHs), (iii) three-ring PAH's, (iv) volatile aliphatics, (v) semi-volatile aliphatics, (vi) low-volatility aliphatics]; (vii) a heavy residual fraction
Hoff (2010)	Offshore spill in Florida (1993)	Adult trees showed moderate to heavy defoliation, root rot; 20% of trees were defoliated. 9-Month mortality of juvenile plants: 5% (unoiled plant), 35% (heavily oiled; inland), 50% (idem, exposed to tidal movements)
Hoff (2010)	Experimental spill	17% mortality after 20 months. After 10 years, nearly half of affected trees completely dead; sediment seriously affected
ITOPF (2011)	Literature review	Oil may impact through chemical toxicity, physical smothering, ecological changes or loss of habitat. Large amounts spilt of heavy oils can cause widespread damage in intertidal zones. Chemical components of light oils are likely to cause toxic effects.
Egberongbe et al. (2006)	Modelling offshore spill	After 162 hours, 26% of oil had been evaporated while slick covered an area of 1,628 km^2.
Grigalunas et al. (1988)	Modelling damage in USA	Damage depends on oil composition. Largest damage from medium heavy crude and refined products. Damage approximately linear to quantity spilled.
UNEP (2011)	Ogoniland	Mangroves 'very badly affected by physical disturbance'. 'Impacts vary from extreme stress to total destruction'. Most impacted areas: only roots remain, 'completely coated in oil' sometimes thick layer of bituminous substance. Floating oil 'right of ways' destroys fringing mangroves. Site contamination remained 4 decades resisting repeated clean-ups.
Lindén and Pålsson (2013)	Ogoniland	Oil 'killed large areas of mangroves'. No recovery due to chronic spills. 'Widespread areas of dead [..] vegetation covered with asphalt tar'.

Source: compiled by the authors

It is beyond the scope of this paper to discuss the mechanisms of potential damage caused by oil spillage in great detail. It is clear that mangrove vegetation is extremely sensitive to oil spills. Chemical damage will be mostly caused by on land spills, occurring within weeks or months of the leakage. Physical damage is to be expected from smothering of roots and tissues plus blankets of heavy fractions covering soils in tidal or inland areas. These sediments can persist for years. Light crudes or refined products cause mostly chemical damage (See Figure 4.2).

▲ *Figure 2: Typical effects on marine organisms range across a spectrum from toxicity (especially for light oils and oil products) to smothering (intermediate and heavy fuel oils (IFO and HFO) and weathered residues).*

Figure 4.2 Toxic and physical impacts of different oil types
Source: ITOPF (2011)

A number of conclusions can be drawn:

- Chemical (toxic) damage is to be expected from on land spills (along pipelines, or pump units), especially from refined products
- Local physical damage is to be expected from residues of on land spills, while residues from offshore spills are bound to cover large areas of mangroves. Physical damage will be higher from (heavy) crudes
- Acute (chemical) damage can be fatal, especially for adult trees. Impacts can be observed up to 10 years after the incident. Young plants seem to be less sensitive
- PAH concentration reduces significantly within six months after spills occur, especially in tidal zones. Inland concentrations remain higher. Chemical damage will therefore be more devastating if incidents are repeated frequently. Physical damage is an aggregated effect over a long period of time
- A dead zone (area with 100% tree mortality) is surrounded by a zone with partial damage (smaller share of trees dead, plus living trees suffering from defoliation and retarded growth). The partially damaged zone may be six times larger
- Mangroves in Ogoniland are badly affected. Large areas apparently are dead

A detailed, quantified, assessment of damage caused by oil production is not possible, as this requires a comprehensive set of data on the size, type and distribution of oil spills in the Niger Delta as well as point observations on damage caused to the vegetation. In order to arrive at an estimate of damage to the vegetation, an overview of (partial) options on impacts has been derived from data presented above plus some additional information:

- There are 31 large oil and gas fields well spread over the Delta area. Oil wells and pipelines are found in almost all parts of the Delta. Relatively few installations are found in the extreme east and west

- Nwilo and Badejo (2007) listed 606 oil fields in the Delta in 2005 (of which 360 were onshore and 246 offshore). Following Ite et al. (2013), however, the number of fields that was developed is much larger (1,182, with 900 being still in production). The number of wells that have been drilled is even higher (5,248 reported by Achebe et al., 2012; and by Steiner, 2010). Approximately half of these will be located offshore

- New drilling activities require additional roads to allow transport of staff, machinery and installations. This requires clearing of the vegetation, often in combination with soil drainage. ‘Right of way’ development may require digging new waterways for transportation of heavy machinery. All these activities affect the vitality of the original vegetation

- Clearing vegetation for road, site or pipeline installations sometimes gives way to new vegetation; 10% of mangrove trees have been replaced by invasive species in Ogoniland (UNEP, 2011). This phenomenon will be found in other parts of the Delta as well. It is unclear, how much is to be attributed to oil production and distribution

- According to Achebe et al. (2012), the Niger Delta hosts an impressive 64,000 km of pipelines. The number of pipeline kilometres presented in this study is much larger than listed in older sources (for example, Egberongbe et al. (2007) report 3,000 km in 2001; Steiner (2010), citing a NDDC report of 2006, reports 7,000). We follow Achebe et al., who covers a wide range of literature and data sources while technical details are presented for over 20,000 km of pipes. Part of the pipes will be laying along other pipes

- Distribution of spills in Nigeria: 25% in mangroves, 69% offshore, 6% on upland (Nwilo and Badejo, 2007)

- 35,000 ha of mangroves (15% of the original area) have been lost in Delta State between 1987 and 2002. Causes include population pressure, oil production/spills and other industrial activities (Omo-Irabor et al., 2007)

The following options, which may partly coincide, have been calculated:

- Site clearance for drilling/prospecting: clearing of 2,500 small plots (0.2 ha each), plus 250 medium and 250 large plots (0.5 and 1.0 ha, respectively)

- Clearing for pipeline development: clearing 10 metres width for 30,000 km of pipes

- Replacement of vegetation by invasive species: 10% of 654,000 ha

- Pressure of oil spills following an even distribution: 30% of 13 million barrels spilled on 3.1 million ha (Niger Delta area); 25% spilled in the mangrove zone (0.67 million ha)

- Observed damage due to a tank rupture and a tanker accident releasing crude oil, diesel oil and bunker oil in Panama presented by Duke et al. (2007). Assuming linear relations between spill size and extent of damage (as observed in the USA by Grigalunas et al., 1988), the average area of affected mangrove is calculated from both incidents

- Modelling area covered by offshore spills: Distribution of offshore oil spilt following the patterns modelled by Egberongbe et al. (2006)

Table 4.5 Mangrove damage calculation assumptions

Option	Area affected, carbon release
Clearing sites	1000 ha, distributed over the Delta area. Causing initial emission of 0.9 million tonnes of carbon
Clearing pipelines	30,000 km at 10m width represents clearing of 30,000 ha of mangrove vegetation, releasing 31.0 million tonnes of carbon
Invasive species	10% of 667,000 ha cleared and replaced equals to 66,700 ha releasing 69.0 million tonnes of carbon
Even distribution	30% of 13 million barrels is spilled on 3.1 million ha of land in the entire Niger Delta, equalling to 160 kg (200 litre) of oil per ha; 25% spilt on mangroves, representing an average pressure of 185 kg (231 l) of oil per ha
Observed damage (Duke et al.)	25% of 13 million barrels spilt in mangroves is causing full mortality of 16,000 ha of mangroves, releasing 16.6 million tonnes of carbon. Impact of offshore spills amounting to 70% of 13 billion barrels on mangrove zones is dead of 21,000 ha, releasing 22.0 million tonnes of carbon
Modelling offshore spills (Egberongbe et al.)	70% of 13 million barrels is spilled offshore, following distribution patterns modelled by Egberongbe et al. (2011), they would cover 2.6 million ha of vegetation. This means that over 55 years, all mangroves could be affected four times

Source: author's calculations

4.4. SCENARIO DEVELOPMENT

The most probable level of damage that has been caused to mangrove vegetation now was calculated by selecting combinations of options. Three scenarios have been developed for this purpose: a Low damage scenario, defining minimum losses; a Most probable scenario, providing the most probable assessment; and a High Damage scenario, defining a high damage estimate.

Development of the scenarios made use of elements that have been presented above:

- Land clearance for the purposes of exploration, construction, extraction, transportation, etc.

- Invasive species following disturbance of vegetation and hydraulic systems
- Damage caused by (onshore as well as offshore) oil spills
- Damage from toxic and other disposed waste originating from oil production, storage and transport
- Loss of carbon sequestration capacity

The area of mangroves that is affected (AA) consists of area cleared for exploration, drilling, transport or storage (Area Cleared, AC), vegetation killed by oil spills (OS), and area affected by toxic waste (TW):

$$AA = AC + OS + TW \qquad \text{(Equation 1)}$$

Detailed information for the Area Cleared (AC) for oil prospecting and extraction is lacking. A fixed area i was set for each of the scenarios. Additional clearance for construction of pipelines was calculated as the product of pipeline network length and an assumed average width.

Damage from oil spills (OS) was calculated using data from Nwilo and Badejo (2001). Spill incidents occur partly (25%) in mangroves, 5% are assumed to take place on land (not affecting mangroves) while the remainder occur offshore. These figures were applied to the total amount spilt of 13 million barrels.

Tree mortality following spills was based on Duke et al. (1997); an average of 4,995 ha of mangroves is killed per million barrels of oil spilt. For offshore spills this was 2,361 ha. The result was rounded to 16,000 ha following onshore and a maximum of 21,000 ha of dead tress from offshore leakages.

Area affected by toxic industrial waste (TW) was calculated as the product of the area affected (defined as a share of the total mangrove area, SA), total mangrove area (MA), and the average mortality ratio (AMR) in affected areas:

$$TW = SA * MA * AMR \qquad \text{(Equation 2)}$$

After the vegetation has been cleared, damaged or affected, the original vegetation regenerates sponteneously. Following data presented by Burns et al. (1993), the National Research Council (2003), Kairo et al. (2005), Hof et al. (2010), Santos et al. (2012), and IUCN (2013), the following Recovery Period (RP) was chosen:

- Low damage scenario: 10 years
- Probable damage scenario: 20 years
- High damage scenario: 30 years

This means that it takes 10, 20, or 30 years before the full carbon stock is recovered. During the recovery period, only a part of the Potential Sequestration Capacity (PSC) is available. Carbon loss, in other words, depends on the share of sequestration capacity that has been restored. It is defined as Actual Sequestration (AS), assuming a linear relationship:

$$AS = PSC * Y * 1/RP \qquad \text{(Equation 3)}$$

Where Y represents a given year ($0 \leq Y \leq RP$).

In part of the area, the original mangroves will be replaced by secondary vegetation which means that the high original sequestration capacity is permanently lost.

The results of the calculations are presented in Table 4.6. Area cleared for production sites was arbitrarily set at 750, 1000 and 1,500 ha for the Low Damage, Most Probable Damage and High Damage scenarios, respectively. Clearing area for pipelines has been set at 5,000, 10,000 and 15,000 ha. Average width of clearing was assumed to range from 5 to 20 metres.

For the Low Damage scenario, it was assumed that damage caused by offshore spills and damage from on land spills partly coincide in such a way that total area affected is not larger than the largest of the two (21,000 ha). Additional damage due to release of chemical and oil industry waste is expected to affect 6% of mangroves, causing 2.5% mortality. No damage due to introduction of invasive species is assumed. There is no effect of high frequency of the oil spills.

The Most Probable Damage scenario includes both direct mangrove spill damage calculated by Duke et al. (16,000 ha) plus damage following from offshore spills. A quarter of the area of invasive is caused by oil production activities (2.5%). Chemical and other waste affects 15% of mangroves, killing 5% of the vegetation (5,000 ha). The high frequency of the oil spills, adding locally to chronic pollution of the vegetation, increases the impact of the spills by 50%.

The High Damage assessment includes both onshore and offshore area affected from oil spills but applying 150% extra impact on tree mortality due to high frequency of spill incidents. Toxic waste affects 40% of the area, killing an average 20% of the trees.

Table 4.6 Main characteristics of three scenarios for damage assessment

Element	Low Damage scenario	Probable Damage scenario	High Damage scenario
Clearing of production sites (ha)	750	1,000	1,500
Clearing pipeline area (km)	5,000	10,000	15,000
Idem (width, m)	5	10	20
Area affected by oil spills onshore (ha)	16,000	16,000	16,000
Idem (from offshore spills)	5,000	21,000	21,000
Recovery Period (years)	10	20	30
High Frequency Effect	0%	50%	150%
Area invasive species (%)	0	2.5%	10%
Area affected by toxic waste (%)	6%	15%	40%
Tree mortality by toxic waste (%)	2.5%	5%	20%

Source: this study

4.5. QUANTIFYING CARBON LOSSES

Some 25,000 ha of mangroves were affected under the Low Damage scenario (Table 4.7). This rose to nearly 80,000 ha and some 190,000 ha under the Most Probable and High Damage scenarios, respectively. These are accumulated areas affected in the period since 1958.

Annual area of mangroves lost amounted to 459, 1,480 and 3,479 ha for the Low Damage, Most Probable Damage and High Damage scenarios, respectively.

Total Carbon Losses (TCL) are a combination of Carbon Releases (CL) that follow the clearing of mangroves and tree mortality caused by oil spills and deposition of chemical waste, and of Loss of carbon Sequestration Capacity (LSC) due to tree mortality or reduced tree vitality.

$$TCL = CL + LSC \qquad \text{(Equation 4)}$$

Loss of sequestration is defined as the difference between the Potential Sequestration Capacity (PSC) and Actual Sequestration (AS) introduced in Equation 3 and calculated as:

$$LSC = RP * (PSC / 2) \qquad \text{(Equation 5)}$$

Following Donato et al. (2011), a maximum total carbon storage in mangroves of 1,031 tonnes of C/ha is assumed. This includes carbon stored in soils. The Potential Sequestration Capacity is 1.6 tonne/ha/year (Breithaupt et al. (2012).
Carbon Losses now are calculated as follows:

$$TCL = AA * [\ 1{,}031 + (RP * 1.6/2)\ ] \qquad \text{(Equation 6)}$$

Carbon Releases amount to 26, 86 and 204 million tonnes of carbon. Total losses due to oil production activities since 1958 have been estimated at some 96, 315 and 748 million tonnes of CO_2. These levels are roughly equivalent to the 2010 national emission levels of Kuwait, Poland or Germany and represent 120%, 400% and 950%, respectively, of Nigeria's national emissions.

Table 4.7 Results of the damage assessment scenarios

Element	Low Damage scenario	Probable Damage scenario	High Damage scenario
Area cleared (ha)	3,250	21,010	46,520
Vegetation killed by spills (ha)	21,000	55,500	92,500
Area of invasive species (ha)	0	16,350	65,400
Area affected by toxic waste (ha)	981	4,905	52,350
Total area affected (ha, since 1958)	25,231	81,415	191,340
Area affected (ha, average per year)	459	1,480	3,479
Carbon Releases (million tonnes C)	26.2	85.8	204.1
Total Carbon Losses (million tonnes CO2)	96.1	314.6	748.2

Source: this study

5. DISCUSSION

Nigeria has a relatively large area of mangrove swamp vegetation, located on its southern shore and covering some 650 thousand ha. Mangroves are highly sensitive to contamination with oil products and industrial waste generated by oil production activities. Damage consists of two elements, including impact of chemicals (occurring acutely after contamination) and physical damage which may occur later but which persists much longer.

The Federal Ministry of Environment published a relatively reliable estimate of the total amount of oil that has been spilt. Following this estimate it is feared that a total of 13 million barrels of oil have been lost since the start of oil production in 1958. This means that over two billion litres of oil have been lost in the more than 10,000 incidents that have been reported. The number of incidents has been increasing; while the long term average includes some 220 to 250 spills per year, recent (since 2005) numbers exceed 500 spills per year.

Since the 1970's, the environmental impacts of accidents involving oil spills have received much public attention, sparking numerous research efforts. A considerable number of studies describing (mostly large) leakages is now available. These studies rarely provide a quantified assessment of damage to mangroves, while experimental research (trials of controlled spills) also remains very scarce. In this study, we used observed damage following two spills in Panama – one tank rupture, and one tanker collision – to estimate and quantify damage in Nigeria.

A major distinction must be made between onshore and offshore spills. As the former are much closer to the vegetation, they cause acute chemical damage, while offshore spills lose a considerable part of the (more toxic) lighter compounds during the time the spillage takes to move towards the coast. In both cases, considerable damage can be caused by heavier compounds which can be washed into the vegetation where it will sink.

As a rule, low tidal activity means that, once settled, toxic compounds persist in sediments, causing damage for very long periods of time. Evidence suggests that toxic effects still occur after 20 years (occasionally exceeding 40 years). Under conditions of frequently repeated spills, physical damage (smothering of plant roots) is highly likely to accumulate and, consequently, worsen.

Given the long history of oil spills, together with the wide distribution of oil installations and the huge amount (1.7 million tonnes) of oil that has been lost, it must be assumed that most of Nigeria's mangroves have been affected in one way or another. Pristine mangrove forests will be very rare, with the possible exceptions of the far west and extreme east of the country.

As damage to the vegetation can only be estimated using literature from one-time accidents, the impact of more frequent contamination had to be modelled. While it is known that chronic toxic pressure is having very strong effects on ecosystems, it is remarkable – and unfortunate – that so few studies providing a quantified assessment seem to be available. A number of factors provide a strong indication that mangroves in Nigeria are bound to suffer more strongly than those in other countries that are affected less frequently:

- Large number (high frequency) of spills reported
- Dense and evenly distributed network of wells, production sites, pipelines, tanks and transport units that have been constructed
- Large amount of oil lost in spills over five decades of oil production
- Poor maintenance and advanced age of the transport network
- Combination of onshore and offshore spills that are highly likely to affect overlapping areas

A model was developed to assess mangrove mortality following oil spills in the Niger Delta region. The model was based on observations provided by Duke et al. (1997). It has been applied in three scenarios providing low, probable and high estimates of damage caused. The scenarios also include estimations of vegetation clearances on behalf of the oil industry since its inception, as well as impacts of industrial waste and replacement of disturbed vegetation by invasive species.

The total area of dead mangrove forests has been estimated at 25,000, 81,000 and 190,000 ha, for the Low Damage, Most Probable Damage and High Damage scenarios, respectively. This means that up to 30% of the mangrove vegetation has died at some point since oil production started 55 years ago.

As recovery after oil damage takes multiple years (if not decades), at any given time a considerable part of the mangrove area will be seriously affected. This is confirmed by literature (for example: Burns et al., 1994; Nwilo and Badejo, 2007; Hoff, 2010; UNEP, 2011; IUCN, 2013) and by feedback provided to the authors by local and international experts although quantified estimates were rarely provided.

Total carbon release caused by oil production in Nigeria since 1958 according to the three scenarios is 96, 315 and 748 million tonnes of CO_2, respectively. This represents 120%, 400% and 950% of the reported annual emission levels for Nigeria in 2010. Average annual emission levels amount to 1.7, 5.7 and 13.6 million tonnes of CO_2 per year under the Low, Most Probable and High Damage scenarios, respectively. Damage to mangroves in Nigeria is thus is causing an emission level equal to the national annual GHG emissions of countries such as Guyana, Ivory Coast or Lithuania.

The uncertainty of damage assessments remains high. This is especially the case for the impact of chronic contamination caused by high frequency spill incidents which, as stated above, have not been quantified in the literature. The extent of the damage may, therefore, be much higher.

The overall impact of carbon losses from oil spills and other damage to mangrove forests on the carbon footprint of Nigerian fossil oil is very limited. Although the total carbon loss is huge, the emission per MJ is limited by the large amount of oil that has been produced since extraction began in 1958. Average carbon release amounts to 0.6, 1.8 and 4.3 g CO_2eq/MJ, for the Low, Most Probable and High Damage scenarios, respectively. This is low in comparison to the non-land related carbon footprint for Nigerian oil (which is around 105 CO_2eq/MJ), but it is higher than land use impacts of most other fossil oils.

The relatively low contribution of direct land use change on fossil fuels' carbon footprint is confirmed elsewhere. According to Yeh et al. (2010), it is caused by the high energy density of fossil fuels. The authors calculated carbon impacts of conventional oil and tar sand extraction in North America (Figure 5.1). Contributions of land use change are small for conventional oil and tar sands mined with steam (average values ranging between 0.1 and 0.5 gCO_2eq/MJ), but may be higher for surface mining of tar sands (average of 3.9 gCO_2eq/MJ).

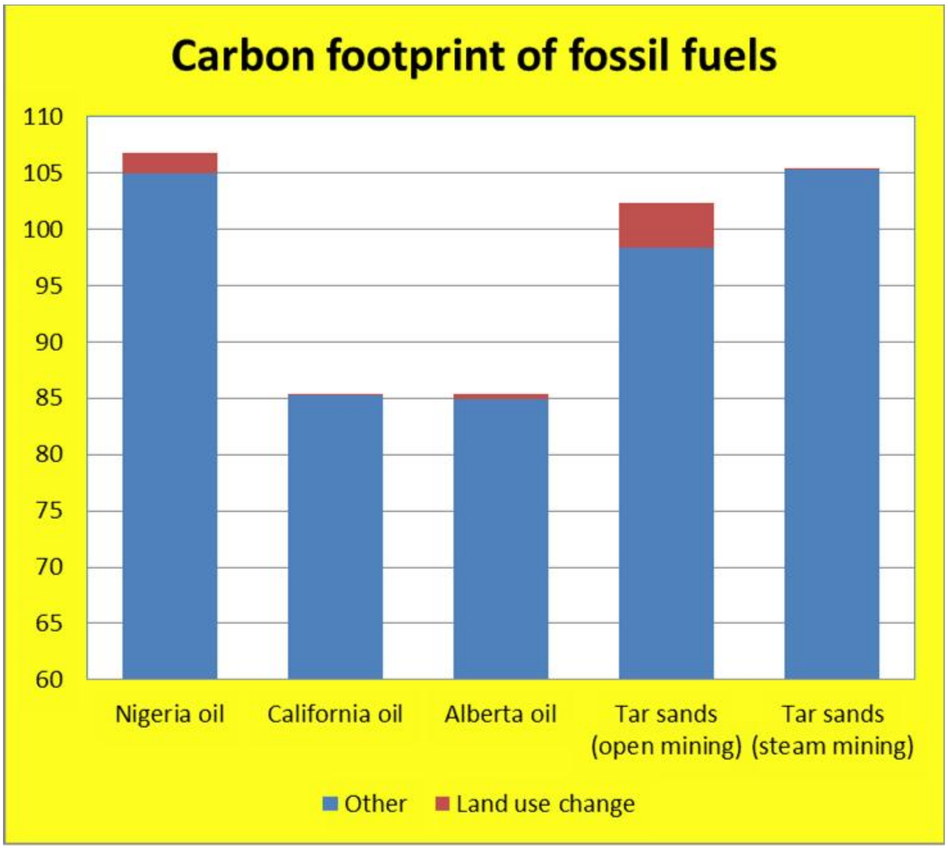

Figure 5.1 Carbon emissions from Nigerian oil compared to other fossil fuels
Source: this study, Yeh et al. (2010)

Figure 5.1 confirms that Nigerian oil is one of the most carbon intensive oils in the world, causing more emissions than tar sands extraction using steam infusion. The high carbon footprint of oil in Nigeria is mainly caused by flaring and inefficient production processes. The impact of carbon releases from mangrove forests is low (remaining less than 4% for the High Damage scenario). Higher contributions may be expected if indirect effects are included.

6. CONCLUSION AND RECOMMENDATIONS

The impact of oil production activities on mangroves in the Niger Delta of Nigeria is considerable and includes not only effects on water, air and soil quality, but also impacts of oil contamination on the extended mangrove ecosystems of the area. A long series of scientific research papers, reports, book chapters and conference contributions has demonstrated that mangrove vegetation is heavily affected by oil spills, waste from oil production activities, and flaring. This includes activities on the mainland, often directly disturbing fragile mangrove vegetation and fauna, as well as offshore activities and transportation movements in between.

Damage to mangroves includes toxic chemical impacts as well as persistent physical disturbances which may form a source of continuous stress. The huge amount of oil lost and the large – and increasing – number of spill incidents, together with the observed disposal of waste from oil-based industrial activities constitute a huge risk, not only for the population in the Delta but also for their sources of food, shelter and energy.

While the evidence of damage is abundant, there appears to be a lack of assessments of direct and indirect damage to the vegetation. Also, methods for deriving damage from number of spills, their distribution, amount of oil spilt and its composition are very rare. This makes it hard to provide a solid estimate of carbon releases caused by hazardous oil related processes in the Niger Delta. The current report therefore developed and applied an evaluation model to assess the impact on mangrove vegetation including carbon releases.

The complexity of the potential ways oil spills and waste may affect plants and animal species in the mangrove ecosystem requires systematic reporting on accidents and emissions, and a science-based analysis of the impacts. So far, however, such reporting or analysis has hardly taken place. Some encouraging efforts have, however, increased awareness but also the apparent determination of stakeholders as well as scientists to draw attention to this problem.

Given the long persistence of oil components, especially in inland waters, and their observed long-term impacts on the growth, composition and vitality of ecosystems, the need for a solid and reliable monitoring system is now as urgent as ever. Even if the causes of the constant chemical and physical stress could be stopped immediately, its effects would be bound to be observed for many years to come. Given the observed trends of increasing incident frequency and scale, as well as the imminent risks caused by the large number of old and often poorly maintained facilities for oil extraction, storage and transport, the cleaning up of these activities seems currently nowhere in sight.

In the light of this, the fact that large areas of mangroves are bound to be already affected, the extent of the damage, and the high frequency of discharges are offering little consolation and it must be concluded that oil production in its current state – given its poor environmental records – continues to form a huge threat to the mangrove zones in Nigeria.

This is not only bad news for the people living near pipelines, drilling installations or harbours of the country, it also forms a serious risk in terms of storm and cyclone impact prevention. It is well known that mangroves play a role in coastal defence and disaster risk reduction and this role will be negatively affected by acute and long lasting tree death or reduced system vitality (Constanza et al. 2008).

One of the most important aspects of the depressed mangrove performance and related carbon releases is the chronic character of the damage. This is also the element of the analysis that has received the least attention. It is therefore suggested that results of the spill monitoring are used as a basis for a thorough science-based analysis of damage and ecosystem vitality. This may also contribute to the development of better carbon release assessment methods than are currently available.

The estimates of carbon releases related to oil production in the Niger Delta zone already, demonstrate that mangrove protection and restoration may play an important role in improving the carbon footprint of oil produced in the region and of the country as a whole.

REFERENCES

Achebe, C.H., Nneke, U.C., and Anisiji, O.E. (2012). Analysis of Oil Pipeline Failures in the Oil and Gas Industries in the Niger Delta Area of Nigeria. Proceedings of the International Multiconference of Engineers and Computer Scientists 2012 Vol II. IMECS 2012, held March 14-16 2012 in Hong Kong

Adekunle, I.M., Igbuku, A.O.O, Oguns, O., and Shekwolo, Ph.D. (2013). Emerging Trend in Natural Resource Utilization for Bioremediation of Oil — Based Drilling Wastes in Nigeria. Retrieved on 21 August, 2103 from: http://cdn.intechopen.com/pdfs/44725/InTech-Emering_trend_in_natural_resource_utilization_for_bioremediation_of_oil_based_drilling_wastes_in_nigeria.pdf

Alongi, D.M. (2012). Carbon sequestration in mangrove forests. Carbon management. Vol. 3, pp.313-322. doi 10.4155/cmt.12.20

Amnesty International (2009). Nigeria: Petroleum, pollution and poverty in the Niger Delta. Gaughran, A. 2009. Amnesty International Publications. http://www.amnesty.org/en/library/info/AFR44/017/2009/en

Amnesty International (2013). Bad information. Oil spill investigations in the Niger Delta. London, UK, Amnestry International

Badejo, O.T. and Nwilo, P.C. (2004). Management of Oil Spill Dispersal Along the Nigerian Coastal Areas. ISPRS Congress 2004, Istanbul, Turkey

Brown, A. and Thieme, M. Niger Delta. (2013). In: FEOW. Freshwater Ecosystems of the World. http://www.feow.org/ecoregion_details.php?eco=506. Accessed 23 December 2013

Burns, K.A., Garrity, S.D., and Levings, S.D. (1993). How many years until mangrove ecosystems recover from catastrophic oil spills? Marine Pollution Bulletin, Vol. 26, pp.239-248

Burns, K.A. and Yelle-Simons, L. (1994). The Galetta oil spills IV. Relationship between sediment organism hydrocarbon loads. Estuarin., Coastal and Shelf science, Vol. 38, pp397-412

Burns, K.A., Codi, S. and Duke, N.C. (2000). Gladstone, Australia field studies: weathering and degradation of hydrocarbons in oiled mangrove and salt marsh sediments with and without the application of an experimental remediation tool. Marine Pollution Bulletin, Vol. 41, pp392-402. http://www.sciencedirect.com/science/article/pii/S0025326X00000941

Chmura, G. L., S. C. Anisfeld, D. R. Cahoon, and J. C. Lynch, Global carbon sequestration in tidal, saline wetland soils. (2003). Global Biogeochemical Cycles, Vol. 17, pp.1111. doi:10.1029/2002GB001917

Costanza, R., Pérez-Maqueo, O., Martinez, M., Sutton, P., Anderson, S., Mulder, K., 2008. The value of coastal wetlands for hurricane protection. Ambio. 37(4), 241–248.

Donato, D.C., J. B. Kauffman, D. Murdiyarso, S. Kurnianto, M. Stidham, and M. Kanninen. (2011). Mangroves among the most carbon-rich forests in the tropics. Nature Geoscience. Letters, Vol. 4, pp.293-297. doi: 10.1038/NGEO1123

Duke, N.C., Pinzón M., Z.S. and Prada, M.C. (1997). Large-Scale Damage to Mangrove Forests Following Two Large Oil Spills in Panama. Biotropica, Vo. 29, pp.2–14, March 1997. DOI: 10.1111/j.1744-7429.1997.tb00001.x

Egberongbe, F.A.O., Nwilo, P.C. and Badejo, O.T. (2006) Oil spill disaster monitoring along the Nigerian coastline. Paper presented at the 5th FIG Regional Conference ‘Promoting Land Administration and Good Governance’, held in Accra, Ghana, March 8-11, 2006

Enujiugha, V.N., and Nwanna, L.C. (2004). Aquatic oil pollution impact indicators. Journal of Applied Science and Environmental Management, Vol. 8, pp.71 - 75

EPA (2013). Greenhouse gas emissions from a typical passenger vehicle. Retrieved 25 September 2013 from: http://www.epa.gov/otaq/climate/documents/420f11041.pdf

FAO (2007). The world's mangroves 1980-2005. Rome, Italy: the Food and Agricultural Organization of the United Nations. Retrieved on 25 September, 2013 from: ftp://ftp.fao.org/docrep/fao/010/a1427e/a1427e00.pdf

Francis, P., Lapin, D., and Rossiasco, P. (2011). Securing development and peace in the Niger Delta. A social and conflict analysis for change. Washington, Woodrow Wilson Center for Scholars

Galadima, A., Garba, Z.N., Leke, L., Almustapha, M.N., and Adam, I.K. Domestic Water Pollution among Local Communities in Nigeria. Causes and Consequences. European Journal of Scientific Research Vol. 52, pp.592-603 (2011)

Giri, C, Ochieng, E., Tieszen, L.L., Zhu, Z., Singh, A., Loveland, T., Maesk, J, and Duke, N. (2010). Status and distribution of mangrove forests of the world using earth observation satellite data. Global Ecol. Biogeogr. DOI: 10.1111/j.1466-8238.2010.00584.x

Grigalunas, Th.A., Opaluch, J.J., Erench, D. and Reed, M. (1988). Measuring Damages to Marine Natural Resources from Pollution Incidents under CERCLA: Applications of an Integrated Ocean Systems/Economic Model. Marine Resource Economics, Vol. 5, pp.1-21.

Hoff, R. (ed.) (2010). Oil spills in mangroves. Planning and response considerations. US Department of Commerce. National Oceanic and Atmospheric Administration NOAA

ITOPF (2011). Effects of oil pollution on the marine environment. The International Tankers Owners Pollution Federation, London

IUCN (2013). Sustainable remediation and rehabilitation of biodiversity and habitats of oil spill sites in the Niger Delta. A report by the independent IUCN - Niger Delta Panel (IUCNNDP) to the Shell Petroleum Development Company of Nigeria Ltd (SPDC).

Jernelöv, A. (2010) The Threats from Oil Spills: Now, Then, and in the Future. AMBIO Vol. 39, pp.353–366. DOI 10.1007/s13280-010-0085-5

Kauffman, J.B., and D.C. Donato. (2012). Protocols for the measurement, monitoring and reporting of structure, biomass and carbon stocks in mangrove forests. Working paper 86. Bogor (Indonesia), Center for International Forestry Research

Kairo, J.G., Bosire, J., and Omar, M. (2005). Assessment of the effects of oil spill on the mangrove forests of Port Reitz, Mombasa. Marine Ecology and Environment Program. Mombasa, Kenya Marine and Fisheries Research Institute. Retrieved on 10 December 2013 from: http://41.215.122.106/dspace/bitstream/0/248/1/Assessment%20of%20the%20Effect%20of%20oil%20spill%20on%20the%20Mangrove%20Forests%20of%20Port%20Reitz%20Mombasa.pdf

Levings, S.C., Garrity, S.D, and Burns, K.A. (1994). The Galetta oil spill III. Chronic reoiling, long-term toxicity of hydrocarbon residues and effects on epibiota in the Mangrove fringe. Estuarine, Coastal and Shelf Science, Vol. 38, pp.365–395

Lewis, R.R., 1983. Impact of oil spills on mangrove forests. In: H.J. Teas (ed.), Biology and ecology of mangroves. Tasks for vegetation science 8. The Hague, the Netherlands, W. Junk, pp.171-183

Lindén, O., and Pålsson, J. (2013) Oil Contamination in Ogoniland, Niger Delta. AMBIO Vol. 42, pp.685-701

MacCay, D.F., Jennings Rowe, J., Whittier,N., Sankaranarayanan, S., and Schmidt Etkin, D. (2004). Estimation of potential impacts and natural resource damages of oil. Journal of Hazardous Materials Vol. 107, pp.11–25

Melville, F., Andersen, L.E. and Jolley, D.F. (2009). The Gladstone (Australia) oil spill – Impacts on intertidal areas: Baseline and six months post-spill. Marine Pollution Bulletin, Vol. 58, pp.263-271

National Research Council (2003) Oil in the Sea III: Inputs, Fates, and Effects. Committee on Oil in the Sea. National Academy of Sciences. Retrieved on December, 20, 2013 from: http://www.nap.edu/catalog/10388.html.

Nwilo, P.C. and Badejo, O.T. (2007) Impacts and management of oil spill pollution along the Nigerian coast. International Federation of Surveyors. Retrieved 30 September, 2013 from: http://www.fig.net/pub/figpub/pub36/chapters/chapter_8.pdf

Obot, E., Antonio, Q.B., Braide, S., Dore, M., Wicks, C., and Steiner, R. (2006). Niger Delta Natural Resource Damage Assessment and Restoration Project. Phase 1 – Scoping Report. Abuja, Federal Ministry of Environment; Lagos, Nigeria Conservation Foundation; London, WWF UK; Wellington, New Zealand, CEESP- IUCN Commission on Environmental, Economic, and Social Policy

Omo-Irabor, O.O., Olobaniyi, S.B., Akunna, J., Venus, V., Maina, J.M. and Paradzayi, Ch. (2010). Mangrove vulnerability modelling in parts of Western Niger Delta, Nigeria using satellite images, GIS techniques and Spatial Multi-Criteria Analysis (SMCA). Environ Monit Assess. DOI 10.1007/s10661-010-1669-z

Onwurah, I.N.E., Ogugua, V.N., Onyike, N.B., Ochonogor, A.E. and Otitoju, O.F. (2007). Crude oil spills in the environment, effects and some innovative clean-up biotechnologies. International Journal of Environmental Research, Vol. 1, pp.307-320

Pampanin, D.M., and Sydnes, M.O. (2013). Polycyclic Aromatic Hydrocarbons a Constituent of Petroleum: Presence and Influence in the Aquatic Environment. Paper retrieved on 19 December 2013 from: http://www.intechopen.com/download/get/type/pdfs/id/41885

Pezeshki, S.R., Hester, M.W., Lin, Q., and Nyma, J.A. (2000). The effects of oil spill and clean-up on dominant US Gulf coast marsh macrophytes: a review. Environmental Pollution, Vol. 108, pp.129-139

Pieprzyk, B, Kortlüke, N and Rojas Hilje, P, 2009. The impact of fossil fuels: Greenhouse gas emissions, environmental consequences and socio-economic effects. Energy Research Architecture.

Steiner, R. (2010). Double standard: Shell practices in Nigeria compared with international standards to prevent and control pipeline oil spills and the Deepwater Horizon oil spill. Amsterdam, Friends of the Earth Netherlands

Toxipedia (2013). Accessed on 18 December 2013 from: http://www.toxipedia.org/display/toxipedia/Polycyclic+Aromatic+Hydrocarbons

UNDP (2006). Niger Delta Human Development Report. Abuja, Nigeria, United Nations Development Programme

UNEP (2011). Environmental assessment of Ogoniland. Nairobi, Kenya, United Nations Environment Programme

UNEP (2013). Africa Environmental Outlook. Nairobi, Kenya, United Nations Environment Programme. Retrieved 15 December 2013 from: http://hqweb.unep.org/dewa/Africa/publications/aeo-1/

US Fish and Wildlife Services. (2013). Mangroves. Retrieved 26 September 2013 from: http://www.fws.gov/verobeach/msrppdfs/mangroves.pdf

Yeh, S., Jordaan, S.M., Brandt, A.R., Turetsky, M.R., Spatari, S. and Keith, D.W. (2010). Land Use Greenhouse Gas Emissions from Conventional Oil Production and Oil Sands. Environ Sci Technol., Vol. 44, pp.8766-72. doi: 10.1021/es1013278

ANNEX 1 ANNOTATED LITERATURE

Main studies used in this report

Obot et al. (2006) Niger Delta Natural Resource Damage Assessment and Restoration Project. Phase 1 – Scoping Report. Federal Ministry of Environment; Nigeria Conservation Foundation; WWF UK; CEESP- IUCN Commission on Environmental, Economic, and Social Policy. This study was the first in-depth quantitative analysis of oil spills, oil spilt and damage. Focus on oil spills and impacts on human rights violation following from spills and complaints. Estimates presented in this report have often been used in reports published later, not always correctly cited. It is one of the most influential sources on the subject. Unfortunately, no follow up report could be found.

UNEP (2011). Environmental assessment of Ogoniland. United Nations Environment Programme, Nairobi, Kenya. This study was the first in-depth quantitative analysis of oil spills, oil spilt and damage of its kind in Nigeria. Restricted to Ogoniland. Geographical and thematic scope were unprecedented in Nigeria and many areas elsewhere. The UNEP team at times included over 100 staff members, including thematic teams for fieldwork related to land contamination, water quality, vegetation and public health. The teams were composed of international as well as national experts, academics and technicians. Additional teams were deployed for tasks such as analysis of satellite images, provision of aerial photographs, legal and institutional reviews, community surveys, well-drilling, topograhical surveys, and land access.

The study was extremely thorough. In a period of more than one year, over 200 locations were examined, over 120 km of pipelines surveyed, more than 5,000 medical records were reviewed and 23,000 people engaged at local community meetings. Detailed soil contamination investigations were conducted at 69 sites, analyzing more than 4,000 samples including water from 142 groundwater monitoring wells which were drilled specifically for the study and soil extracted from 780 boreholes.

Amnesty International (2013). Bad information. Oil spill investigations in the Niger Delta. Describes the lack of clarity on quantified information on oil spills and oil spilt. Presents original data on oil spills reported by Nigerian government (NOSDRA database). Discusses responsibility for spills in the face of increasing sabotage efforts. Explicitly making a distinction between onshore and offshore spills.

Nwilo, P.C. and Badejo, O.T. (2001) Impacts and management of oil spill pollution along the Nigerian coast. An early example of good scientific work by Nigerian scientists. Part of a book, but so far unclear which book or publisher. Following this work, the authors have published more papers in the period up to 2008. An excellent and quantitative scientific paper, modelling the fate of oil spilt offshore, including a description of impacts and an overview of legal frameworks related to soil spills. Restricted to western part of Niger Delta. It is one of the most cited and widely available studies on the subject.[3]

National Research Council (2003) Oil in the Sea III: Inputs, Fates, and Effects. Committee on Oil in the Sea. National Academy of Sciences. Retrieved on December, 20, 2013 from: http://www.nap.edu/catalog/10388.html. This report provides the best available estimate of oil pollutant discharge into marine waters, including an evaluation of the methods for assessing petroleum load and a discussion about the concerns these loads represent. Featuring close-up looks at the Exxon Valdez spill and other notable events, the book identifies important research questions and makes recommendations for better analysis of—and more effective measures against—pollutant discharge. The book reviews (i) discharge sources, behaviour or fate of oil that has been spilt—how oil is affected by evaporation as it moves through the environment, and (iii) effects—knowledge on the effects of petroleum hydrocarbons on marine organisms and ecosystems.

Other studies used

Category 1

There is an increasing number of scientific (journal) papers analysing the situation in the Niger Delta. Many, but not all, are written by Nigerian scientists, often co-authoring with researchers from universities and institutes in western countries (often UK-based). Excellent work has been presented, especially after the year 2000. A few of the most relevant studies are listed here.

Egberongbe, F.A.O., Nwilo, P.C. and Badejo, O.T. (2006) Oil spill disaster monitoring along the Nigerian coastline. Paper presented at the 5th FIG Regional Conference ‘Promoting Land Administration and Good Governance’, held in Accra, Ghana, March 8-11, 2006. Follow up on Nwilo and Badejo book chapter. Modelling movements of offshore oil spills in Nigeria, studying a fictional spill opposite Ikebri Creek Forest Reserve (Bayelsa State). The model considered amount spilled, type of oil, location, wind and water currents. Well documented.

Jernelöv, A. (2010) The Threats from Oil Spills: Now, Then, and in the Future. AMBIO 39, pp.353–366. DOI 10.1007/s13280-010-0085-5. Analysis and comparison of major oil spills around the world (arctic areas in Russia, Niger Delta, Gulf of Mexico, northwestern Amazon, Gulf war). Generalised description of environmental effects.

Lindén, O., and Pålsson, J. (2013) Oil Contamination in Ogoniland, Niger Delta. AMBIO 42, pp. 685-701. Reporting oil contamination in Ogoniland. Contamination levels of petroleum hydrocarbons including benzene exceed WHO guidelines over 900 times. Polycyclic aromatic hydrocarbons (PAH) concentrations found in most sites. Oil spills casued by ageing, neglected infrastructure; transport and artisanal refining of stolen oil. Generalised descrip-

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[3] A study with a similar name but published in a journal (Nwilo, P.C. and O. T. Badejo, 2001. Association for Environmental and Health Sciences (AEHS) Magazine, October.), cited by Steiner (2010) could not be obtained on the internet.

tion of environmental effects. Heavy damage to mangroves reported, but no quantification given. Recovery of contaminated areas prevented by the chronic character of the contamination.

Pezeshki, S.R., Hester, M.W., Lin, Q., and Nyma, J.A. (2000). The effects of oil spill and clean-up on dominant US Gulf coast marsh macrophytes: a review. Environmental Pollution, Vol. 108, pp.129-139. Excellent review of literature on damage caused by oil spills. Focus on the USA Gulf region. Tables with summaries of other papers, but rarely providing quantified data.

Category 2

International organisations have taken the lead in demaning attention for the situation in Nigeria. Reports by UNDP and Amnesty International (2009) have already been listed above. Here we present some other reports.

Amnesty International (2013). Bad information. Oil spill investigations in the Niger Delta. Following up on the 2009 report by the same organisation, this report explores the number of oil spills, their impact including clean up activities. It also describes lack of clarity on good quality quantified information, and discussions on responsibility for spills in the face of increasing sabotage efforts.

Francis, P., Lapin, D., and Rossiasco, P. (2011) Securing development and peace in the Niger Delta. A social and conflict analysis for change. Woodrow Wilson Center for Scholars. An extended analysis of the roots of social conflicts in the Niger Delta. Includes an overview of conflicts and stakeholders involved and their activities in the delta area. Originally prepared for internal use by the World Bank.

UNDP (2006). Niger Delta Human Development Report. Abuja, Nigeria, United Nations Development Programme. The report by a UN institution was one of the first of its kind. It studies uneven economic and human development in the Niger Delta in the light of intensive oil production activities and prevailing environmental damage. The authors lists numbers of spills and amount of oil spilt. Damage is considered in a general framework of regional development, emphasising issues of health and economic development including income and food security, social inclusion and institutional development.

Achebe, C.H., Nneke, U.C., and Anisiji, O.E. (2012). Analysis of Oil Pipeline Failures in the Oil and Gas Industries in the Niger Delta Area of Nigeria. Proceedings of the International Multiconference of Engineers and Computer Scientists 2012 Vol II. This conference paper is an authoritative source of key data on pipeline quality and distribution as well as spills and their causes. The authors have analysed major data sources including Data collected from known periodicals and other literature, as well as the databases of Nigerian National Petroleum Corporation (NNPC), Department of Petroleum Resources (DPR), Shell Petroleum Development Company (SPDC) and other secondary sources that are responsible for operating oil and gas pipelines in the Niger Delta Area.

Studies not included in this report

A number of studies have not been included for a variety of reasons. Usually, they provided no new (original) information, basing themselves on data presented in other studies that were included. This is a brief overview of other relevant studies.

Steiner (2010). Double standard: Shell practices in Nigeria compared with international standards to prevent and control pipeline oil spills and the Deepwater Horizon oil spill. Amsterdam, Friends of the Earth Netherlands. Authoritative overview of the extent and number of spills, amount spilt, in a report providing an overview of the legal framework of oil production and environmental protection. Complaint against Shell's activities.

Adoki, A. (2012). Soil and Groundwater Characteristics of a Legacy Spill Site. Journal of Applied Science for Environmental Management. Vol. 16, pp.103-113. Identification of water pollution near a spill site in Rivers State. Groundwater measurements and modelling. Potential sources of contamination include stockpiles of excavated surface material deposited at the site; accidental leaks of crude oil, impacted surficial and subsurface Soils and Groundwater. The chemicals of potential concern include Petroleum Hydrocarbons and Heavy metals (chromium and lead).

ANNEX 2 LIST OF EXPERTS

All experts have been contacted, usually via email. Some have provided feedback, or suggested alternative literature. The authors are grateful for their collaboration.

Table A.2 List of experts

Name	Affiliation	Remark
Omo Omo-Irabor	Department of Earth Sciences Federal University of Petroleum Resources Effurun, Nigeria	Modelling movement of oil spilt offshore. GIS. Provided feedback.
Valentijn Venus	Faculty of Geo-Information Science and Earth Observation P.O.Box 217, 7500AE Enschede, the Netherlands	Modelling spatial effects, mangroves. Provided feedback and information.
Kathryn Burns	Australia	Expert on assessing damage from oil spills (observed as well as experimental).
Steve Crooks	San Francisco	Independent consultant on wetlands, damage caused by oil spills. Contact via LinkedIn.
Magne O. Sydnes	Norway	Paper on toxicity of PAH's to aquatice ecosystems, especially fish and crustaceae.
Olof Lindén	Sweden	Paper on damage from oil in Ogoniland. Provided feedback
Olusegun Badejo	Department of Surveying and Geoinformatics University of Lagos Lagos 234 NIGERIA	