Environmental Impacts of oil mining activities in the Niger Delta Mangrove Ecosystem.

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ABSTRACT

Since the discovery of oil in the Niger Delta nearly 50 years ago, oil mining has been reported to be associated either directly or indirectly with a myriad of environmental problems. Outstanding among them is estuarine acidification resulting from access creation through dredging and abandonment of pyritic spoils/sediments, which has resulted in the release of acidic leachates causing the death of mangrove and associated fauna; and general habitat degradation which prevent the re-colonization of the site by native mangrove species. This paper therefore focuses on the environmental consequences of abandoned sulfidic dredge spoils, extent of spoil abandonment, and options available for their handling, restoration and rehabilitation. It concludes by recommending beneficial uses of spoil rather than disposal.

KEY WORDS: acidification; acidithiobacilli; acid mine drainage, dredged sediment; mangrove; pyrite; rehabilitation; restoration; spoil handling; sulfidic spoil.

1. INTRODUCTION AND BACKGROUND

The Niger Delta is a wetland of about 76,000 sq km and has the largest mangrove forest in Africa (11,134 sq km) and the fourth largest in the world (Spalding et al., 1997). Hydrocarbon exploration started in the Niger Delta in 1937, and it was not until 1956 that the first oil well was struck, other discoveries followed and two years after Nigeria made her first batch of oil export. Nigeria became an independent country in 1960, and soon became an important member of the organization of petroleum exporting countries (OPEC). Nigeria is currently rated as the sixth largest producer and the eighth largest exporter of petroleum with a daily crude oil production rate of 2.4 million barrels. As at today the country's crude oil and gas reserve stands at over 20 million bbl and 3.4 trillion cubic meters respectively (Imevbore, 2001).

In addition to petroleum resources, the Niger Delta has been reported to be highly diverse and rich in biological resources (ERML, 1997). Being the largest wetland in Africa, the biological diversity of the Niger Delta is of both regional and global importance (Moffat and Linden, 1995). For instance the Delta hosts a number of endangered species listed in the 1996 IUCN red list; including the pygmy hippopotamus (*Choeropsis liberiensis*), manatees (*Trichechus senegalensis*), maritime hippopotamus (*Hippopotamus amphibious*) and all species of crocodiles, including the Nile (*Crocodylus niloticus*), slender nosed (*C. cataphractus*) and dwarf (*Osteolaemus tetraspis*) (Moffat and Linden, 1995; World Bank, 1995). Other wildlife of conservation interests include the Cape clawless otter (*Aonyx capensis*), African palm nut vulture (*Gypohierax angolensis*), Cuviers fire footed squirrel (*Funisciurus pyrropus*), Hammerkop (*Scopus umbretta*), African fish eagle (*Haliaetus vocifer*), Sclater's guenon (*Cercopithecus sclateri*), sitatunga (*Tragelaphus spekei*), white throated monkey (*Cercopithecus erythrogaster*) just to name a few.

The Niger Delta is also rich in fishery resources; it provides breeding grounds for numerous species of finfish, prawns and as habitats for crabs and mollusks (IPIECA, 1993). Available records show that the delta has more freshwater fish species (197) than any other ecosystem in West Africa (Moffat and Linden, 1995). Beyond these, the extensive mangrove forest provides nesting sites for sea and shore birds; stabilizes and protect the Nigerian coastline, and filters and traps water borne pollutants. In addition, plants products are obtained from the forest such as logs, fuel wood, charcoal, building materials, stakes for fish traps, paper pulp, railway sleepers etc (Semesi and Howell, 1992; IPIECA, 1993; IUCN, 1993). Other products of medicinal and agricultural values are also got from mangrove forests (Semesi and Howell, 1992; Miles et al., 1999). The mangrove swamps have sustainably supported the economics of the local populace for decades before the advent of oil mining. Despite the socio-economic, ecologic and biodiversity value of these wetlands, they are being threatened by anthropogenic influences, outstanding among these is dredging and the concomitant disposal of dredge spoil.

The Niger Delta is swampy and poorly serviced by roads. Access to these wetlands is one of the major challenges faced by oil companies. Typically, access is required during seismic operations; exploratory drilling; development drilling and well completion; construction of production facilities, base camps; and for waste management. Dredging is carried out in order to increase access to these wetlands. It involves deepening/widening of an existing channel or cutting a new access channel and typically the resultant spoils are deposited over bank (unconfined) mostly upon fringing *Rhizophora* mangrove and then abandoned. The subsequent poor spoil management practices have led to a number of environmental impacts through direct burial and destruction of fringing mangroves and associated fauna, change in topography and hydrology, siltation of navigable canals, flooding and suffocation of mangroves, degradation of water quality, habitat fragmentation and alteration of vegetation and land use (Ohimain, 2003). Also, Ohimain *et al* (2002a) reported a case in Warri River where dredging caused a re-suspension of nutrient (eutrophication) which in turn enhanced the growth of phytoplankton leading to the formation of algal bloom in some stagnant portions of the river especially at the extremities of the canals. Dredging has also been shown to decrease the population and diversity of zooplankton (Ohimain *et al*, 2002b) and benthic invertebrate (Ohimain *et al*, 2002c). Degradation of water quality through increased turbidity and siltation caused by dredging to clear vegetation in drilling sites has been reported to be one of the major environmental problems resulting from oil mining in the Niger Delta (Moffat and Linden, 1995). In fact dredging has been reported to impact virtually all components of the environment (ASA, 1998).

Like other mangrove ecosystems, the Niger Delta soil/sediments are sedimentary in origin and contained reduced sulphur compounds particularly pyrite and are therefore referred to as acid sulphate soils (Anderson, 1966; Okonny et al, 1999). When intact in the undisturbed and reduced state under wetlands conditions, these pyrite are innocuous, but their exposure through dredging and the unconfined disposal of the concomitant spoils leads to pyrite oxidation and estuarine acidification, which is quite similar to acid mine drainage (AMD) caused by the oxidation of mine overburden/tailings in every sense, both in the acid forming processes and the accompanying environmental impacts (Dent, 1986; Rose and Cravotta, 1998). The difference is only in terms of industry terminologies; in the agricultural sector it is referred to acid sulphate soil (ASS), whereas in the mining industry it is synonymously called acid rock- or mine drainage (ARD or AMD). The source of the substrates is similar; being sulphidic spoils from wetlands soils/sediments and from mine overburden/tailings causing ASS and AMD respectively.

The environmental impacts of oil mining in the Niger Delta ranging from oil spills to gas flaring have been well documented (Moffat and Linden, 1995; World Bank, 1995; ERML, 1997, Aston-Jones, 1998, Human Rights Watch, 1999; Imevbore, 2001; Okonta and Douglass, 2001), however, only few publications recognize the problem of acidification (Anderson, 1966; van Dessel and Omuku, 1994; Okonny et al, 1999), but non has itemized the full range of impacts nor proffered options for the management of pyritic spoils; these are the major focus of this paper. Furthermore, the paper highlights the results of a preliminary assessment into the cause of the mortality of about 120 ha of mangrove following the dredging of an oil well access canal in the Western part of the Niger Delta. The paper also examines the similarities between ASS and AMD.

2. ENVIRONMENTAL IMPACTS

The full spectrum of environmental impacts associated with oil mining activities with regard to dredging and spoil management will be discussed using a case study. In November 2001, an oil producing company completed the dredging of a 3 km long oil well access canal in the Western part of the Niger Delta. Shortly after, the tall red mangrove, *Rhizophora racemosa* fringing the newly created canal became stressed and four months after (March 2002), large-scale mortality of about 120 ha of primary mangrove forest was observed (see Figure 1). One year after the vegetation damage, fish kills were observed within the dredged canal. The results of a preliminary assessment of the cause of the observed vegetation damage and fish kills is discussed in the following sections:

Figure 1. Vegetation damage resulting from dredging

2.1 PHYSICAL IMPACTS ON VEGETATION

During dredging, the resultant spoils were deposited above tidal influence, mostly upon adjacent mangroves; thus asphyxiating them. Burial of the breathing roots of mangroves has been reported to cause mangrove mortality (IPIECA, 1993; IUCN, 1993). This is plausible for those mangroves at the dredge spoil dumpsite, but what would have caused the death of the un-buried mangroves immediately behind the spoil dumps and further inland? These are considered in the following sections.

2.2 ALTERED SITE TOPOGRAPHY AND LOCAL HYDROLOGY

The dumped spoils were placed continuously along the bank of the canals; thus forming a barrier against freshwater and tidal inundation and causing leachates from the spoil to stagnate and flood the back swamp. IUCN (1993) emphasized that it is critical to maintain the freshwater flow and normal tidal circulation patterns in mangrove areas. Furthermore, mangroves are known to be tolerant to both tidal and freshwater inundation, but they are quite sensitive to continuous flooding by either tidal or freshwater (Kathiresan and Bingham, 2001).

The Niger Delta is low lying with topographic height ranging from 0.8 to 1.8 m above mean sea level (Nwilo and Onuoha, 1993). The deposited spoil also causes an alteration in site topography in the hitherto low-lying mud flats. The elevation of the spoil dump ranged from 1.8 to 2.6 m above the high tide. Hoff (2002) reported that mangroves are flooded periodically with frequency and magnitude of flooding determined by local topography combined with tidal action, river flow, rainfall, surface runoff and evapotranspiration. Mangroves have been reported to be highly sensitive even to minor alteration in topography (Hughes, 1998). Such minor changes can cause an important change in the hydrology of an area (Mitsch and Gosselink, 1993). The consequence of this is that wide variations in hydrology occur with differences in the frequency and duration of tidal inundation, which is closely linked to elevation (Hughes et al, 1998). Hydrological changes often result in mangrove destruction. For instance in India, changes in topography and tidal flushing caused a large-scale degradation of mangroves (Kathiresan and Bingham, 2001).

Habitat modification has also been reported to exacerbate erosion, flooding and subsidence in the Niger Delta (Ebisemiju, 1985; Eedy *et al*., 1994; World Bank, 1995, Ebisemiju *et al*., 1988). This change in the physical landscape of the delta have been reported to have directly or indirectly cause the death of coastal vegetation particularly mangroves and freshwater swamp forest.

2.3 ALTERED SOIL CONDITIONS CAUSING ACIDIFICATION

The results of the preliminary assessment of the soil and water from the area of damaged vegetation are presented in Tables 1 and 2 respectively. Evidence suggests that acidification is going on in the spoil dump, on account of the low pH, high sulphate concentration and a correspondingly high chloride and electrical conductivities. Moreover, the result of the leachates revealed a serious acid situation with pH ranging between 1.47 and 2.48, while soluble sulphate and total iron were also high. The population of actively growing *Acidithiobacillus* sp. was in the order of 10^7 MPN/100m. Previously Ohimain (2001) had isolated a number of acid forming and acid tolerant microorganisms from a similar dredge spoil dump elsewhere in the delta. Literature abounds on the role of microorganisms in ASS (van Breemen, 1976; Arkesteyn, 1980; Dent, 1986) and AMD (Colmer and Hinkle, 1947; Kleinmann, 1979; Mills, 1988; Nordstrom and Southam, 1997; Edwards et al., 1998; Robbins, 1998). The high concentration of elemental sulphur in the mangrove forest ranging from 0.7% in the recently deposited alluvium soils to 6.3 in the more aged soils (Anderson, 1966).

Table 1. Characteristics of abandoned dredge spoil adjacent to the dying mangroves

	Fresh Spoils (<4 months) (n = 10)		Weathered spoils[1] (< 5 years Spoils) (n = 4)	
	Mean ± std. Dev.	Range	Mean ± std. Dev.	Range
pH[2] (soil paste)	2.02 ± 0.37	1.47 – 2.48	2.15 ± 0.08	2.03 – 2.21
Electrical Conductivity[3] ($mScm^{-1}$) (soil paste)	11.30 ±1.43	8.82 – 13.06	2.11 ± 0.26	1.89 – 2.41
Exchangeable Acidity[4] (meq/ 100g)	29.78 ± 10.59	16.20 – 44.20	18.10 ± 0.38	17.80 – 18.60
Chloride[5] (mg/kg)	7752.33 ± 985.64	6558.30 – 9621.80	176.83 ± 0.85	175.55 – 177.25
Sulphate[6] (mg/kg)	18982.34 ± 901.86	17866.60 – 20338.70	6907.70 ± 639.12	6323.22 – 9649.24
Phosphate[7-] (mg/kg)	59.66 ± 30.53	17.30 – 97.50	155.89 ± 17.92	129.00 – 164.85
Total Nitrogen[8] (%)	0.21 ± 0.07	0.11 – 0.31	0.92 ± 0.36	0.40 – 1.18
Total organic carbon[9] (%)	5.78 ± 0.69	4.70 – 6.60	3.80 ± 0.28	3.58 – 4.16

[1] Collected from an abandoned spoil dump less than 4 km from the site of vegetation damage
[2] In-situ using Hach's pH meter (USDA, 1996)
[3] In-situ using Hach EC/salinity meter (USDA, 1996)
[4] Titrimetric method (IITA, 1979)
[5] Mohr titration methods (USDA, 1996)
[6] Turbidimetric/colorimetric method (USDA, 1996)
[7] Colorimetric method (USDA, 1996)
[8] Kjedahl method (USDA, 1996)
[9] Loss on ignition method (IITA, 1979)

Table 2. Comparison of the physico-chemical and microbiological properties of dredge spoil leachates and uncontaminated estuarine water

	Dredge spoil Leachate (n =10)		Uncontaminated river[10] water (n =10)	
	Mean	Std. deviation	Mean	Std. deviation
pH[11]	2.3785	0.24	7.01	0.13
Iron[12], mg/l	144.7	128.59	4.24	2.20
Sulphate[13], mg/l	5468.16	1579.50	608.17	165.11
Conductivity[14], us/cm	7298	2287.42	5486.20	3596.13
Dissolved oxygen[15]	1.56	0.52	5.74	0.59
Acidithiobacillus[16], MPN/100 ml (X 10^7)	1.14	1.52	Nil	

Beyond these, there were visible signs of acidification such as the presence of jarosite mottles/yellow ochre and brownish leachates. These are regarded as positive signs of acidification (Bloomfield, 1973; Dent, 1986). The weathered spoil had similar chemical properties to the freshly deposited spoil except for the higher nutrient levels (nitrogen and phosphate), lower organic carbon, sulphate and chloride. This confirms that soil acidification is a long-term problem. The impacts of acidification on wetlands are discussed below:

2.3.1. IMPACTS ON VEGETATION

Apart from physical damage and altered topography and hydrology, acidification can also cause vegetation damage. The acidified leachates trapped in the backswamp may be a major cause. Van Breemen et al.(1973), while working in humid tropical mangrove in Thailand found that draining of mangrove soils often causes lowering of pH, which in turn brings into solution aluminum, iron, arsenic, at times manganese and other heavy metals from the clay particles. This may probably be the case in this situation as the exchangeable acidity was observed to be high, which implies high aluminum content. Aluminum is known to be highly toxic to plant roots (van Breemen, 1973), this may explain in part why the mangroves were observed dying from the root upwards. Other heavy metals may also impact the mangroves as well. Ohimain (2001) has similarly reported high levels of heavy metals emanating from abandoned spoils elsewhere in the delta. Mangrove soils/sediments, which are known to sequester a large amount of heavy metals (Tam and Wong, 1996), appear to release these metals after disposal of dredge spoils due to changes in the speciation and stability of metal bearing phases (Stephen et al., 2001).

AMD has similarly been reported to cause the death of upland vegetation elsewhere (Schippers et al., 2001). Strock used plant species diversity and succession pattern as indicators of mine spoil chemistry.

[10] Tidal water draining the area, not impacted by acidification
[11] Using Hach's pH meter (APHA, 1995)
[12] Using Bulk Scientific Atomic Absorption Spectrophotometer (APHA, 1995)
[13] Turbidimetric/colorimetric method using Hach DR 4000 spectrophotometer (APHA, 1995)
[14] Using Hach conductivity/salinity meter (APHA, 1995)
[15] Winkler's method (APHA, 1995)
[16] Using 9k medium (Silverman & Lundgren, 1959) and incubating for 30 days at 28°C

2.3.2 IMPACTS ON FISHERIES

At the site of vegetation damage, fish kills occur a year later at the onset of the rainy season. The fiddler crab (*Uca tangeri*) and mudskippers (*Periophthatmus koelreuteri*) that used to be abundant in these areas are now less common, and the few individuals seen exhibited signs of pathological stress and weakness. In Australia, fish kills have also accompanied the early rains preceding a prolonged dry season (Callinan et al., 1993; Sammut and Lines-Kelly, 2000). These authors opined that fish mortality at the onset of the rainy season is due to the release of substantial quantities of acids and aluminium stored during the dry months into the waterways. Literature abounds which suggests that the impact of acidification is high on coastal fisheries (Sammut et al, 1995; Callinan et al., 1993; Willet et al., 1993; Russell and Helmke, 2002). AMD has also been reported to negatively impact aquatic fauna (Lackey, 1949; Earle and Callaghan, 1998).

According to Sammut and Lines-Kelly (2000) drainage of coastal wetlands constantly releases enough sulphuric acid and aluminium to affect the aquatic food chain, fish populations and the health of fish. The report further stated that acid water affects the health of fish and other aquatic life through damage to their skin and gills, which increases their susceptibility to fungal infections, which often precedes a number of fish diseases such as epizootic ulcerative syndrome and others mentioned in Callinan et al, 1993.

It has been reported that the reduction in fisheries in the Niger Delta coincided with the advent of oil mining in the area (Moffat and Linden, 1995). Though the authors opined that other factors such as population increase, over harvesting of juveniles, construction of upstream dams as the probable causes of the decline. Habitat degradation through dredging and subsequent acidification may also contribute substantially.

2.3.3 IMPACTS ON WATER QUALITY

The quality of the leachates and normal tidal water presented in Table 3 suggest that acidification has the potential to degrade water quality by impacting it with ochre, acidity and other toxicities. A pH of 2.3 was recorded in the impounded leachate, whereas it has been reported that pH < 5 is critical for fish species (Brocksen et al., 1992). The observed fish kills are obvious signs of water quality degradation. Russell and Helmke (2002) reported that degradation of water quality through reduction in pH and dissolved and elevated iron and aluminium are the factors responsible for fish mortality. These factors seem to be valid here. The authors further presented evidences linking fish kills and changes in abundance and diversity of fish and crab to episodic discharges of acid water. The characteristic red brown flocs/jarosite/precipitate of iron hydroxide or oxyhydroxide typical of pyrite oxidation (Bloomfield, 1973; Dent, 1986, Sammut et al., 1997) was seen flowing into the newly created canal from the backswamp (Figure 1).

2.3.4 IMPACTS ON LAND USE

After several cycles of natural weathering, the spoils often become relatively lower in salinity and acidity, and become colonized by invading non-mangrove species. Factors which restrain the mangroves from re-colonizing the area, such as altered topography and hydrology that prevent tidal water and mangrove seedlings from reaching the site, favour the non-mangrove to invade the area. Grasses (*Paspalum vaginatum* and *Mariscus ligularis*) and the siam weed (*Chromolaena odoranta*) are usually the first to colonize the sites, followed by shrubs (mostly *Alchornia cordifolia*), and as conditions become more favourable other non-mangrove plants become established. Woody trees such as *Alstonia boonei* (stool wood), *Musanga cecropioides* (umbrella tree) and *Anthoclesta vogelii* (cabbage tree) are now common on abandoned spoils in the delta.

Because of the limited dry lands in the study area, elevated spoils become attractive to the natives for the establishment of fishing camps and home gardens and in the process reside dangerously close to oil infrastructure. Plantain (*Musa* sp) commonly grows well on spoil heaps. Although, this is a positive impact, there is the need to carry out toxicological studies to ascertain the safety of crops cultivated on spoils as plants are known to bio-accumulate heavy metals when grown on spoils (Bramley and Rimmer, 1988) and mangrove/estuarine sediments (Delaune and Smith, 1995; Tam *et al*., 1995).

2.3.5 IMPACTS ON OIL AND GAS INFRASTRUCTURE

Oilfield infrastructure located in the Niger Delta includes the three refineries; four export terminals, 159 oil fields, 1481 production wells and several hundreds of pipelines and flowlines (ERML, 1997). Oil mining is the mainstay of Nigeria's economy and the multi-billion dollar infrastructures may be at risk through corrosion caused by dredge spoil acidification.

3. EXTENT OF IMPACTS

The extent of canalization and the consequential habitat change has not been documented. However, the type and extent of oilfield infrastructure can be used to estimate the impacts. Typically, the dimensions of dredge canals are determined by a number of factors especially the intended use as well as the clearance requirements for the draught of drilling rigs, barges, pipeline laying equipment, boats or other utilities. A major oil producing company in the Delta has Oil Mining Leases (OML) covering an area of over 31,000 sq km, produces nearly half on Nigeria's oil (2.2 Million bbl/d), and uses 220 sq km to operate an extensive network of over 1000 producing oil/gas wells, 6000 km of oil/gas flow lines, 100 flow-stations/gas plants, and over 1500 km trunk lines through which oil flows to two export terminals in the mangrove zone (Environment Australia, 2001). Other producing oil companies probably operate similar oilfield infrastructures in the Delta. Each of these activities is associated with either vegetation clearance and/or dredging. Over half of these activities may have occurred in the mangrove zone. An oil company operating in the Delta was reported to have cut (including dredging) a total of 37,000 and 24,000 miles through mangrove forest to create 2D and 3D seismic lines respectively (Okonta and Douglas, 2001).

Canalization has been reported to be extensive in the Delta (Moffat and Linden, 1995). A number of hitherto intact swamps is now networked by a series of canals (see Figure 2). This change in hydrology has been reported by IUCN (1993), to be capable of altering the intertidal hydrology over a much wider area than the immediate site and they regard it as a potentially serious problem. According to Human Rights Watch (1997), canals disrupt the delicate hydrological system, especially when they are constructed in the border zone between freshwater and mangrove swamp. This was the case in the Mahin Coast adjacent to the Niger Delta, where the dredging of a canal linking the Atlantic Ocean to the swamp forest impacted about 200 sq km of swamp vegetation (mangrove and freshwater). The vegetation was reported to suffer from varying degrees of damage as a result of canal dredging (Fagbami *et a*l, 1988) and about 10% of this vegetation was lost in the process (Eedy *et al*., 1994). The dredging was reported to cause accelerated erosion and destroyed the local hydrology by allowing salt water into swamp forest, creating a less productive salt march in their stead (Human Rights Watch, 1997). Other ecological problems were also attributed to this dredging such as the observed 1.2 km shoreline recession in Mahin Coast during the period 1972 – 1991 (Eedy *et al*., 1994). A recent field visit revealed that the entire area is now permanently flooded with floating grass marsh vegetation, dominated by *Cyperus articulatus* and scanty stumps of dead woody trees (Figure 3), which is a relic of the thick tropical rain forest that once dominated the area.

Figure 2. A network of artificial canal as a result of oil mining

Likewise, information on the extent of impacts resulting from spoil abandonment is not available because land use changes are not documented. However, a major oil producing company generated approximately 20 million cubic meters of spoils between 1990 and 1996 (Ade Sobande & Associates 1998). It is estimated that the amount of spoils has increased substantially since the nearly 50 years of such operations by several oil companies started in the delta. The impact of changes in the physical landscape of an area can be far reaching. Habitat degradation has been reported to occur in large-scale in the mangrove zone (Moffat and Linden, 1995). This and similar anthropogenic influences caused the deforestation of 500 ha of mangroves annually (Ainodion *et al*., 2002). Moffat and Linden (1995) reported that about 5 – 10% of mangrove might have been lost in the process. However, recent estimate suggests that about 50% of Nigerian mangroves have been lost through deforestation occasioned by anthropogenic influences particularly dredging/canalization (UNEP, 1999).

Figure 3. Flooding and alteration of vegetation caused by dredging

4. DREDGE SPOIL MANAGEMENT OPTIONS

The proper handling of dredge spoils is one of the several ways of minimizing acidification. Environmental factors, which control the growth of acidithiobacilli also influence spoil acidification (Rose and Cravotta 1998), such factors include water, air and the presence of pyrite (Sturgess and Wasserman, 1995). Proper handling of spoils to prevent or control their acidification need to be focused on techniques, which prevent either air or water from reaching the spoils, neutralize acidity or inhibit acid forming bacteria (Ohimain 2002d). Some of the common techniques for spoil handling are presented in Table 3 (Ohimain et al., 2003).

Table 3. Techniques for handling sulphidic spoils to prevent acidification

Technique	Mechanism of action	Reference (s)
Pyrite separation	Prevent contact with air, water, and acidithiobacilli	Saffigna et al. 1996
Submergence or flooding	Eliminates oxygen	Perry et al. 1998
Constructed wetland treatment (Anaerobic)	Eliminates oxygen	Fennessy and Mitsch 1989
Capping with impervious materials	Eliminates both water and air	Perry et al. 1998
Placement of sulphidic spoils above surface and ground water levels	Prevent tidal and freshwater inundation	Perry et al. 1998
Alkaline treatment	Neutralizes acidity	Smith and Brady 1998
Bacteriocidal control	Kills acidithiobacilli	Kleinmann 1998

Source: Ohimain et al., 2003

Notwithstanding, the results presented in Table 2 suggest that the pH of the natural water of the Niger Delta is highly buffered, ranging from neutral to slightly alkaline, which suggests that tidal flushing can ameliorate the acidic conditions at the site of vegetation damage. Elsewhere, tidal flushing and dilution has been successfully used to treat acidity (Indraratna et al 2002). However, for tides to gain access into the site, the continuous mass of spoil dump may have to be traversed by a series of horizontal channels/drains. This can be done in the peak of the rainy season in July or September for more effective flushing. Although tidal flushing alone has been reported to remove acidity, its efficiency may depend on the distance from the site to the sea and the local hydrology. In order to complement tidal action, slow release limestone boulders can be installed at the bottom of the drains, similar to the anoxic limestone drain techniques for the treatment of AMD (Hedin and Watzlaf, 1994; Schmidt et al., 1996; Cravotta and Trahan; Robbins et al., 1999). US EPA (1996) presented various designs for the construction of treatment wetlands.

For mangrove to re-colonize the area, the local topography, which controls the hydrology, may have to be restored. This can be achieved through re-contouring to pre-dredging topography. The re-contouring is expected to restore the ‘normal’ hydrology, tidal exchange and residence times, site elevation and drainage, and freshwater in puts (Kaly and Jones, 1998). As the hydrology of the area is fully restored, the damaged vegetation site becomes tidally inundated once again. This will permit the oxidation products (mostly acids, iron and aluminium) to leach out and allow the return of the site to anaerobic conditions, which will permit the growth of estuarine bacteria (Kaly and Jones, 1998), particularly sulphate reducing species, which have been reported to reverse acidification conditions by catalyzing the reduction of soluble sulphate to insoluble sulphides (Ohimain, 2003). The process by which these tidal flushing treats AMD is similar to and perhaps more efficient than constructed wetlands. The result of laboratory scale treatment using sulphate-reducing bacteria appears promising (Ohimain, 2003).

Also, the restoration of the site hydrology will facilitate the restoration of site salinity and allow mangrove seedlings to get to these area. These among other factors will permit mangrove re-colonization of the site (Lewis and Streever, 2000).

Note that re-contouring will necessitate moving the ‘excess spoils’ to back fill in a new location, such as canals leading to derelict/dry oil wells, abandoned canals from unsuccessful prospects and other natural depressions where spoils could be inundated. Alternatively, the spoil can be used more beneficially by allowing it to weather under controlled conditions to permit the removal of toxicities (acids/sulphate, aluminium, iron and other heavy metals) then using it to reclaim degraded areas for habitation and to form elevated beds for agriculture as currently practiced in Vietnam, Thailand and other South East Asian countries (Minh et al 1997a, b, c).

CONCLUSION AND RECOMMENDATIONS

Dredging and concomitant spoil disposal, which are often carried out during oil mining have a number of impacts on the Niger Delta wetlands, particularly vegetation damage. The results of the preliminary assessment show that vegetation damage resulted from several factors including alteration in site topography, hydrology and soil conditions, which has led to the oxidation of sedimentary pyrite, which in turn leads to wetland acidification. The impact of acidification on the mangrove ecosystem is severe and long term. It has caused widespread destruction of habitats and associated fauna including fish, degradation of water quality, and the multi-billion dollar oilfield infrastructure in the delta may be at risk through corrosion.

Spoil abandoned also indirectly causes changes in the land use pattern, with grasses, shrubs and freshwater species succeeding mangrove in disturbed areas. Human migrants found these spoil dumps useful for the establishment of fishing camps and home gardens, which unfortunately are situated dangerously close to oil installations.

Several hectares of mangroves have been lost since the advent of oil mining in the Niger Delta. The WWF (2001) rated the Gulf of Guinea mangroves including that of the Niger Delta as 5th in the World’s Top Ten Most Vulnerable Forest Ecoregions. Many relatively rare fauna species are endemic in the Niger Delta; hence the area is of both local and international conservation concerns.

A number of options are available for the management of dredge spoils, including proper handling to prevent oxidation, restoration of site topography and hydrology to permit natural mangrove re-colonization, and tidal flushing to leach out acidity and other toxicities to create an environment conducive for mangrove restoration.

Beyond these, the beneficial use of dredge spoils for agriculture should be encouraged after controlled leaching of acidity and other forms of toxicities. Such use of treated/weathered spoils should not be incidental, but carefully planned in such a way that the spoils are reclaimed away from oilfield infrastructure.

In conclusion, it is only when dredging and dredge spoil management issues are addressed upfront and integrated into oilfield development plans can the mining of oil from the Niger Delta be sustainable.

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