Educational Research and Review Vol. 2 (7), pp. 151-156, July 2007
Available online at http://www.academicjournals.org/ERR
ISSN 1990-3839 © 2007 Academic Journals

Review

Phytoremediation: an environmentally sound technology for pollution prevention, control and remediation in developing countries

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Accepted 30 May, 2007

The problem of environmental pollution has assumed an unprecedented proportion in many parts of the world especially in Nigeria and its Niger-Delta region in particular. This region is bedeviled with this problem perhaps owing to interplay of demographic and socio-economic forces coupled with the various activities that revolve round the exploration for and exploitation of large deposit of crude oil discovered there. Many methods and processes of preventing, removing and or correcting the negative effects of pollutants released into the environments exist but their application in this country for this purpose has either been poorly implemented or not at all, a situation that is worsening owing probably to claims of lack of virile regulatory bodies and overwhelming dependence of government on crude oil for income. Studies have shown that the livelihood of local inhabitants largely depend on renewable natural resources which is environment dependent, thus, it is imperative that the environment should be sustainably managed in order to continue serving this function through comparatively cheaper means, one of which phytoremediation is. The objective of this review is to discuss phytoremediation studies using *in-situ* techniques and their potentials as a remediation technique that utilizes the age-long inherent abilities of living plants to remove pollutants from the environment but which is yet to become a commercially available technology in many parts of the world including Nigeria.

Key words: Phytoremediation, environmental pollution, crude oil exploration, Niger-Delta, developing countries.

INTRODUCTION

Evidence abounds in literature that substantiate the fact that environmental degradation that results from pollutants generation has been traced to anthropogenic sources in the quest for exploiting nature as a source of means of livelihood.

In Nigeria, the scourge of environmental pollution has reached a frightening scale in recent years especially in the Niger-Delta region, the largest delta in Africa and the third largest in the world where most of the crude oil in the country is found (HRW, 1999). This region encompasses an area of approximately 70,000 km^2 accounting for about 7.5% of the country's total land mass, covering a coastline of 560km, about two-third of the country's entire coastline. Figure 1 is the map of Nigeria showing the extent of the region in terms of the constituting states.

Various reasons have been attributed to the increasing intensity of environmental degradation as a result of pollution in the region among which are the fluctuating demographic parameters with an estimated human population of 30 million as at 2005 according to Niger Delta Development Commission (NDDC) record, accounting for about 23% of Nigeria's total population. According to NDDC, this region is among those with the highest population density in the world with 265 people per km^2 and this population is expanding at a rapid rate of 3% per year. The socio-economic characteristics and the exploittation of large crude oil deposit discovered in this region are other major contributory factors to environmental pollution in this region.

There exist some mitigation treatments for wastes associated with industrial and crude oil exploration activities before being introduced into the environment but reverse seems to be the case in the country owing perhaps to inefficient enforcement of standard by regulatory bodies, corruption, high cost of procuring and maintaining some of the mitigation equipments, ignorance, lack of vision, or carelessness among others.

The problem of environmental pollution is an issue that

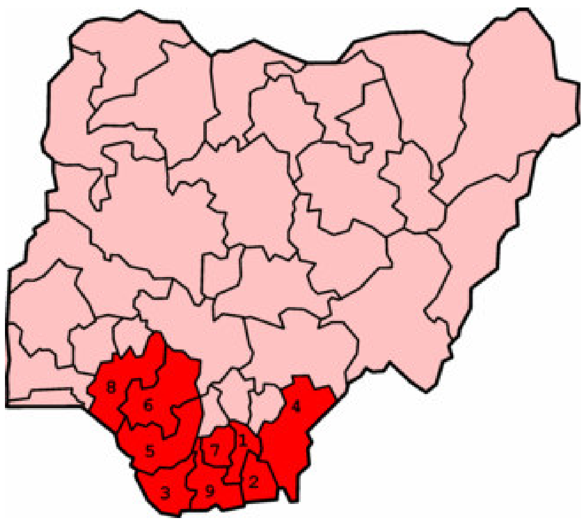

Figure 1. Map of Nigeria numerically showing states typically considered part of the Niger-Delta region; Abia, Akwa Ibom, Bayelsa, Cross River, Delta, Edo, Imo, Ondo, Rivers. Source: Wikipedia Online Encyclopedia.

should be on the front burner in this part of the world, where the majority of the inhabitants depend on renewable natural resources which is itself environment dependent, as means of livelihood, if the objectives of the Millennium Development Goals are to be achieved.

The environment has been defined in development terms as life supporting system for human existence and survival as well as provider of physical milieu and raw materials required for socio-economic progress therefore, comparatively cheaper and feasible sustainable methods of pollutants removal from it are necessary. One of such methods is phytoremediation, which is the use of plant origin microbes, green plants and their associated micro biota for the *in-situ* treatment of contaminated soil and ground water (Sadowsky, 1999).

The application of phytoremediation can either be achieved through the use of already existing plants in their natural habitat, for example, natural wetlands or as artificial marshes or swamps known as constructed wetlands cultivated and designed to emulate the capability of natural wetlands to remove sediments and pollutants from anthropogenic discharge such as wastewater, sewage treatment, reclamation of land after mining, storm water and other disturbances to the environment.

These technologies based on phytoremediation technique can be applied to both organic and inorganic pollutants present in soil (solid substrate), water (liquid substrate) or the air (Raskin et al., 1994; Salt et al., 1998; Kania et.al., 2002) although, an old concept (Henry, 2000) but new in this and many parts of the world.

Various researches employing the process of phytoremediation had been carried out for the remediation of contaminated water, both domestic and industrial wastewater ranging from the use of micro organisms, shrubs to trees (Shumate and Strandberg, 1985; Guntensbergen, 1989; Breen, 1990; Rogers et al., 1991; Andres et al., 1992; Fourest and Roux, 1992; Burken and Schnoor, 1997; Twilley, 1998; Ewel et al., 1998; Mcfarlane and Burchett, 1999; Hussein et al., 2003; Hussein et al., 2004).

As promising and comparatively cheaper as this technology is, there has not been any deliberate effort geared towards its development and utilization for pollutants removal from the environment in the country and particularly Niger-Delta region in the past to the best of the author's knowledge.

This paper is therefore focused on phytoremediation studies using *in-situ* techniques in order to stimulate the awareness of stakeholders as regards issues relating to environmental pollution management in the developing world with Niger-Delta region of Nigeria as a case study.

PROCESSES AND MECHANISM OF PHYTOREMEDIATION

The generic term 'phytoremediation' consists of the Greek prefix *phyto* (plant), attached to the Latin root *remedium* (to correct or remove an evil) (Cunningham et al., 1996). Phytoremediation is an alternative or complimentary technology that can be used along with or, in some cases in place of mechanical conventional clean-up technologies that often require high capital inputs and are labour and energy intensive. Phytoremediation is an *in-situ* remediation technology that utilizes the inherent abilities of living plants. It is also an ecologically friendly, solar-energy driven clean-up technology, based on the concept of using nature to cleanse nature (UNEP, Undated).

Reports on plants growing in polluted stands without being seriously harmed indicate that it should be possible to detoxify contaminants using agricultural and biotechnological approaches. Higher plants possess pronounced ability for the metabolism and degradation of many recalcitrant xenobiotics and can be considered as "green livers", acting as an important sink for environmentally damaging chemicals (Schwitzguébel, 2000). Plants are unique organisms equipped with remarkable metabolic and absorption capabilities, as well as transport systems that can take up nutrients or contaminants selectively from the growth matrix, soil or water (UNEP, Undated).

Contaminated soils, waters and air pose a major environmental and human health problem in the Niger-Delta region of Nigeria and may be partially solved by the emerging phytoremediation technology. Phytoremediation involves growing or encouraging the growth of plants in a contaminated matrix, either artificially (constructed wetlands) or naturally for a required growth period, to remove contaminants from the matrix, or facilitate immobilization (binding / containment) or degradation (detoxification) of the pollutants. The plants can be subsequently harvested processed and disposed.

The main difference between constructed and natural wetlands is that while the size of the former might be small and remain constant the latter can be large and increase in size with time, which thus, affect the intensity and efficiency of phytoremediation capability of both systems. Also, the plant species involved in constructed wetlands are those that do not directly connect with groundwater as compared with natural wetlands with species like trees e.g. mangrove.

The volume of sediments accommodated by both systems varies as a result of their size. It is also important to note that constructed wetlands develop desired diversity of plants and associated organism more quickly than the natural wetlands. Several types of phytoremediation can be defined according to Schwitzguébel (2000) as:

Phytoextraction: The use of pollutant-accumulating plants to remove pollutants like metals or organics from soil by concentrating them in harvestable plant parts;

Phytotransformation: The degradation of complex organic molecules to simple molecules or the incorporation of these molecules into plant tissues.

Phytostimulation: Plant-assisted bioremediation, the stimulation of microbial and fungal degradation by release of exudates/enzymes into the root zone (rhizosphere).

Phytovolatilization: The use of plants to volatilize pollutants or metabolites.

Rhizofiltration: The use of plant roots to ab/adsorb pollutants, mainly metals, but also organic pollutants, from water and aqueous waste streams.

Pump and tree (Dendroremediation): The use of trees to evaporate water and thus to extract pollutants from the soil.

Phytostabilisation: The use of plants to reduce the mobility and bioavailability of pollutants in the environment, thus preventing their migration to groundwater or their entry into the food chain.

Hydraulic control: The control of the water table and the soil field capacity by plant canopies.

As highlighted above, there are several ways in which plants are used to clean up or remediate contaminated sites. To remove pollutants from soil, sediment and/or water and air plants can break down, or degrade organic pollutants or contain and stabilize inorganic contaminants by acting as filters or traps. Table 1 shows an overview of some phytoremediation processes and status of research.

FEASIBILITY OF PHYTOREMEDIATION AS A MEANS OF ENVIRONMENTAL POLLUTION REMEDIATION

Phytoremediation techniques of pollutants removal from the environment has been successfully tested in many locations, in the US and Europe for example (Table 2), although, full-scale applications are still limited. Results of the tests indicated that phytoremediation is not only a feasible environmental remediation option but also presents many advantages, as compared to other remediation techniques as shown on Table 3.

The Niger-Delta region has an environment which is continuously degraded by the activities of oil prospecting companies, refineries and other oil-servicing companies, fertilizer and many other industrial plants, ocean ports among others. They do this through the use of explosives, rampant oil spills, accidents, leaks, discharge of wastes into water bodies and onto land, gas flaring amongst others which lead to dislocation of inhabitants from their place of abode and source of livelihood, contamination of water sources used mainly for drinking, cooking and washing, damage to food supplies, ill health, reduced income among other negative impacts.

It is no more news that the presence and the exploitation of large deposit of crude oil in the region, resulting in over $30 billion annually in revenue for the government and much more for the oil companies in Nigeria, has not had a significant positive impact on the local inhabitants who have suffered more from the environmental consequences of poorly controlled oil exploration activities (Borasin et al., 2002; Hassan et al., 2002).

Since phytoremediation has been identified as a cost effective, environmentally friendly, aesthetically pleasing environmental pollutants removal approach most suitable for developing countries (Ghosh and Singh, 2005), it is the author's view that this nascent technology that seeks to exploit the metabolic capabilities and growth habits of plants be exploited for the benefit of the inhabitants of the Niger-Delta region.

This system of environmental remediation is beneficial in terms of lesser financial commitment by both the government and the inhabitants to its development and utilization especially when the peculiar economic condition of the majority of the inhabitants in this region is considered. The relative inexpensiveness of phytoremediation has been highlighted by Wantanbe, (1997).

According to Geseksechaff for Techeiche zussameNarbeit, (GTZ), 70% of the people in the Niger-Delta region live below poverty line and the rate is far below the African standard. Another World Bank report also corroborated this by asserting that the Gross National Product (GNP) per capita in the Niger-Delta region is below the national average of US$280 despite the population growth rate.

It is important to add that as laudable as this method of cleansing contaminated site is, as everything in life, it is not without its drawbacks which are not insuperable (Tab-

Table 1: Overview of some phytoremediation processes

Mechanism	Process Goal	Media	Contaminants	Plants	Status of research
Phytoextraction	Hyper-accumulation, Contaminant extraction and capture	Soil, sediment, sludges	Inorganics: Metals: Ag, Cd, Co, Cr, Cu, Hg, Mn, Mo, Ni, Pb, Zn, Radionuclides: $^{\infty}Sr$, ^{137}Cs, ^{230}Pb, $^{238,234}U$	Indian mustard, pennycress, alyssum, sunflower, hybrid poplars	Laboratory, pilot and field applications
Rhizofiltration	Rhizosphere accumulation Contaminant extraction and capture	Groundwater, surface water	Organics/Inorganics: Metals, radionuclides	Sunflowers, Indian mustard, water hyacinth	Laboratory, pilot scale
Phytostabilization	Complexation, Contaminant destruction	Soil, sediment, sludges	Inorganics: As, Cd, Cr, Cu, Hs, Pb, Zn	Indian mustard, hybrid poplars, grasses	Field application
Rhizodegradation	Contaminant destruction	Soil, sediment, sludges,groundwater	Organic compounds (TPH, PAHs, pesticides, chlorinated solvents, PCBs)	Red mulberry, grasses, hybrid poplars, cattail, rice	Field application
Phytodegradation	Contaminant destruction	Soil, sediment, sludges,groundwater, surface water	Organic compounds, chlorinated solvents,phenols, herbicides,munitions	Algae, stonewort, hybrid poplar, black willow, bald cypress	Field demonstration
Phytovolatilization	Volatilisation by leaves, Contaminants extraction from media and release into air	Groundwater, soil, sediment, sludges	Organics/Inorganics: Chlorinated solvents, some inorganics (Se, Hg, As)	Poplars, alfalfa, black locust, Indian mustard	Laboratory and field application
Hydraulic Control (plume control)	Contaminant degradation or containment	Groundwater, surface water	Water-soluble organics and Inorganics	Hybrid poplar, cottonwood, willow	Field demonstration
Vegetative cover (evapotranspiration cover)	Containment erosion control	Soil, sediment, sludges	Organic and inorganics compounds	Poplars, grasses	Field application
Riparian corridors	Containment destruction	Surface water, groundwater	Water-soluble organics and inorganics	Poplars	Field application

Source: Adapted Kania et al. (2002); Ghosh and Singh (2005).

Table 2. Examples of sites demonstrating phytoremediation.

Location	Application	Contaminants	Medium	Plants
Edgewood, MD	Phytovolatilization Rhizofiltration Hydraulic control	Chlorinated solvents	Ground water	Hybrid poplar
Forth Worth, TX	Phytodegradation Phytovolatilization Rhizodegradation Hydraulic control	Chlorinated solvents	Ground water	Eastern cottonwood
Ogden, UT	Phytoextraction Rhizodegradation	Petroleum Hydrocarbons	Soil Ground water	Alfalfa, poplar Juniper, fescue
Porthsmouth, VA	Phytodegradation Rhizodegradation	Petroleum	Soil	Grasses Clover
Trenton, NJ	Phytoextraction	Heavy metals Radionuclides	Soil	Hybrid poplar Grasses
Chernobyl, Ukraine	Rhizofiltration	Radionuclides	Ground water	Sunflowers

Source: Adapted from EPA (1998).

Table 3. Some merits and drawbacks of phytoremediation processes

Advantages	Disadvantages/Limitations
Amendable to a broad range of organic and inorganic contaminants including many metals with limited alternative options.	Restricted to sites with shallow contamination within rooting zone of remediative plants; ground surface at the site may have to be modified to prevent flooding or erosion.
In Situ / *Ex Situ* application possible with effluent/soil substrate respectively; soil can be left at site after contaminants are removed, rather than having to be disposed or isolated.	A long time is often required for remediation; may take up to several years to remediate a contaminated site.
In Situ applications decrease the amount of soil disturbance compared to conventional methods; it can be performed with minimal environmental disturbance; topsoil is left in a usable condition and may be reclaimed for agricultural use; organic pollutants may be degraded to CO_2 and H_2O, removing environmental toxicity.	Restricted to sites with low contaminant concentrations; the treatment is generally limited to soils at a meter from the surface and groundwater within a few meters of the surface; soil amendments may be required.
Reduces the amount of waste to be landfilled (up to 95%), can be further utilized as bio-ore of heavy metals.	Harvested plant biomass from phytoextraction may be classified as a hazardous waste hence disposal should be proper.
In Situ applications decrease spread of contaminant via air and water; possibly less secondary air and/or water wastes are generated than with traditional methods.	Climatic conditions are a limiting factor; climatic or hydrologic conditions may restrict the rate of growth of plants that can be utilized.
Does not require expensive equipment or highly specialized personnel; it is cost-effective for large volumes of water having low concentrations of contaminants; it is cost-effective for large areas having low to moderately contaminated surface soils.	Introduction of non-native species may affect biodiversity.
In large scale applications the potential energy stored can be utilized to generate thermal energy; plant uptake of contaminated groundwater can prevent off-site migration.	Consumption/utilization of contaminated plant biomass is a cause of concern; contaminants may still enter the food chain through animals/insects that eat plant material containing contaminants.

Source: Adapted from Schwitzguébel (2000); Ghosh and Singh (2005).

le 3).

Conclusion

Based on the 'success stories' recorded by the various studies on phytoremediation in the developed countries some of which are highlighted above, it is of the author's view that researches relating to this emerging technology should be encouraged, intensified and applied in this part of the world in order to serve as a cheap environmentally friendly approach to pollutants removal especially in the coastal Niger-Delta region of Nigeria where the main crude oil exploration and associated activities are currently ongoing with corresponding reduction in the size of vegetation cover especially mangrove forest which is the dominant vegetation in the area.

Various studies have shown that mangrove vegetation can develop ecosystems with adaptation to exist in hostile coastal water environment and has been discovered to contribute to water quality maintenance through the removal of excess nutrient, an assertion that is attested to by the poor water quality seen in inland waters which contrasts with the health of the coastal waters beyond the mangrove forests.

Therefore, efforts should be geared towards conservation of the remaining and establishment of more mangrove plant species including other types of vegetation in this ecological zone in such a way that will assist in exploiting this technique of environmental pollution remediation.

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