Chapter 6
A Review on Bioremediation Potential of Vetiver Grass

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Abstract Wastes generation and contamination are increasing drastically due to industrial activities and population growth. Many approaches are in place such as chemical and physical treatments to tackle these wastes and contamination. However, other means of remediation are necessary to overcome the challenges in wastes treatment. In the last decades, research in bioremediation has increased dramatically owing to its potential application in cleaning up all kinds of waste from soil and other contaminated areas. Numerous plants and microorganisms prove to be efficient for bioremediation for various kinds of wastes such as metal, nuclear, mineral, fuels, and chemicals. Among them, vetiver grass could play pivotal role as bioremediation agent for numerous waste categories. Originally being a native from India, vetiver perennial grass has spread to the tropical and subtropical parts of the world due to its application in various fields, such as soil conservation, fragrance, energy fuel, handcrafts, hedge formation, medicinal preparations, and carbon sequestration. The unique property of vetiver plant is their ability to grow in harsh conditions and absorb contaminants leading to remediation. Therefore, several research studies reported on bioremediation potential of vetiver grass among other potential application. In this study, a review of these studies is carried out to highlight the benefits and the limitation of vetiver in bioremediation across industries and to provide some insights on how to incorporate vetiver grass in industries, municipalities, and households in the current and future wastes remediation programs that demand a sustainable approach.

Keywords Bioremediation · Contamination · Heavy metals · Chemicals
Soil remediation · Vetiver grass · Water contamination

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1 Introduction

The contamination level in soil and water has drastically increased several folds due to population growth, modernization, and industrial revolution, and it is to increase further. High-, medium-, and low-level toxic chemicals reach soil and water from several industries, households, municipals, and hospital and agriculture areas despite several toxic and waste treatment and management measures. It is more prevalent in developing countries due to limited management measures, awareness, and regulation (Kahn Danielle et al. 2009). Wastewater treatment used to tackle various wastes is chemical treatment and biological treatment (aerobic and anaerobic). Waste management measures are landfilling, composting, recycling, and incineration.

Bioremediation is an emerging and effective waste treatment or management procedure that uses biological resources to degrade and detoxify waste pollutants. Bioremediation is considered as the best sustainable way to treat toxic, household waste, and contaminated soil and water. Within bioremediation, the treatment of waste using plants is termed as phytoremediation, and treatment using both plants and microbes is termed as rhizoremediation (Kuiper et al. 2004). Bioremediation works through the principle of biogeochemical cycle that could be applied for soil, surface water, groundwater, sediments, ecosystem cleanup and restoration (Prasad 2011). Bioremediation of various wastes uses several microorganism and plant variants depending on their ability to degrade or accumulate certain type of waste chemical. Bioremediation is in use since ancient times to recover soil and water from contamination, e.g., Lotus and vetiver (Mishra and Clark 2013; Lavania 2008; Prasad 2011).

Bioremediation use numerous plants and microbes. Vetiver (*Vetiveria zizanioides* (L.) Nash), a perennial grass variety, native to India and grown in several parts of the world, has its application in soil and water conservation, disaster risk management, perfumery, medicine, households, energy and bioremediation. Vetiver has taken a predominant place in bioremediation research for mining spills, oil spills, landfills and garbage dumps treatment, agrochemicals and pesticides removal, heavy metal absorption, water treatment and purification, removal of effluents, nuclear waste, wetland application (Islam et al. 2008; Maiti and Kumar 2015). The unique characteristics of vetiver such as growing in harsh conditions, deep long roots, fleshy leaves, root aroma, soil agglomeration due to high root penetration, metal adsorption capacity, and withstanding extreme weather conditions being both hydrophyte and xerophyte make vetiver an excellent candidate for bioremediation (Dalton et al. 1996; Truong et al. 2010). Vetiver bioremediation has been the topic of study in several journals, reports, and news. In this chapter, the objective was to make a review of such literature to give an updated status on vetiver bioremediation in different industries and to provide few policy recommendations for successful implementation along with the limitation in the vetiver bioremediation system.

2 Vetiver Bioremediation

The vetiver system for bioremediation has its application potential in most of the industries to manage the soil and water contamination. This section is the review of the corresponding studies related to each industry to highlight the importance of vetiver plant in bioremediation.

2.1 Mining Industry

Mining operation in natural resources is inevitable to supply the mineral needs for the growing population and modernization in the developing and developed countries. However, these operation leaves behind a huge scar in the land creating a large soil dump with heavy metals that correspondence to 35% of the soil contaminant in Europe (EEA 2015) for instance that abolishes almost all the possibility to use that land. In addition, it also contaminates the surrounding area such as lakes, rivers, and fertile land as the minerals runoff in the rain due to erosion (Navarro et al. 2008). Recovery of such sites is important to decrease the contamination level, well-being of the species living around the mines and to create a pleasant environment. Several measures are available to accomplish this target, among that vetiver cultivation in such dump soil could be one of the cheapest options due to its cultivation easiness, mineral absorption, and soil erosion control capacity. Recently, Banerjee et al. (2016) tested dump soil from Odisha, India, containing heavy metals from iron ore mine with vetiver to study the mineral removal capacity. The pot experiments planted with vetiver grass showed that vetiver plant could remove heavy metals (Fe, Ni, Cr, Mn, Al, Cu, and Zn) from iron ore soil after 3 months. The roots accumulated more heavy metals compared to the shoot. Heavy metals in the soil stimulated malondialdehyde and proline as the tolerant factor during the plant growth due to stress and several enzymes that favor metal accumulation in roots and shoot (Banerjee et al. 2016). Similarly, Shu et al. (2002) examined the heavy metals (lead, copper, and zinc) removal capacity of vetiver and three other types of grass from contaminated soils. Vetiver grown in glasshouse using contaminated soil showed the highest accumulation of Pb, Cu, and Zn after 7 months in roots and shoots compared to other grasses. Study on the impact of root oil yield on heavy metal contamination leads to conclusion that oil yield decrease with increase in heavy metals concentration mainly due to low root growth because of the heavy metal stress. In line with this work, Pang et al. (2003) and Danh et al. (2010) demonstrated the capability of vetiver cultivation for heavy metals removal and oil production in mining contaminated soil. Similarly, Antiochia et al. (2007) reported the use of vetiver for remediation of soil contaminated with Pd and Zn.

2.2 Chemical Industry

The increased economic growth in developing countries will lead to higher chemical generation and use contributing to a third of global chemical consumption by 2020 (UNEP 2017). According to cleantech service (cleantechsg.com), annually around 10 million tons of toxic chemicals are released into the environment (cleantechsg.com). Management and treatment of these chemical wastes is vital for the good health condition of all living being. Bioremediation of chemical waste is economical among the waste treatment options. Several research findings were reported in the last decade on bioremediation of chemical waste, and vetiver has played a predominant role in chemical bioremediation. Research on bioremediation of phenol using vetiver was reported by Singh et al. (2008a) showing the results of complete removal of phenol from a solution with 50–100 mg/L and 89, 76 and 70% removal from 200, 500, and 1000 mg/L, respectively. Inherent production of peroxidase and hydrogen peroxide during vetiver plant growth in phenol environmental were found to be responsible for removing phenol. On the other hand, phenol inhibited vetiver biomass growth (Singh et al. 2008a). In another study, Ho et al. (2012) reported that use of endophytic bacterium *Achromobacter xylosoxidans* strain improves vetiver biomass growth while degrading phenol. Similar to phenol, cyanide remediation using vetiver was reported by Saeb et al. (2015) with a capacity of 8 mg/kg and the cyanide removal capacity increased with increasing pH, water quantity and growth time. Cyanide accumulation was higher in vetiver roots compared to that of shoots.

Explosive chemicals such as 2,4,6-trinitrotoluene (TNT) are carcinogen and pose a serious threat. TNT migration from explosive site and wastewater site to river and lakes is a concern. Similar to other chemicals, treatment with vetiver grass uptake TNT as well (Makris et al. 2007; Das et al. 2010). Makris et al. 2007 studied the TNT uptake capacity of vetiver and reported 1.03 mg/g in soil-pot experiments. Whereas, Das et al. (2010) reported a higher uptake of TNT (40 mg/g) using vetiver-urea system, where urea enhances the TNT uptake by acting as a chaotropic agent. Moreover, Liu et al. (2010) had also reported on cadmium accumulation using vetiver bioremediation. Treatment at 30 mg/L concentration, cadmium accumulation of up to 2232 and 93 mg/kg Cd dry weight were detected in roots and shoots, respectively.

2.3 Nuclear Industry

Radioactive compounds contaminants are generated from nuclear power plant, nuclear fuel mill, nuclear weapon testing, and from nuclear disasters. Significant amount of these compounds end up in soil and water. They cause serious health hazard to living beings by entering the food chain. Bioremediation of nuclear waste is also possible using vetiver cultivation (Shaw and Bell 1991; Singh et al. 2008b).

Radionuclides such as ^{90}strontium and ^{137}cesium were tested using vetiver plant for their bioremediation potential. Vetiver grown on solution spiked with ^{90}Sr and ^{137}Cs individually for 168 h showed 94 and 61% removal of ^{90}Sr and of ^{137}Cs, respectively. However, when they were grown on combined solution, the removal reduced to 91 and 59%. The accumulation was higher in shoots for ^{90}Sr compared to the roots, and the opposite behavior was observed for ^{137}Cs. Moreover, vetiver plant exposed to low-level nuclear waste for 15 days was able to reduce the waste level below the detection limit (Singh et al. 2008b). Similarly, Mahmood et al. (2014) also reported vetiver remediation to treat cesium-contaminated soil with 95.58% removal capacity. In addition, vetiver has the capacity to uptake uranium as well. According to the report by Hung et al. (2010), up to 126.45 mg/kg plant biomass of uranium could accumulate in vetiver grass when grown in soil contaminated with uranium at a concentration of 250 mg/kg.

2.4 Pharmaceutical Industry

Pharmaceutical industry is a major source for contamination, and the trend is increasing at alarming rate (Depledge 2011). The source of pharmaceutical pollutants is from pharmaceutical production firms, disposal of unused and expired drugs from households and hospitals (Wu et al. 2012; Wojcieszynska 2015). These drugs pose a serious danger to aquatic organism and human life. In addition, they also increase the antibiotic resistance of several microorganisms in the environment (Fent et al. 2006; Pruden et al. 2006; Luo et al. 2014; Sengupta et al. 2016). Several micro-pollutants contained in pharmaceutical waste reach the soil and water. Based on the frequency of use, naproxen is classified under micro-pollutant. It is a non-steroidal anti-inflammatory general medicine drug taken for inflammation and pain. Marsidi et al. (2016) reported the capacity of vetiver to treat wastewater and soil containing naproxen at concentrations ranging from 50, 100, 300 and 500 mg/L. After 56 days of treatment, 81.5, 64.5, 36.4, and 60.9% of naproxen were removed, respectively. In addition, the phytotoxicity results showed that bacterial activity around the roots also played a role in naproxen degradation. Similarly, the contamination of antibiotic in water could be reduced using vetiver. After 60 days growth in contaminated hydroponic system at a concentration of 5, 10, and 15 mg/L, complete removal of tetracycline was observed within 40 days (Datta et al. 2013). The metabolic profiling of vetiver treated with tetracycline reveals that biosynthesis of secondary metabolites TCA cycle, glyoxylate metabolism tryptophan metabolism, and inositol phosphate metabolism pathways has an impact due to tetracycline, and the tetracycline detoxification process is mediated by amide hydrolysis and GST-mediated conjugation (Sengupta et al. 2016).

2.5 Food Industry

Food is the primary need of all living beings and its demand directed the industrial revolution throughout the world. However, as the development toward modern agriculture technologies to improve the feed output and to fill the food needs of the growing population, several fertilizers, pesticides, herbicides, and fungicides were introduced. Despite gaining several benefits from these chemicals, environmental contamination occurred that lead to ill effects for aquatic, human, and other living organisms. This trend will continue to rise in future and several measures are being taken to control contamination from food industry (Aktar et al. 2009; Pretty and Bharucha 2014). Agriculture and food processing industries are the backbone of food industry that caters the nutrition needs (protein, carbohydrate, and lipids) through cereals, vegetables, meat, and oil.

Fertilizer and pesticide runoff to lakes and rivers is the main concern associated with agriculture practices. Bioremediation could be one of the strategies to clean up the waterways and soil. Several reports on vetiver used as a bioremediation agent is available in the literature. Atrazine is used a common herbicide for controlling grass weeds and broadleaf, and it is one of the general chemicals detected in water and soil (Lin et al. 2008; Fan and Song 2014). Vetiver's ability to take herbicide atrazine was the topic of research reported by Gupta et al. (2004), Schwitzguébel et al. (2006), and Marcacci et al. (2006). Vetiver grown in water contaminated with atrazine herbicides, deethylatrazine, and deisopropylatrazine (compounds formed due to degradation of atrazine by the action of bacteria in soil) showed a reduction of 5.2, 4.9, and 4.8 mmol/L of transpired water, respectively. Experiments conducted by Marcacci et al. (2006) on the mechanism of atrazine resistance in vetiver confirmed that atrazine conjugation to glutathione catalyzed by glutathione-S-transferases was the dominant pathway to detoxification. Inorganic arsenic was used in pesticides in the previous decades and several arsenic pesticides were banned in early 80s and 90s. However, the pesticide contamination spreads across and persists in many regions around the world (Pandey and Singh 2015). Greenhouse experiments on vetiver grown in arsenic contaminated soil showed good arsenic tolerance up to 225 mg/kg. Maximum arsenic removal (10.6%) was observed in 45 mg/kg arsenic soil contaminated and reduced to 0.6 and 4.5% at 450 and 225 mg/kg (Datta et al. 2011). Persistent organic pollutant such as organochlorine pesticides is a concern when present in adequate measures. These pollutants can be easily magnified over the food chain (Burgess 2013; Ye et al. 2014). After washing organochlorine with oil and natural polymers to remove majority of the pesticides, vetiver cultivation in washed soil further degrades these pollutants and enriches the soil with nutrients (Ye et al. 2013). Similar to other pesticides mentioned above, 2,4-bis(Isopropylamino)-6-methylthio-s-triazine (prometryn) is also a common pesticide used in USA, China, India, and other parts of the world for broadleaf weeds and annual grasses control in the cultivation of vegetables, cotton, wheat, and rice. Greenhouse hydroponic experiments on application of vetiver in prometryn pesticide removal for 65 days revealed that vetiver could reduce the half-life of this pesticide to 11.5 days in three-phase uptake following first-order kinetics. Vetiver roots rapidly removed prometryn from the solution and translocated to the shoots in first 8 days followed by a slower removal in the second phase (between 14 and 30 days) and a more gradual removal in third phase till 67 days (Sun et al. 2016a, b). Endosulfan is a hazardous organochlorine insecticide used in several crop and vegetable cultivations. In Africa, endosulfan is commonly used in the cotton fields and alarming rate of this insecticide is found in the air, water, and soil (Abaga et al. 2014; Dousset et al. 2016). The influence of vetiver on endosulfan-contaminated soil was studied by Abaga et al. (2014). The research results from the pot experiments revealed that half-lives of endosulfan could be reduced significantly and endosulfan could be completely removed after six months. On the other report, addition of rhizospheric microbes enhances the uptake of endosulfan in treatment of contaminated soil with vetiver (Singh et al. 2016). Similar to pesticides and insecticides, fertilizers are applied to the cultivation field and gardens. Excess amount of fertilizers in the soil contaminates the environment through runoff and erosion. Boron is an essential requirement for plant grown that is required in low quantity due to its high toxicity. Boron toxicity is reported in several countries, and bioremediation technique is the cost-effective and environmental friendly technique to treat boron-polluted locations (Rámila et al. 2016). Application of vetiver to treat boron-contaminated sites has been reported by Angin et al. (2008), Smolcz and Cortés (2015) and Xin and Huang (2017). In addition, vetiver cultivation toward successful onsite obsolete pesticide contamination bioremediation in Africa was reported by Harmsen et al. (2009).

Palm industry is one of the major industries that supply cheap and essential oil needs for food in many parts of the world. However, processing of palm for its oil generates high amount of secondary effluent that contaminates the soil and water around the mill. Several conventional measures are available to treat such effluent; however, they are not cost effective. Bioremediation using vetiver has been identified as one of the cost-effective approaches to reduce the BOD and COD from palm oil mill secondary effluent (Darajeh et al. 2016). Similarly, vetiver application in remediation of wastewater from coconut husk retting area has shown promising results in reducing biological oxygen demand, total dissolved solid, electrical conductivity, chemical oxygen demand, dissolved CO_2, H_2S, fluoride, chloride, hardness, phosphate, iron, polyphenols, nitrate, and coliform, and increasing the pH and oxygen (Girija et al. 2011).

2.6 Textile Industry

Textile, being the second basic need of a human being, is the second largest polluter in the world accounting to more than 8000 chemicals use that are toxic and persist in the environment such as rich dyes, fixing agents, detergents, solvents, bleaches, and heavy metals (Scott 2015). Bioremediation of chemicals from the textile industry through vetiver is reported in various studies. Charoenlarp et al. (2016)

used floating platform technique to study the textile effluent treatment using vetiver grass. This technique was effective in removing 36, 77, 88, and 43% of COD, BOD, SS, and color removal, respectively. The vetiver grass growth was good in textile effluent with 95.5% survival rate and the shoot reached 134 cm in height and the root to 24.62 cm.

2.7 Energy Industry

As one of the essential need in modern era, energy production generates a significant amount of pollutants released to air, water, and soil. Among different energy supply available, the largest contribution for pollution is from fossil energy that is mainly responsible for climate change. Most of the waste from fossil oil processing is dealt with utmost care to control contamination; however, complete control is not achievable, and the contamination is large due natural seeps followed by urban runoff, accidental oil spills, and extraction of oil (NRC 2003). Bioremediation using vetiver in oil-contaminated site is a promising technique to degrade the oil components in the soil. Experiments conducted in non-remediated and vetiver-remediated crude oil spilled Nigerian soil for jute mallow cultivation showed that vetiver was effective in hydrocarbon and heavy metal accumulation, decreasing the soil acidic pH and improving soil microbial community favoring jute mallow to attain maximum growth compared to non-remediated soil (Charles et al. 2013). Similar results were reported by Bangash et al. (2016), Li et al. (2006), and Xia (2004) for the study on effect of diesel, benzo[a]pyrene, and oil shale-contaminated soil on vetiver growth, respectively. Likewise, 90 days vetiver pot culture experiments conducted in real field oil sludge contaminated soil concluded that vetiver system helps to restore soil quality and augmentation of microbial consortium. In addition, vetiver cultivation is more effective for oil sludge contaminated sites remediation (Dhote et al. 2017) and fly ash remediation (Ghosh et al. 2015). On the other hand, greenhouse study results from vetiver cultivation in Venezuelan heavy crude oil in soil show that vetiver could tolerate mild petroleum contamination up to 5% and could be used to improve slightly polluted soil (Brandt et al. 2006). In addition to the above-mentioned industries, vetiver has also been applied in compost (Vázquez et al. 2013; Bakhshoodeh et al. 2017), biomethanation (Wietlisbach et al. 2016), municipal wastewater treatment (Kumar and Prasad 2015; Badejo et al. 2017), and tannery industry (Srisatit et al. 2003).

3 Policy Suggestions and Limitation

The review results and highlights on vetiver bioremediation to reduce contamination in soil and water in the above sections clearly support the advantages that could be gained from vetiver use. These advantages reassure to frame policy recommendations to harness the full benefit of this bioremediation system through proper and regulated implementation along with addressing all the associated limitations.

Policy suggestions

- Most of the results on vetiver bioremediation in mitigating contamination are from laboratory research. Therefore, policies and projects on testing vetiver bioremediation in real-time large application have to be drawn to know the effect of scale in this application.
- Most of the studies are from developing and least developed countries. Therefore, more policies should support such kind of studies in the developed countries in collaboration with developing countries.
- In several parts of the world, vetiver is cultivated as a commercial crop for its root oil. However, root removal from unregulated cultivation has devastating effect on the environment. Therefore, policies on vetiver use in bioremediation should be regulated to avoid roots removal.
- Environment agencies in all countries should recognize the benefits of vetiver remediation and provide tax incentives to encourage this contamination mitigation tool.
- Recommendation to open vetiver research stations and nursery to teach the cultivation mechanism to people and to provide the necessary saplings.
- Provide instructions across industries to implement vetiver bioremediation in the contaminated sites around the industry and to have a target plan for every five years.
- Conduct public vetiver cultivation drive to introduce vetiver in farm areas through public–private (fertilizer and pesticide companies) partnership.
- Policies to encourage research activities to improve economic returns through combine vetiver bioremediation and energy from vetiver grass shoots such as biofuels (Pandey and Singh 2015; UNEP 2015; Kumar and Prasad 2015; Schwitzguébel et al. 2006).
- Vetiver cultivation not only favors bioremediation, it also provides carbon sequestering that mitigates greenhouse gas. Therefore, providing incentive for greenhouse gas reduction could be an additional benefit to encourage vetiver cultivation for bioremediation.
- Conduct more awareness programs through TV, radio, concerts, street arts, sports event, public cleaning events, and social media to dissipate the benefits of vetiver as a bioremediation tool in urban and rural areas.

Limitations

- The benefit of vetiver in bioremediation is proved mostly in research and pilot scale studies. However, the output results from large-scale studies are uncertain.
- The detoxification of contaminants is often slow and there is no complete decomposition. In such case, the toxic compounds accumulated in the plant do not favor the environment while using the shoots or roots for other application and it could enter the food chain if the cattle graze the shoots (Aken 2008).
- Vetiver is effective for soil remediation with medium to low toxic chemicals; therefore, more improvement is needed to tackle contamination involving high concentration and more variety of chemicals such as heavy and extra-heavy oil contamination (Infante et al. 2010).
- At present, vetiver is cultivated in several parts of the world for its root to extract oil. Root removal could trigger soil erosion and create adverse effect to the environment. Therefore, controlling misuse of vetiver from remediation soil could be complex issue.

4 Conclusion

Vetiver is a highly resilient and versatile plant that is used in various applications including soil erosion control, water conservation, bioremediation, fragrance oil production, household and energy applications. Among the applications, vetiver application in bioremediation is vastly studied. The review of all these studies confirms that vetiver is a promising agent in bioremediation for removal and degradation of several toxic contaminants in soil and water. However, several policy measures that are given as a suggestion here are required for successful implement of this bioremediation system in large scale that needs to overcome several limitations through rigorous research, collaboration from developed and developing countries and large-scale test trials. In addition, growing vetiver for bioremediation and harvesting the shoots for energy purpose could generate economic returns and employment. Therefore, government should draft the suitable policies measures to encourage vetiver cultivation for bioremediation and other applications.

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