VETIVER PHYTOREMEDIATION TECHNOLOGY FOR REHABILITATING SHIRAZ MUNICIPAL LANDFILL, IRAN

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Abstract

The overall concept of landfill treatment is to keep the entombed waste isolated and to minimize its offsite pollution spreading to adjacent the adjacent environment. In Shiraz 69.1% of its domestic wastes contain putrescible organic matter which produces large quantities of leachate and gas. Construction of conventional leachate treatment plants is limited due to their high cost and leachate characteristics. Therefore, to control the production of landfill leachate from 2009 till now, several greenhouse and field experiments on vetiver grass were carried out to determine the possibility of using this technology for vegetative capping the landfill area and its potential to decontaminate the soil around the landfill. Greenhouse experiment results showed vetiver can tolerate irrigation with 45% of leachate. Field experiments showed that vetiver can well adapt to Shiraz landfill conditions and survive. Cultivation of vetiver in large scale offers a pleasant view as an additional advantage, as well as to become a very effective soil and water conservation measure. Therefore, it can be concluded that vetiver planting is the best option for Shiraz landfill capping after closing

Key words: Phytoremediation, landfill, Iran, rehabilitation, soil and water conservation

1. Introduction

1.1 Landfill leachate phytoremediation

Wastewater output is growing faster than the world's population, and management of wastewater is a matter of considerable human concern (Kalka, 2012). Comparative studies of the various possible means of eliminating solid urban waste have shown that the cheapest way, in terms of implementation and capital costs, is landfilling (Renou et al., 2008).

On the other hand, one of the major pollution problems caused by the municipal solid waste landfill is landfill its leachate (Ngo et al., 2008). The landfill leachate problem is a long-term issue, since it is produced a long time after closing the site (Li et al., 2009). Sanitary landfill leachate is a highly and complex polluted wastewater. Its quality is the result of biological, chemical and physical processes in landfills combined with the specific waste composition and the landfill water regime (Stegmann, 2005).

Prevention of leachate migration and contamination of ground, surface water and soil can be accomplished through implementing effective operational practices and engineering controls at the landfill facility (ISWA, 2010).

An emerging technology that uses various plants to degrade, extract, contain, or immobilize contaminants from soil and water is phytoremediation (EPA, 2000). Plant species are selected for use based on factors such as ability to extract or degrade the contaminants of concern, adaptation to local climates, high biomass, depth of root structure, compatibility with soils, growth rate, ease of planting and maintenance, and ability to take up large quantities of water through the roots (EPA, 2000). Few existing plants have the unique attributes of multiple uses, such as being environmentally friendly, effective and simple to use. One of these plants is vetiver grass (Truong et al., 2007).

1.2 Vetiver grass

Vetiver grass has a strong and massive root system, which can grow in the first year to 2-3 m vertically (Truong et al., 2007). It permits excellent infiltration of soil moisture and penetrates through compacted soil layers (hard pans) and reduces/prevents deep drainage (Truong et al., 2006). The erect and stiff shoots of vetiver can grow to 3 m and form a living porous barrier that retards water flow (Truong et al., 2004).

Vetiver is a non-invasive plant; it produces neither stolons nor rhizomes and has to be established vegetatively by root (crown) subdivisions or slips. Vetiver can be killed easily either by spraying with glyphosate or uprooting and drying out (Truong et al., 2000). Vetiver has great tolerance to extreme climatic variations such as prolonged drought, flood, submergence and temperature levels ranging from -20˚C to 55˚C (Truong et al., 2004).

Vetiver is highly tolerant to heavy metals including Zn, Cu, Pb, Cr and Ni (Chayotha et al., 2002); Mn, Zn, Cu, Cd and Pb (Roongtanakiat and Chairoj, 2002); N, K, Ca, Mg, Pb and Cd (Sripen et al., 2000); Pb and Zn (Bannasak, 2001) and agrochemicals include endosulfan (Mahisarakul et al., 2003).

Treating effluent with vetiver is actually a ‘recycling process’, not a treatment process as in the process of ‘treatment’; the vetiver plant absorbs essential plant nutrients such as N, P and cations, and stores them for other uses (Truong et al., 2003).

2. Application of Vetiver Phytoremediation Technology for Disposal and Treatment of Landfill Leachate

Vetiver phytoremediation technology (VPT) is a recently developed method for treating wastewater.

In Australia, at Wellington Point, vetiver was used (10 to 12 plants/m^2) for seepage control. Leachate seepage was reduced substantially during the wet season and eliminated during the dry season. At spots where gas emissions occurred mature vetiver plants turned chlorotic but both mature and young plants did not die (Truong, 2002). At Tweed Shire Council 6 ha of vetiver were planted on the top of the landfill mound. Results to date have been excellent; as soon as an area was planted it was irrigated with leachate by overhead spray irrigation and almost 100% establishment was achieved (Percy and Truong, 2003).

In China, leachate from the Likeng landfill site in Guangzhou was used to irrigate four plants. Among the four species tested vetiver grass was the least affected by leachates. The tolerance of the four species to landfill leachate was ranked as vetiver>alligator weed>Bahia grass>water hyacinth (Truong, 2002).

In Thailand, a study was conducted using vetiver for phytoremediation of contaminated soil collected from a landfill site. Surat Thani ecotype vetiver plants planted in pots were treated with landfill leachate at the strength of 0, 50, 70 and 100%. The results indicated that the growth of vetiver was reduced as the landfill leachate strength increased. The vetiver grass treated with 100% leachate could not survive at 80-85 days after planting (Nualchavee et al., 2003).

2.1 Shiraz municipal landfill

Shiraz is one of the biggest cities in Iran. Shiraz is the capital of Fars Province in southwest Iran. The landfill site of Shiraz city is located 20 km southeast of the city, with a total area of 40 ha. It has a semi-arid climate with mild winters, average annual precipitation of 389 mm mainly in autumn and winter. Average temperatures in the coldest and warmest months range from 6.7 to 28.2°C. Potential evapotranspiration with Penman-Mantis method is 5 mm per day and 1,825 mm per year. Average annual wind speed is 200 km/h at 2 m height (Master plan of Shiraz solid waste management, 2009).

Green vegetation in Shiraz landfill has been established since 2000, and 20 ha of landfill area are devoted for fruit and fruitless tree cultivation (Fig. 1). In addition a 780 ha orchard was established with 370.800 olive trees. Forestry trees, including mostly eucalyptus, pine and cypress were cultivated on 100 ha hillside around the landfill for soil and water conservation, stabilizing the slopes, to present a better view, and control runoff in the landfill area. Due to water scarcity some of the olive trees are under dry irrigation method and other trees had different irrigation rotation with fresh water.

Figure 1. Green vegetation in Shiraz landfill

2.2 Environmental hazards associated with the Shiraz landfill

Despite the enormous and costly remedial measures mentioned above, the landfill still produced several environmental hazards to Shiraz City.

During the last 5 years, the mean average of Shiraz domestic solid waste was 950 tons per day, composed of 69.1% of normal domestic wastes which are putrescible organic matter (Physical analysis of Shiraz domestic waste at source, 2013). Landfill with such a high amount of organic matter produces large quantities of leachate. The discharge of leachate was estimated at 121,824 L/day in 2013. The leachate, with high organic content (BOD_5, COD), high concentration of heavy metals, ammonia, toxic compounds, bacterial contamination and unpleasant odor creates environmental and health problems, unseemly sights and adverse effects on soil and water resources.

Construction of leachate treatment plants equipped with physical, chemical and biological technologies is limited in Shiraz due to the high cost and leachate characteristics such as unsuitable pH range, BOD_5/COD ratio less than 0.5 and ammonia concentration more than 200 mg/L. Therefore in order to control the quantity of landfill leachate, Shiraz Solid Waste Management organization has tried to find simple, low cost and low maintenance methods. Vetiver phytoremediation technology (VPT), a simple and affordable solution, became one of the best options.

2.3 Leachate characteristics of Shiraz municipal landfill

Data in Tables 1 and 2 shows that COD and BOD levels are extremely high throughout the year and both nitrogen and phosphorus are also very high, particularly nitrogen. While these leachate characteristics make them toxic to most plants, they are well within the tolerant levels of vetiver grass.

Table 1. Leachate characteristics of Shiraz municipal landfill in 2005

Date of sampling	22 Aug	22 Sept	22 Oct	22 Nov	22 Dec
COD (total)	54,100	41,000	75,000	89,000	76,000
COD (soluble)	54.96	37,584	74,500	85,000	74,500
BOD_5 (t)	50,000	37,000	42,500	62,300	53,000
BOD_5 (s)	50,000	34,000	42,100	61,400	51,000
TSS	1,500	2,000	500	1,367	1,550
PO4-P	30	24	27	38	21
NH3-N	1,368	1,420	2,805	2,231.3	1,750
ALK as CaCO3	15,000	12,000	25,000	11,000	9,000
Zn	15	8	17	7.56	9
Mn	0	4	0	1.64	5.34
Cu	0	0	0	0.29	0.36
Ni	0	0	0	0.77	1
pH	5.5	5.7	6.5	5.8	5.6

Table 2. Leachate characteristics of Shiraz municipal landfill in 2007

Date of sampling	March	April	May	June	July	August	September	October
COD	5,568	53,333	60,808	55,266.6	48,552	62,150.4	60,882.8	60,883
BOD_5	44,300	48,200	53,600	45,600	41,900	56,900	51,200	43,600
BOD_5/COD	0.796	0.904	0.881	0.825	0.863	0.916	0.841	0.716
TSS	1,420	1,290	1,680	1439	1,962	2,136	2,453	2,634

NH_3-N	-	1,695	1,812	2,056	1,546	1,060	864	973.1
ALK $_{as}$ $CaCO_3$	10,235	14,625	11,983	11,018	14,071	12,000	11,965	14,000
Mg	1.695	1.098	1.149	2.764	1.009	2.038	0.099	1.024
Mn	9.36	11.39	10.56	8.17	9.599	8.273	10.97	20.57
Zn	2.12	1.201	0.479	0.645	1.015	1.245	0.221	2.182
Cu	0.036	0	0.054	0	0.103	0.077	0.060	-
Ni	1.102	1.275	1.012	0.091	1.030	0.966	1.521	2.03
Fe	31.79	89.41	98.101	386.4	149.17	229.8	81.65	741
pH	6.01	5.69	5.88	5.98	6.74	6.17	6.02	6.4

Table 3. Characteristics of leachate collected from lagoons in Shiraz municipal landfill in 2010 (from rain)

Parameters	**Average of summer and autumn**	**Average of spring**
pH	8.6	8.2
COD (mg/L)	64,000	91,308
BOD_5 (mg/L)	15,500	25,286
UBOD (mg/L)	22,143	36,400
UBOD/COD	0.35	0.39
NH_3-N (mg/L)	1,428	-
NH_4-N (mg/L)	12,400	-
Mn (mg/L)	1.089	-
Pb (mg/L)	0.169	-
Na (mg/L)	0	-
K (mg/L)	0	-
Sn (mg/L)	0.367	-
Ca (mg/L)	26.43	-
Mg (mg/L)	3.367	-
Cu (mg/L)	0.418	-
Ni (mg/L)	0.618	-

3. Preliminary Trials

VPT was first conducted in 2009 to treat leachate from Shiraz landfill. In 2010 the Waste Management organization of Shiraz Municipality decided to cultivate 1 ha of vetiver as a pilot study in terraces around leachate ponds and on top of a completed cell. Solid wastes are buried in open cells; once a cell is full it will be closed by covering it with 3-4 m of soil. In the first 4 months vetiver grass was irrigated daily with fresh water. After being established the irrigation interval (with fresh water) was extended (Figs 2 and 3).

Figure 2. Vetiver planted on terraces around leachate ponds, at planting (1) and at 4 months old (4)

Figure 3. Vetiver planting on top of a completed cell, at planting (1) and at 4 months old (4)

Results of these trials show that, under a normal irrigation schedule vetiver was established successfully at both sites, particularly on top of the completed cell, with plants reaching over 1 m tall after 4 months. Unfortunately there was an accident at the landfill and all the vetiver plants were buried under the waste.

In another field trial to test vetiver adaptability to Shiraz landfill environment, vetiver was planted approximately 45 m from an open cell. The plants were green and actively growing with erect and stiff shoots, while most of the Eucalyptus trees were broken by strong winds and the olive trees in the orchard 15 m from the open cell turned yellow gradually and were dying in rows (Fig. 4).

The plants were watered with fresh water at planting; in the dry season vetiver was watered as part of the Green Vegetation, but they relied on rainfall in the wet season.

Figure 4. Olive tree orchard and vetiver rows on Shiraz landfill

Results of this trial show that under the same watering schedule, vetiver established and grew well; its growth was unaffected by strong winds. (average annual wind speed at 200 km/h at a height of 2 m), while olives and Eucalyptus trees were badly affected.

4. R&D of Vetiver Phytoremediation Technology at Shiraz

In 2012 Jalalipour and Ghaemi (2012) conducted a glasshouse study on the potential of using vetiver to remediate contaminated soil at Shiraz City landfill. Four irrigation treatments in triplicate with concentrations of 0%, 20%, 50% and 80% of landfill leachate were used (Fig. 5). Experimental duration was 80 days and the plants were watered every 7 days, first with fresh water for 2 weeks then with leachate until the end of the experimental period.

Figure 5. Vetiver watered with landfill leachate with 0%, 20%, 50% and 80% concentrations

Results of this experiment indicated that vetiver can grow in landfill leachate up to 20% concentration without any problem. Vetiver growth was severely affected at 50% concentration, with only a few shoots surviving after 80 days. All plants died at 80% concentration. The concentrations of heavy metals such as Ni, Zn, and Mn in the plants were lower than the tolerant limits of vetiver for these metals. The uptake of Cu in 80% leachate concentration was 25.14 mg/kg which was at the threshold toxic level for vetiver. These results showed that vetiver can be used to prevent, uptake and purify water and contaminated soil in old landfills and around new landfill site where the leachate strength is not very high.

In 2013 Naderi and Mohsen-zadeh (2013) studied the physiological responses and growth of vetiver shoots under different leachate concentrations of Shiraz municipal leachate (Fig. 6). The statistical design was a randomized complete block and each block was treated with 5 concentrations of landfill leachate: 0%, 15%, 30%, 45% and 60%. Experimental duration was 8 months. The leachate for treatment was collected and transferred to the greenhouse four times during the experimental period. Irrigation was scheduled using FC and Salter method.

Figure 6. Leachate container and vetiver experimental plots

Results from this experiment indicated that as the leachate concentration increased the quantity of dry biomass, the level of chlorophyll, carotenoids and anthocyanins decreased, but the leaf area, soluble sugars and total protein increased. In addition leaf moisture contents at 45% and 60% concentrations were higher than those at 0% concentration. At 15% of leachate the proline concentration increased significantly compared to control, whereas at higher concentrations it decreased. Leaf area progressively decreased in all concentrations with time. But the decreasing was much more rapid at higher concentrations. *The highest concentrations of nickel and lead were found on the leaf tips and the highest concentration of copper and zinc were in the two final internode stems.* Results show that vetiver can tolerate irrigation with a leachate concentration of up to 45%, which is equivalent up to 40,000mg/l of COD and 28,000mg/l of BOD based from data on Tables 1 and 2.

Nazari and Mohsen-zadeh (2013) studied physiological responses and growth of vetiver roots with similar statistical design, experimental duration and 5 leachate concentrations as Naderi and Mohsen-zadeh (2013).

Results indicated that as the leachate concentration increased the level of root dry biomass, carotenoids, anthocyanins, and root length decreased. But the amount of soluble sugars and total protein increased. *Most heavy metal accumulation was recorded in root hairs and the apical region*. The lowest accumulation was at the beginning of the roots. Results show that Vetiver can tolerant irrigation with leachate concentration of up to 45%.

5. Conclusion

The above results show that vetiver can tolerate up to 45% of old leachate concentration (up to 40,000mg/l of COD and 28,000mg/l) and has a very high tolerance to heavy metal toxicity. In addition, field experiment shows vetiver can adapt well to Shiraz landfill conditions and survive better than other plants. The cultivation of vetiver in large scale, in addition to providing a pleasant view, also creates a very effective soil and water conservation measure. Therefore it can be concluded that Vetiver planting is the best option for Shiraz landfill capping after closing**.**

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