Recent Advancements in Research, Development and Applications of Vetiver System Technology in Environmental Protection

Paul Truong* and Nicholas Truong**

TVNI Board Director and Coordinator for Asia and Oceania

Director Veticon Consulting, Brisbane, Australia

***** Wastewater Modeller, Veticon Consulting, Brisbane, Australia***

Email: p.truong@veticon.com.au

Abstract

Although the Vetiver System (VS), which is based on the applications of Vetiver Grass *(Chrysopogon zizanioides,* Roberty L.), was first developed for soil and water conservation in farmland, over the last 20 years *The Vetiver Network International* (TVNI) has supported R&D and promoting VS as an environmental protection tool. Application of VS for environmental protection is a new and innovative phytoremedial technology. VS is being used in more than 100 tropical and subtropical countries in Australia, Asia, Africa and Latin America for treating and disposing polluted wastewater, mining wastes and contaminated lands due to its effectiveness and low cost natural methods of environmental protection.

This paper will review the current status of these applications and recent advancements of its R&D and Applications in wastewater management and degraded and contaminated land rehabilitation in Asia, Africa, north America and Latin America

Keywords: Vetiver grass, leachate, effluent, mine tailings, contaminated land, heavy metals,

1.0 INTRODUCTION

The Vetiver System (VS), which is based on the application of vetiver grass (*Chrysopogon zizanioides,* Roberty L), was first developed by the World Bank for soil and water conservation in India in the 1980s. Further research and development by *The Vetiver Network International* (TVNI) in the last 20 years have established VS as an innovative phytoremedial technology for treating and disposing polluted wastewater, mining wastes and contaminated lands due to its effectiveness and low cost natural methods of environmental protection (Truong et al, 2008).

VS is being used in more than 100 tropical and subtropical countries in Australia, Asia, Africa and Latin America for treating and disposing polluted wastewater from domestic and industrial discharges due to its effectiveness and low cost natural methods.

Extensive R&D in Australia, China, Thailand and recently Chile and Venezuela have established that vetiver Grass is non invasive it has a high water and nutrient uptake and thrives under most adverse soil and climatic conditions. Vetiver grass is tolerant to elevated and sometimes toxic levels of salinity, acidity, alkalinity, sodicity as well as a whole range of heavy metals and agrochemicals. Latest research also shows its exceptional ability to absorb and to tolerate extreme levels of nutrients, capable of consuming large quantities of water under wet conditions and to produce a massive growth (Truong and Baker, 1998)

It is a green and environmentally friendly wastewater treatment technology as well as a natural recycling method. Its end-product has several uses including animal fodder, handicraft, biofuel and green manure for organic farming.

For these reasons, vetiver grass is known as a wonder grass, a miracle grass and a magic grass in various parts of the world. The two main applications of VS for Environmental Protection are:

- Prevention, Disposal and Treatment of Wastewater.
- Rehabilitation and Treatment of Contaminated Land

2.0 PREVENTION, DISPOSAL AND TREATMENT OF WASTEWATER.

2.1 Effluent Management

2.1.1 Modelling

The use of computer model is now an accepted procedure for any effluent management program. During the preliminary design of a dry land irrigation system, a crucial consideration is the amount of land required to dispose of a specified amount of wastewater. The most efficient method to determine the land area required is to simulate a site specific model for the wastewater disposal.

In Queensland State of Australia the Environmental Protection Authority has adopted MEDLI (Model for Effluent Disposal by Land Irrigation) as a general model for industrial and municipal wastewater management (Truong et al. 2003; Vieritz et al,2003.). MEDLI models the partitioning of water, nutrients and salt from the waste stream as it passes through pond treatment and irrigated onto land growing crops or pastures, and percolates to groundwater. As with many sophisticated models, MEDLI combines a number of sub-models, each deal with different aspects of wastewater management. The main components for effluent treatment are;

- Effluent quantity and quality
- Plant species
- Soils
- Climate

However MEDLI application is limited to large scale industrial and municipal wastewater management. In addition it is based on a wide range of pasture plant species and is not suitable for simple or smaller scale using vetiver grass. Therefore there was a need for a model that could be applied to sites where MEDLI is not suitable. As a result, Veticon Consulting developed **EDVI** for situations where MEDLI is not applicable. **EDVI** is based on some components of MEDLI and the well known Boughton (1965) water balance and the update "Australia Water Balance Model" of Boughton (2006). Boughton’s water balance models are similar to those used in Europe and North America. In addition **EDVI** was designed exclusively for vetiver grass, using data from extensive R&D results on the effectiveness and capacity of vetiver grass in treating effluent and leachate.

EDVI Modelling Input Parameters and Results

The calculation method requires information about the effluent stream and properties of the disposal site. Some or all of the following information is required by the method:

- ***Effluent / Waste Water Stream***
    - Quantity – Total Volume and Seasonal Variations
    - Quality - Volume of nutrients (N, P, Salt))
- ***Site Soil***
    - Soil profile description and depth
    - Water holding capacity
- ***Site Climate***
    - rainfall, temperature and evapo-transpiration)
- ***Preliminary Crop (Vetiver) Management Plan***

Using the results of the model recommendations the following can be made:

- Optimal land area and maximum area required
- Options for overland run off (if applicable)
- Vetiver and irrigation Management Plan

Where information is limited or unavailable it may be possible to adopt conservative assumptions for some properties. Assumption may also be made at the conceptual design stage before detailed site surveys are conducted.

EDVI is now operational and in the final verification phase

2.1.2 Disposal of domestic effluent:

The first application of the VS for effluent disposal was conducted in Australia in 1996, and subsequent trials demonstrated that planting about 100 vetiver plants in an area less than $50m^2$ have completely dried up the effluent discharge from a toilet block in a park, where other plants such as fast growing tropical grasses and trees, and crops such as sugar cane and banana have failed (Truong and Hart, 2001). Groundwater monitoring showed that after passing through 5 rows of vetiver the levels of total N reduced by 99% (from 93 to 0.7 mg/L), total P by 85% (from 1.3 to 0.2 mg/L), and faecal Coliforms by 95% (from 500 to 23 organisms/100mL). These levels are well below the following thresholds used by the Australian EPA of total N <10 mg/L; total P <1 mg/L and *E. coli* <100 organisms/100mL

2.1.2 Disposal of municipal effluent

Natural and constructed wetlands have been shown effective in reducing the amount of contaminants in runoff from both agricultural and industrial lands. The use of wetlands for the removal of pollutants involves a complex variety of biological processes, such as microbiological transformations and physio-chemical processes, e.g. adsorption, precipitation or sedimentation.

In Australia, at Toogoolawah an ephemeral wetland was constructed to treat sewerage effluent output from a small rural town. The aim of this scheme was to reduce/eliminate the 500ML/day effluent produced by this small town before the effluent is discharged to the waterways. The results so far has been outstanding, vetiver wetland has absorbed all the effluent produced by this small town Table 1. (Ash and Truong, 2003).

The treatment program composes of two stages:

- Hydroponics treatment of effluent in ponds
- Ephemeral wetland

Table 1. Effluent quality levels before and after vetiver treatment

Tests	Fresh Influent	Results 2002/03	Results 2004
PH (6.5 to 8.5)*	7.3 to 8.0	9.0 to 10.0	7.6 to 9.2
Dissolved Oxygen (2.0 minimum)*	0 to 2 mg/l	12.5 to 20 mg/l	8.1 to 9.2 mg/l
5 Day BOD(20 - 40 mg/l max)*	130 to 300 mg/l	29 to 70 mg/l	7 to 11 mg/l
Suspended Solids (30 - 60 mg/l max)*	200 to 500 mg/l	45 to 140 mg/l	11 to 16 mg/l
Total Nitrogen (6.0 mg/l max) *	30 to 80 mg/l	13 to 20 mg/l	4.1 to 5.7 mg/l
Total Phosphorous (3.0 mg/l max) *	10 to 20 mg/l	4.6 to 8.8 mg/l	1.4 to 3.3 mg/l

*Licence requirements.

Vetiver pontoons in the ponds ephemeral wetland with land area of 1.5ha

At a small recreational airfield in Queensland, Vetiver was planted to dispose a small volume sewage effluent, with the following results:

- **Inflow**: Average daily flow: 1 670L; Average total N: 68mg/L; Average total P: 10.6mg/L;Average Faecal Coliform:>8 000

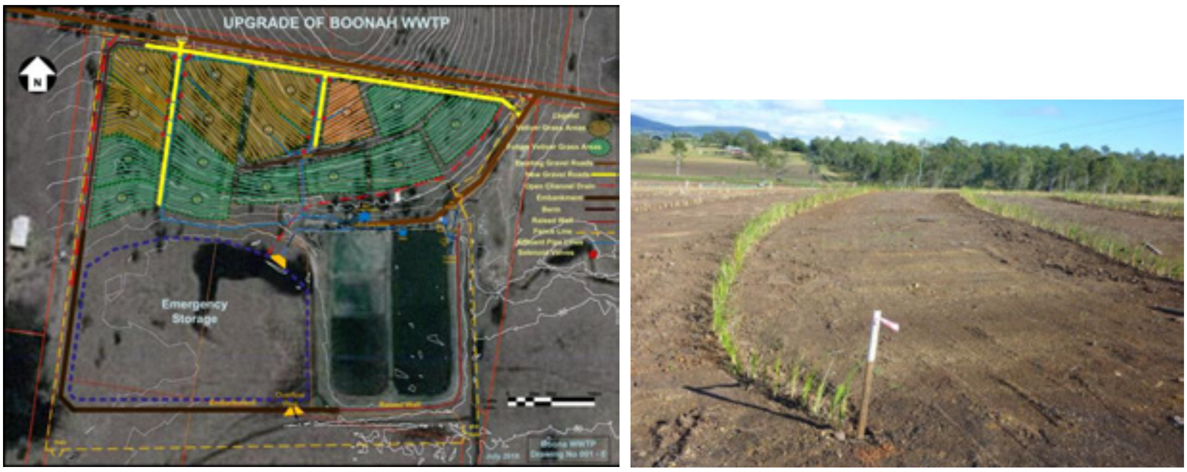
- **Out flow:**Average daily flow: Almost Nil*;Average total N: 0.13mg/L; Average total P: 0.152mg/L;Average Faecal Coliform:<10

Watts Bridge effluent disposal land area of 100m^2

The Boonah town near Brisbane need to upgrade its sewage treatment plant to comply with new environmental protection law. An Options Planning Report investigated various upgrade options to the plant. The report investigated a number of possible upgrade options for the treatment plant using multi-criteria analysis, determining that a dedicated irrigation disposal system for the effluent was the most suitable, taking into consideration timing and cost factors. The recommended solution was to provide a dedicated grass irrigation solution, which would have required an irrigation area of between 50ha and 60ha.

Subsequently preliminary design investigations have been undertaken to develop the dedicated irrigation solution, and in particular a variation to use Monto Vetiver grass wetland for the disposal area. The Vetiver grass option will provide a solution that has a considerably smaller land requirement than other irrigation systems, is cost effective and has low operating costs. The systems investigated are designed to provide a zero discharge to the creek.

Using EDVI, with inputs vary from 400KL/day to 700KL/day, the model predict a land area between 10ha-17ha is required for the complete disposal of the effluent inputs. A comprehensive Management Plan, based on this preliminary result, was developed resulting in significant reduction in land area needed for the complete disposal, from 50-60ha with pasture grass to 4-5ha with Vetiver. This project is now being implemented with a very significant saving in construction and maintenance costs.



Design and construction plan and initial vetiver planting

Panoramic view of 4ha vetiver planting site

In Indonesia, as part of the rebuilding Aceh following the tsunami, in 2005 American Red Cross built 2 000 home units for the victims, using a very simple VST domestic effluent disposal system as at Watts Bridge site in Australia mentioned above. The system was highly successful and another 1500 units was built in 2 009

Domestic effluent disposal system using VST in Aceh, Indonesia

2.1.3 Treating industrial effluent:

In Australia the disposal of industrial wastewater is subjected to the strict environmental guidelines enforced by the Environmental Protection Authority. The most common method of treating industrial wastewater in Queensland is by land irrigation, which is presently based on tropical and subtropical pasture plants. However with limited land area available for irrigation, these plants are not efficient enough to sustainably dispose of all the effluent produced by the industries. Therefore to comply with the new standards, most industries are now under strong pressure to upgrade their treatment processes by adopting VS as a sustainable means of disposing wastewater (Smeal *et al*, 2003).

Incitec Pivot's fertiliser manufacturing facility at Gibson Island in Brisbane faces these environmental issues:

- *Elevated nutrients in stormwater*
- *Elevated nutrients in wastewater discharged from site*
- *Nutrient contaminated soil & groundwater*

The solution is a pollution control program includes vetiver planting on areas with high ground water level, floating pontoons on storage ponds, constructed wetlands and riparian planting to remove nutrients draining into water courses.

Preliminary vetiver pontoons results:

- Excellent growth achieved in the first 3 months, averaging 9.1kg/pontoons ($1.5m^2$) dry biomass.
- Nutrient removal (shoots only) in 3 winter months:
  - **N:** 231g/pontoon;
  - **P:** 30 g/pontoon. S 23 g/pontoon
  - **Na**: 19 g/pontoon
- Heavy metal removal (shoots only) in 3 winter months:
  - **B:** 122 mg/pontoon
  - **Cr**: 39 mg/pontoon. S 23 g/pontoon
  - **Cu:** 81mg/pontoon;
  - **Zn:** 309mg/pontoon

Based on these results, the projected annual removal rate of each pontoon are:

- **N:** 2310g; **P**: 300g; **S:** 230g and **Na:** 190
- **B:** 1 220mg; **Cr:** 390 mg; **Cu:** 810 mg and **Zn**: 3 090 mg

(Miller and Truong, 2010)

In China the disposal of wastewater from intensive animal farms is one of the biggest problems in densely populated areas as China is the largest pig raising country in the world

Nutrients and heavy metals from pig farm are key sources of water pollution. Wastewater from pig farm contains very high N and P and also Cu and Zn, which are used as growth promoters in the feeds. The results showed that vetiver had a very strong purifying ability. Its ratio of uptake and purification of Cu and Zn was >90%; As and N>75%; Pb was between 30% -71% and P was between 15-58%. The purifying effects of vetiver to heavy metals, and N and P from a pig farm were ranked as Zn>Cu>As>N>Pb>Hg>P (Xuhui *et al*., 2003).

In Venezuela, VS is currently being used to dispose wastewater from beer breweries and animal farms, as well as polluted water in lakes and dams (O. Luque pers. com).

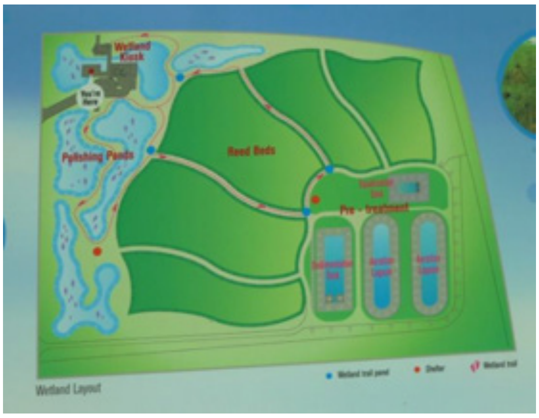
2.2 Landfill leachate

Disposal of landfill leachate is a major concern to all large cities, as the leachate is often highly contaminated with heavy metals, organic and inorganic pollutants. In Australia and China this problem can be solved by irrigating vetiver planted on the top of the landfill mound and retaining dam wall with leachate collected at the bottom of the dumps. Results to date have been excellent, the growth was so vigorous that during the dry period, there was not enough leachate to irrigate the vetiver. A planting of 3.5ha has effectively disposed of 4 ML a month in summer and 2 ML a month in winter (Percy and Truong, 2005).

In Vietnam, results from most recent research show that at Cd levels from 5 – 60ppm, Zn from 200 – 500ppm; Cu from 50 – 100ppm; Pb from 100 – 700ppm Vetiver growth (in terms of biomass, shoot number, root length and plant height) was not affected, indicating vetiver has all the important requirements for remediation of soil and water contaminated with heavy metals. It was also noted that the uptake of heavy metal increased with their concentrations in the soil. The uptake of heavy metals varies greatly with their degrees of availability and soil types. The results indicate that although the uptake and translocation rate of heavy metals vary greatly, in general vetiver growth was not affected. Therefore a large amount of these pollutants is removed from the soil, this is the ideal characteristics of a plant needed for phytoremediation (Vo Van Minh, PhD thesis).

Growth was unaffected by high levels of Cd and plant under leachate irrigation

In Singapore, following a rigorous selection trial over a period of two years, vetiver was selected from a group of plants commonly used in constructed wetlands for planting on a 40 000m^2 constructed wetland complex at Lorong Halus



Lorong Halus wetland complex and vetiver planting on 4ha of constructed wetland


In Morocco at Palmavira a dysfunctional constructed wetland using Typha is being replaced with vetiver.


The dysfunctional wetland using Typha (left) and seedbed ready for vetiver planting (right)

At Oujda City near the eastern border of Morocco a very large new landfill complex is being built. When various options was considered for the disposal of a highly concentrated leachate, a product of combined industrial and domestic wastes, vetiver was recommended and is being implemented now.


Fresh industrial and domestic wastes being compacted (left) and site ready for vetiver planting

In the USA, the first leachate disposal project in North America was implemented in June 2011 at Biloxi, Mississippi on the Gulf of Mexico. Due to environmental regulation, this site uses subsurface irrigation, in contrast with surface irrigation on other sites. This project was implemented by Leggette, Brashears & Graham, Inc for Republic Inc.

This site at Biloxi was machine planted and subsurface irrigated, 3 months after planting

Currently Los Angeles City is interested in using VS for disposing between 200KL/day to 400KL/day of leachate. If this project was implemented, it would be one of the biggest phytoremediation projects in America.

In Mexico, currently Leggette, Brashears & Graham, Inc. is implementing a leachate disposal using vetiver for a very large landfill at Leon and investigating two other sites at Posa Rica and Villahemosa for PASA, the Mexican landfill company

Large landfill at Leon, Mexico

3.0 REHABILITATION AND TREATMENT OF CONTAMINATED LAND

In term of environmental protection, the most significant breakthroughs in the last 15 years are firstly research leading to the establishment of benchmark tolerance levels of vetiver grass to adverse soil conditions and secondly its tolerance to heavy metal toxicities. These have opened up a new field of application for VS: the rehabilitation of mining waste and contaminated lands (Truong, 2004; Shu, 2003).

Recently in a review entitled: ***Vetiver grass, Vetiveria zizanioides: A Choice Plant for Phytoremediation of Heavy Metals and Organic Wastes***, Luu Thai Danh *et al* (2009) explained why vetiver can perform such an outstanding task : *Both glasshouse and field studies showed that Vetiver grass can produce high biomass (>100t/tha-1year-1) and highly tolerate extreme climatic variation such as prolonged drought, flood, submergence and temperatures (-15°C to 55°C), soils high in acidity and alkalinity (pH 3.3 – 9.5), high levels of Al (85% saturation percentage), Mn (578 mg kg-1), soil salinity (ECse 47.5 dS m-1), sodicity (ESP 48%), and a wide range of heavy metals (As, Cd, Cr, Cu, Hg, Ni, Pb, Se and Zn). Vetiver can accumulate heavy metals, particularly lead (shoot 0.4% and root 1%) and zinc (shoot and root 1%). The majority* *of heavy metals are accumulated in roots thus suitable for phytostabilization, and also for phytoextraction with addition of chelating agents. Vetiver can also absorb and promote biodegradation of organic wastes (2,4,6-trinitroluene, phenol, ethidium bromide, benzo[a]pyrene, atrazine). Although Vetiver is not as effective as some other species in heavy metal accumulation, very few plants in the literature have a wide range of tolerance to extremely adverse conditions of climate and growing medium (soil, sand and tailings) combined into one plant as vetiver. All these special characteristics make vetiver a choice plant for phytoremediation of heavy metals and organic wastes.*

3.1 Mining Waste

3.1.1 Australia

tensive applications of VS in rehabilitating mining overburden and tailings of coal, gold and bentonite mines, which have been reported previously:

Coal mine waste before and after vetiver planting

Gold mine tailings vetiver planted to protect cover crop for wind erosion/dust storm control

3.1.2 Chile

Copper mines are the main economic income of. In 2005 a series of pilot studies using the Vetiver System to remediate the wastes produced by the copper mining industry, which represents an important source of contaminants to the environment - water, soil and air. Demonstration trials were set up on a number of Copper mines in Central region to:

- Determine whether vetiver can grow on highly contaminated copper waste rock and tailings
- Find out whether vetiver can grow on these extreme climatic conditions: high altitude, cold and wet winter, very hot and dry summer

- Ascertain whether vetiver is effective in stabilising the tailings ponds wall (built with copper tailings material only) and waste rock dump against wind and water erosion

Determine whether vetiver is effective in preventing wind and water erosion in fresh and old tailings ponds (Fonseca,et al, 2006)

In 2010, the following conclusion was presented in the Latin American Vetiver Conference in Santiago, Chile by Arochas *et al* (2010): *Results to date are very encouraging; vetiver could be established on both highly contaminated copper tailings dump and waste rock, where it grew to 1.5m in 6 months. Reasonable growth was also observed at a 3 500m altitude site and although covered by 50cm of snow for one month, it has survived winter at this site. Five years after planting, it can be concluded that Vetiver can be established and grow successfully without topsoil with the addition of nutrients on tailings dams with very high levels of copper (2369mg/kg). Specimens show regular development of the root system. But the roots are weak while the leaves reach a small development in length and diameter under very high Cu levels. But the greatest damage to this species in the tailings dam was caused by dehydration and damage by herbivores. To achieve optimum plant acclimation should have at least:*
To achieve optimum plant acclimation should have at least:

- *Optimal quality of the vetiver plant.*
- *Adding fertiliser to provide nutrients to the soil.*
- *Irrigation at least twice a week in summer during the first year.*
- *Protection against herbivores*

November 2006 **APRIL 2010**

3.1.3 Thailand

Roongtanakia *et al*.(2008) reported that vetiver could grow well in lead mine tailings. The application of compost or chemical fertilizer resulted in better growth in height and dry weight than no fertilisers, but did not increase the concentration of lead in the vetiver plant. Higher concentration was found in the root than in the shoot.

3.1.4 Venezuela

The bauxite mine, CVG BAUXILUM, located in Los Pijiguaos, Bolivar State, incorporated the VS into its general policy to mitigate the impact of mining activities on the local community with the aim of providing social assistance, and economical development to the people of the region. Vetiver system has been used in this project, for stabilization of various gradient slopes, on the soil-concrete interface to protect infrastructures on the mine site, stabilization of gullies and border drains, reinforcement of lagoon dikes, bio-filter in gullies and around lagoons. For erosion control a total of 26 300m of vetiver barriers have been planted, from 2003 to June 2006. Now CVG BAUXILUM is planning to plant another 7 400m of Vetiver barriers.

Based on the above results, during the past three years, CVG BAUXILUM has successfully adopted the Vetiver System for land rehabilitation and environmental protection to restore this open cut bauxite mining site of Venezuela, to a desirable environmentally friendly level. (Luque et al. 2006; Lisenia et al. 2006)

3.2 Contaminated Lands Rehabilitation and Phytoremediation

Industrial wastes contain very high levels of both organic and inorganic compound have been successfully treated in Australia, China, India, Thailand and Vietnam.

3.2.1 Australia,

Vetiver grass was successfully used to rehabilitate an old waste dump at an explosive factory heavy contaminated with N, as shown below:

- Contaminated soil volume: Approx 6 990m3
- Total contaminated soil volume: 71 120 m3
- Soil Ammonia level, ranging from 20-1 220mg/kg, averaging 620mg/kg
- Soil total N level, ranging from 31-5 380mg/kg, averaging 2 700mg/kg
- Water Ammonia level, ranging from 235-1 150mg/L, with one sample at 12 500mg/L

Based on the above average levels of NH3 and total N, the grand total N content of the top soil (20cm depth) is 0.66kgN/m^2, which is equivalent to 6 600kgN /ha. Vetiver research has shown that Vetiver under optimum moisture supply can be grown on soil applied up to 8 000kgN/ha (Wagner *et al* 2003). Hence it is projected that most of the N in the fill will be removed by vetiver in less than 4 years under favourable weather and at most 6 years under normal weather conditions. In the last few years vigorous growth produced very high biomass with high N content indicating that this projection is on course.

3.2.2 India.

Coal-based power generation is a principal source of electricity in India and many other countries. About 15–30% of the total amount of residue generated during coal combustion is fly ash (FA). FA is generally alkaline in nature and contains many toxic metals like Cr, Pb, Hg, As and Cd along with many essential. FA contaminates the biosphere by mobilization of its fine particles and hazardous metals. Despite the negative environmental impact of FA, coal continues to be a major source of power production in India and therefore FA disposal is a major environmental issue.

To overcome this problem, FA dumping sites have been started as a potential resource for biomass production of tree species. Phytoremediation is a strategy that uses plants to degrade, stabilize, and remove contaminants from soils, water and waste FA. Phytomanagement of FA is based on the plants'root systems, high biomass, woody nature, native nature, and resistance to pH, salinity, and toxic metals.

Recently Indian researchers have started using Vetiver grass in phytoremediation and revegetation of FA dump sites. Chakraborty and Mukherjee (2011) grew vetiver on different combinations of FA amended with garden soil. The plants showed massive, mesh-like growth of roots which could have a phytostabilizing effect. The plant achieved this without any damage to its nuclear DNA as shown by comet assay done on the root nuclei, which implies the long-term survival of the plant on the remediation site. The study revealed a marked decrease in concentration of heavy metals in the amendments and their leachates, over a period of 18 months. The decrease of heavy metal concentration in fly ash-soil amendments/ leachates could be well correlated with the reduction of genotoxic potential of fly ash. When Vetiver is used for phytoremediation of coal FA, its shoots can be safely grazed by animals as very little of heavy metals in fly ash were found to be translocated to the shoots. These features make planting of Vetiver a practical and environmentally compatible method for restoration of fly ash dumpsites.

According to Pathak (2011) the followings can be addressed by VST on open cut mines:

- Stabilization of spoil dumps
- Erosion control on broken areas, spoil dumps
- Control siltation of water courses in the catchment areas
- Toxic water in tailing dams
- Rehabilitation of project affected people. The neighbouring villagers need to have economic activities after mine closure, demands for domestic fuel leading to deforestation and hindrance to forest restoration programme.

if properly planned and implemented with close monitoring, this plant can help in complying with the CSR and EMP requirements in a surface mine.

4.0 OVERALL ADVANTAGES OF VETIVER SYSTEM APPLICATION

Simplicity, low cost and low maintenance are the main advantages of VS over chemical and engineering methods for contaminated water and land treatments.

4.1 Simplicity

Application of the Vetiver System is rather simple compared with other conventional methods. In addition appropriate initial design, it only requires standard land preparation for planting and weed control in the establishment phase.

4.2 Low cost

Application of the Vetiver System in wastewater treatment costs a fraction of conventional methods such as chemical or mechanical treatment. Most of the cost lies in the planting material, with small amounts in fertiliser, herbicides and planting labour.

4.3 Minimal maintenance

When properly established, the VS requires practically no maintenance to keep it functioning. Harvesting two or three time a year to export nutrients and to remove top growth for other usuages is all that needed. This is in sharp contrast to other means which need regular costly maintenance and a skilled operator, often an engineer, to operate efficiently.

5.0 REFERENCES

Arochas, A., Volker, K. and Fonceca (2010): Application of of Vetiver grass for mine sites rehabilitation in Chile. Latin American Vetiver Conference, Santiago, Chile, Oct. 2010.

Ash R. and Truong, P. (2003). The use of vetiver grass wetland for sewerage treatment in Australia. Proc. Third International Vetiver Conference, Guangzhou, China, October 2003.

Chakraborty and Mukherjee (2011). Vetiver can grow on fly ash without DNA damage. 5th Internatioinal Vetiver Conference, Lucknow, India 2011

Danh, L. T, Truong, P., Mammucari, R., Tran, T. and Foster, N. (2009). Vetiver grass, *Vetiveria zizanioides*: A Choice Plant for Phytoremediation of Heavy Metals and Organic Wastes. International Journal of Phytoremediation, **11**:8,664-691

Fonseca,R, Diaz, C, Castillo. M., Candia, J and P. Truong, P. (2006). Preliminary results of pilot studies on the use of vetiver grass for mine rehabilitation in Chile. Proc. ICV4, Caracas, Venezuela.

Lisena, M., Tovar, C., Ruiz, L,(2006). Estudio Exploratorio de la Siembra del Vetiver en un Área Degradada por el Lodo Rojo". Proc. ICV4, Caracas, Venezuela.

Luque, R., Lisena, M. and Luque, O. (2006) Vetiver System For Environmental Protection of Open Cut Bauxite Mining At "Los Pijiguaos" –Venezuela.

Miller and Truong (2010). Vetiver System: A Low Cost and Natural Solution for Water Quality Improvement. Australian Water Association North Queensland Regional Conference June 2010, Townsville, Australia.

Pathak (2011). CSR-EMP integration through implementation of Vetiver Technology for Environmental Management in mines. 5th Internatioinal Vetiver Conference, Lucknow, India 2011

Percy, I. and Truong, P. (2005). Landfill Leachate Disposal with Irrigated Vetiver Grass. Proc, Landfill 2005. National Conf on Landfill, Brisbane, Australia, Sept 2005

Roongtanakiat, L., Osotsapar, Y., and Yindiram,C. (2008). Effects of soil amendment on growth and heavy metals content in vetiver grown on iron . Kasetsart J. (Nat. Sci.) 42 : 397 - 406

Shu Wensheng (2003).Exploring the Potential Utilization of Vetiver in Treating Acid Mine Drainage (AMD). Proc. Third International Vetiver Conference, Guangzhou, China, October 2003.

Smeal, C., Hackett, M. and Truong, P. (2003). Vetiver System for Industrial Wastewater Treatment in Queensland, Australia. Proc. Third International Vetiver Conference, Guangzhou, China, October 2003.

Truong, P.N. and Baker, D. (1998). Vetiver grass system for environmental protection. Technical Bulletin N0. 1998/1. Pacific Rim Vetiver Network. Office of the Royal Development Projects Board, Bangkok, Thailand.

Truong, P.N. and Hart, B. (2001). Vetiver system for wastewater treatment. Technical Bulletin No. 2001/2. Pacific Rim Vetiver Network. Office of the Royal Development Projects Board, Bangkok, Thailand.

Truong, P. and Smeal (2003). Research, Development and Implementation of Vetiver System for Wastewater Treatment: GELITA Australia. Technical Bulletin No. 2003/3. Pacific Rim Vetiver Network. Office of the Royal Development Projects Board, Bangkok, Thailand

Truong, P., Truong, S. and Smeal, C (2003). Application of the Vetiver System in Computer Modelling for Industrial Wastewater Disposal**.** Proc.Third International Vetiver Conference, Guangzhou, China, October 2003

Truong, P.N.V. (2004). Vetiver Grass Technology for mine tailings rehabilitation. Ground. and Water Bioengineering for Erosion Control and Slope Stabilisation. Editors: D. Barker, A. Watson, S. Sompatpanit, B. Northcut and A. Maglinao. Published by Science Publishers Inc. NH, USA.

Truong, P., Tran Tan Van and Elise Pinners (2008). Vetiver System Applications: A Technical Reference Manual. The Vetiver Network International, February 2008.

Vieritz, A., Truong, P., Gardner, T. and Smeal, C (2003). Modelling Monto vetiver growth and nutrient uptake for effluent irrigation schemes. Proc.Third International

1. Vetiver Conference, Guangzhou, China, October 2003

Wagner, S., Truong, P, Vieritz, A. and Smeal, C (2003). Response of Vetiver Grass to Extreme Nitrogen and Phosphorus Supply. Proc. Third International Vetiver Conference, Guangzhou, China, October 2003

Xuhui Kong, Weiwen Lin, Biqing Wang and Fuhe Luo (2003). Study on vetiver's purification for wastewater from pig farm. Proc. Third International Vetiver Conference, Guangzhou, China, October 2003.