IMPACT ASSESSMENT OF LANDFILL ON SOIL HEALTH AND WATER QUALITY IN A WASTE DISPOSAL SITE

by

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(2012-21-129)

THESIS

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DECLARATION

I, hereby declare that this thesis entitled **"IMPACT ASSESSMENT OF LANDFILL ON SOIL HEALTH AND WATER QUALITY IN A WASTE DISPOSAL SITE"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associate ship, fellowship or other similar title, of any other University or Society.

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LIST OF ABBREVIATIONS

%	Per cent
° C	Degree Celcius
µg	Microgram
µm	Micrometer
Al	Aluminium
AMF	Arbuscular Mycorrhizal Fungi
As	Arsenic
Av.	Available
BOD	Biological oxygen demand
Ca	Calcium
CD	Critical Difference
Cd	Cadmium
CEC	Cation Exchange Capacity
cfu	Colony forming units
cm	Centimeter
CO	Carbon monoxide
Co	Cobalt
CO_2	Carbon dioxide
COD	Chemical oxygen demand
Cr	Chromium
CRD	Completely Randomized Design
Cu	Copper
dS	deci Siemens
EC	Electrical Conductivity
et al.	And others
Fe	Iron
Fig.	Figure
g	Gram
GPS	Global Positioning System

LIST OF ABBREVIATIONS CONTINUED

H_2S	Hydrogen sulphide
Hg	Mercury
K	Potassium
KAU	Kerala Agricultural University
kg	Kilogram
kg ha^{-1}	Kilogram per hectare
m^3	Cubic meter
Mg	Magnesium
mg kg^{-1}	Milligram per kilogram
Mn	Manganese
MPN	Most Probable Number
MSW	Municipal Solid Waste
N	Nitrogen
ND	Not Detected
Ni	Nickel
No.	Number
NO_2	Nitrous oxide/ Nitrite
NO_3	Nitrate
NS	Non significant
OC	Organic carbon
P	Phosphorus
Pb	Lead
pH	H^+ ion activity
PO_4	Phosphate
SO_4	Sulphate
SWM	Solid Waste Management
TDS	Total dissolved salts
viz.	Namely
Zn	Zinc

Introduction

1. INTRODUCTION

Waste generation is an inevitable part of development and industrial progress of any country and India is no exception. In the absence of scientific and efficient waste management, environment sustainability of any region will be questioned and consequently multitude of problems crops up threatening the environmental tranquility and ultimately shattering the sub-ordinate legislations of the region clamped for balancing the objectives of development with the environmental safety and health concerns.

The demographic details of Thiruvananthapuram district show a geographical area of 141 km^2 with a total population of 3,301,427. But the estimate on the urban population fixes the values at 743,691. In order to contain and mange the waste problems of this urban population, the Corporation of Thiruvananthapuram had identified with 47.8 acres of land in a nearby Panchayath at Vilappilsala and started its waste management operations in 2000. The treatment plant had the designed capacity to handle and convert nearly 200 tonnes of biodegradable garbage per day. The technology used for waste conversion was aerobic windrow composting. Even a very lenient assessment of the per capita waste generation in the capital, if put at 200 to 300 g per day, and when translated to bulk levels, the quantum of waste reaching the plant has already exceeded its handling capacity. The statistics of waste generation can be inconsistent because they come from many sources which cannot be validated and are sometimes based on assumptions but not scientific measurements (Annepu, 2012). Since the nature of the waste which reached this site was highly heterogeneous and inconsistent in nature and un-segregated, it took time for partial segregation into non-degradable and bio- degradable. The common waste materials reaching the site invariably had different physical characteristics depending on their sources; notably in their composition. An average composition of the waste would qualify the presence of food materials, textile waste, wood, leather, plastics, papers, metals, rubbers, inert materials, batteries, paint containers, construction and

demolishing materials and many others which would be rather difficult to classify. However, studies conducted in Indian scenario indicated that 51–58 % of the waste maintained was organic in nature (Annepu, 2012). Several studies confirm that much of the municipal solid waste from developing countries are generated mostly from households (55–80 %), followed by commercial or market areas (10–30 %) and remaining part from streets, industries or others sources (Nabegu, 2010).

Absence of source segregation of waste was one of the major problems at Vilappilsala. The excessive moisture content in the waste was yet another problem which complicated the social issues in the locality through emanation of bad odour during the windrow composting procedure.

With incessant receipts of different bio-degradable waste materials having high moisture content at the site, possibly at quantities more than the handling capacity, accumulated waste promoted anaerobic fermentation and attendant emission of bad odour, which challenged the air quality in and around the dumpsite. The leachate which flowed down from such unattended heaps of waste in the area started polluting the downstream areas in and around the waste dumping site. The teething troubles never subsided as there were neither midway corrective mechanisms nor lasting solutions to contain social issues. Violent protest from locals and panchayath officials forced the intervention of Government in the issue and finally the closure of the plant was ordered after an operational period of 10 years of waste handling.

Till the closure of the processing plant in December 2011, an approximate quantity of 9.67 lakh tonnes of waste has reached the site and 70% of this quantity has been converted to useful manure and the remaining 30% of the waste which cannot be put to any use had been disposed off at two nearby sites in the designated waste treatment plant area without any scientific compliance required for a basic sanitary landfill. Hence for this reason, the disposed waste materials in the area does qualify to be identified as landfill materials or the entire operations at Vilappilsala waste treatment plant never led to a scientific sanitary landfill. Waste materials after

conversion to manures, are stacked over two identified area, levelled and compacted using machinery and one covered with UV stabilized polythene sheet and soil packed over it to provide a natural look with sufficient air vents to allow landfill gases to escape. But before getting the UV stabilized and welded polythene sheet over the next dump, the entire process had to be abandoned due to plant closure and hence this dump turned out to be source of origin of perennial problems including leachate and heavy metal contamination. In the absence of a leachate treatment plant, both the dump sites permitted incessant out flow of leachates which flowed down through half a kilometer through the waste processing plant area and later crossed the designated borders of the waste treatment plant to join the *Meenampally thodu*, which further moved down and joined the Karamana river contaminating the soil and water particularly drinking water sources (well water) in the locality on either side of the canal. The gravity of all kinds of problem associated with dump sites were more towards its origin and as distance increased, the extent of problems were on the decline.

It is in this background that a scientific study had been planned both within and outside the plant area with the consent of Thiruvananthapuram Corporation and local panchayath to get hands on information about the real situations existing in the area. The present scientific study comes after three years of the closure of the plant, with no basic data available on record with respect to the initial physical, chemical or biological status of the soils or underground water for any comparison or for assessing the swing in changes that might have occurred to the environment over a period of time due to waste dump.

The gazette notification issued by Government of India under the Ministry of Environment, Forest and Climate Change on 8th April, 2016, comes as a supersession of the Municipal Solid Waste (Management and Handling) Rules, 2000 and gets re-designated as Solid Waste Management Rules, 2016 (GOI, 2016). Since the present

study was over in 2016, the results of the study are compared against the criteria and standards insisted in this gazette notification.

The main objectives of the study were framed

(i) To assess the impact of dumping Municipal Solid Waste (MSW) on soil and water quality,

(ii) Spatial variability in the level of biological and chemical contamination along the leachate flow zone and

(iii) Identification of a few bioremediators and their possible effectiveness on decontamination.

Review of literature

2. REVIEW OF LITERATURE

In any developing country, urbanization and industrialization are inevitable components which promote waste generation in one form or other. Once the waste generation goes beyond the ambit of 3 R's (reduce, reuse and recycle) of waste management, pollution is initiated and the very ambience of environment is questioned. Compared to rural areas, urban areas are seen to generate more than twice the quantity of waste. As long as segregation of waste has not taken place, the normal composition of Municipal Solid Waste (MSW) includes residential waste (households), commercial waste (from stores, markets, shops, hotels, plastic containers, packaging materials) and institutional waste (schools and hospitals) which ultimately are bound contain both biodegradable and non biodegradable waste.

According to Kumar *et al.* (2008), a typical classification of MSW can accommodate one or more of the following categories of waste.

1. Biodegradable: food waste from hotel and kitchen, plant and animal debris
2. Recyclable: metals, jars, tin cans, aluminum cans, glass, bottles, paper, cardboard, aluminum foil, plastics, fabrics, clothes, tires, batteries, etc.
3. Inert waste: building waste from demolition site, construction waste and other debris
4. Electrical and electronic waste: electrical appliances, CFL lamps, tube lights, damaged units of TV, computers, washing machine, mobile phones etc.
5. Composite wastes: Tetra packs, plastic toys, other plastic waste, waste clothing etc.
6. Hazardous waste: including batteries from different sources, most paints, chemicals, tires, light bulbs, electrical appliances, fluorescent lamps, aerosol spray cans, fertilizers etc.
7. Toxic waste: including pesticides, herbicides and fungicides
8. Biomedical waste: expired pharmaceutical drugs, syringes and other hospital waste

A rough estimate of the municipal solid waste generation calculated per person per day by Karak *et al.* (2012), in an urban area indicate that it has enhanced to almost double the quantity over a period of 10 years. Further, their estimate of total worldwide MSW generation is 1.3 billion tonnes per year of which the contribution of USA touches 254.10 million tonnes of MSW annually, which incidentally is one of the highest in the world.

Among the metros in India, Kolkata, had been identified to generate the maximum quantity of solid waste (Rajput *et al.*, 2009) and according to them, the estimated figure is 12,060 tonnes/day. However, according to Annepu (2012), the highest per capita generation of waste among Indian metros is Chennai with 0.71 kg/person/day.

In Kerala, the highest solid waste generating cities have been identified as Thiruvananthapuram, Kozhikkode, Kollam and Kochi (Ambat and Ajayan, 2003).

The sectoral status study on MSW Management done in Kerala by Varma (2006), has indicated that the total solid waste generation in the state is about 8300 tonnes per day. According to him, 70-80% of the total waste generated is biodegradable in nature. Further he provided the statistics of waste generation in Kerala from corporations, municipalities and panchayaths. According to him, 13% of the total waste generated in Kerala come from 5 city corporations, 23% from 53 municipalities and balance 64% from 999 panchayaths.

According to Wilson (1999), the income levels and living standards of urban population are very much correlated with their quantum of waste generation. As long as the waste generated cannot be contained at the respective sites of generation, they get forcefully moved to streets and public places initiating pollutions of all kinds. This becomes severe, when it goes beyond the assimilative capacity of our environment and management capacity of the existing waste management systems.

According to Rao and Shantaram (2003), about 60% of the wastes generated in India are disposed off in open which necessarily pollute the soil and water resources.

According to Mohan (1989), pollution is the introduction of contaminants into the natural environment that can initiate any undesirable change in physical, chemical or biological characteristics of air, water or land which may or will affect the plant and animal health adversely. Sharma (2015) shortly defined environmental pollution as the release of environmental contaminants, generally resulting from human activity.

The main sources of environmental pollution are from industrial waste and solid waste dumping. Singh *et al.* (2007) identified different sources of industrial and chemical pollutants in the environment, and the extent and kind of pollutants in an area depends on the presence or absence of these industries. According to them, major industrial pollution could arise from;

1. Metal plating industries
2. Photographic waste
3. Motor industries
4. Paper and paperboards wastes
5. Industries dealing with animal waste
6. Wood / plywood wastes
7. Asbestos wastes
8. Paint and polishing ink waste
9. Fuel, lubricant and oil wastes
10. Glass and ceramic wastes

Further according to them, chemical wastes in environment are always associated with the generation of the following materials;

1. Acid waste
2. Soap and detergent waste
3. Pesticide waste
4. Hospital and lab waste
5. Plastic and resin waste
6. Solid wastes from animals and human

Once the pollution problems are initiated soil, water and air quality or their combination gets affected. Lasat (2002) identified the presence of 38 metals in an industrially polluted area and according to him, only 12 metals (Cd, Cr, Co, Cu, Fe, Hg, Mn, Mo, Ni, Pb, Sn and Zn) are found to cause ecological problems.

Bharti (2012) indicated that out of these 12 metals, seven metal ions are essential for plants (Cu, Co, Fe, Mn, Mo, Zn and Ni) and two for animals (Cr and Sn) for optimum biological activities in trace quantities. But in the environment, if they are found in excess, they create pollution. At this point it is to be recognized that three metal ions (Cd, Pb and Hg) which are really found to create pollution in the environment are neither required by plants or animals at any point of their growth stage. Thus these metals offer tremendous threat not only to environment but also to human kind.

2.1. SOCIAL PROBLEMS

Pollution of the local environment gets initiated the moment the waste gets dumped at any undesirable site which gradually contaminates the soil, ground water or surface water. With passage of time, emission of foul smell and methane gas do occur on account of anaerobic decomposition from decaying organic wastes. Parallel attempts to carry out open burning in such sites results in the emission of smoke and other carbonaceous gases causing health problems to human and animals. Food waste that reaches such sites attracts rodents, birds and stray dogs (Wilson, 1999).

2.2. HEALTH HAZARDS

Many inadequacies in Solid Waste Management (SWM) have led to the gradual buildup of wastes in different areas causing potential threat to public health and environment. According to Hamer (2003), there had been tremendous enhancement of disease vectors like rats, flies and mosquitoes near dumping sites and associated escalation of many communicable diseases like dengue fever and dog bites. Further, according to him, there was considerable impairment in the

water quality both at surface and subsurface levels around such sites. Such situations in general presented filthy and unaesthetic looks with emanation of bad odour and are very common plights around any waste dumping areas.

Upadhyay *et al.* (2005) reported high percentage of disease incidence like breathing problem, lung infections, musculoskeletal problems, respiratory and gastro-intestinal ailments, altered immunity etc. among waste pickers and waste workers when compared with normal working population.

Annepu (2012) reported that improper SWM introduced heavy metals in soil and once some crops are grown in such contaminated soil, through food chain there is every chance for these metals to enter human body. Such prolonged heavy metal entries into human body are known to cause serious damage to liver and kidney functions besides many other known health problems in children.

According to Jha *et al.* (2013), cumulative accumulation of arsenic poison can cause damage to brain, kidney and heart besides skin problems once there are chances for the introduction of arsenic in soil through some waste dumping processes. Further they also reported that introduction of Cr or Hg can cause similar damages and once selenium gets an entry into human body, hair loss and nail deformities do occur.

Enhancement of particulate matter in breathing air due to open burning can cause many chronic obstructive pulmonary diseases and respiratory infection besides many allergic and cancer problems (Nagar *et al.*, 2014).

Studies conducted on human health risk in 10 polluting cities of Maharashtra by Maji *et al.* (2016) revealed that the rate of mortality was more associated with cardiovascular and respiratory problems. Incidentally these pollution sites were around ill managed SW dumping areas.

In a similar health study conducted in Thiruvananthapuram Corporation by Mathew and Rani (2010) among the workers handling solid waste, reported that the workers faced many occupational health hazards like injuries and accidents during job, skin disorders, respiratory disorders, musculoskeletal disorders and eye disorders.

2.3. CHARACTERIZATION OF SOLID WASTE

Asnani (2004) segregated MSW generated in Kerala for its composition and reported that the waste accounted for 77 % biodegradables, 7 % plastics and glass materials, 8 % domestic and hazardous waste, 4 % paper and cardboards and 4 % others.

Upadhyay *et al.* (2005) indicated that the average composition of Indian MSW accounted for 59 % organic materials, 10 % plastics, 8 % paper and cardboards, 3 % glass and ceramics, 1 % metals and 19 % textiles.

2.4. ANAEROBIC DECOMPOSITION

Anaerobic decomposition in a landfill takes place in three stages. Firstly the fermentative bacteria hydrolyze the complex organic matter into soluble molecules. Then these molecules are converted to simple organic acids, carbon dioxide and hydrogen by acid forming bacteria. Finally this is achieved either by breaking down the acids to methane and carbon dioxide or by reducing carbon dioxide with hydrogen, where involvement of methanogenic bacteria is confirmed (Themelis and Ulloa, 2007).

Occurrence of rain or presence of moisture within the dumped waste particularly with biodegradable fractions create a congenial atmosphere for production of methane and other gases with bad odour questioning the ambience of air in and around the waste dumping sites. Kumar *et al.* (2004) identified SW dumping sites as the third largest emitter of anthropogenic methane in the world and further according to them 3% of the green house gas emission in the world is accounted from these sites.

According to Chiemchaisri *et al.* (2012), 40–45%, v/v evolution of CO_2 has been reported from MSW dumping sites under aerobic conditions. According to them, one tonne of the deposited MSW in landfill areas can result in the generation of 160–250 m^3 of gaseous emissions where 50–60% v/v of methane production occurs.

Niloufer *et al.* (2014) estimated global annual emissions of gases from solid waste disposal sites and reported that the contribution of methane account in the range of 20 - 40 million tonnes which is almost equal to 1-4 % of the total anthropogenic greenhouse gas emissions.

According to Aziz *et al.* (2010), anaerobic odours which emanate from dump sites include a wide range of compounds of which the most notorious one is the range of reduced sulfur compounds like hydrogen sulfide, dimethyl sulfide, dimethyl disulfide, and methanethiol. Volatile fatty acids, aromatic compounds and amines also contribute to bad odours

2.5. SOLID WASTE MANAGEMENT

In India, in the absence of proper management capacity, existing waste management systems cannot accommodate the entire solid waste generated and hence they are forced to get disposed in open condition resulting in soil and water pollution (Rao and Shantaram, 2003).

Viswanathan *et al.* (2005) studied the disposal of solid waste generated in India and reported that 15% of the waste generated in India goes for land filling, 11% for composting, 3.5% for incineration and obviously, the remaining 70.5% is open dumped.

Firdaus and Ahmad (2010) suggested the best management practices to be followed for effectively controlling the waste management problems. According to them, if 3R's (Reduce, Reuse and Recycle) are practiced properly, there could be a substantial reduction in the quantum of handled waste and associated reduction in the pollution problems.

Yedla and Parikh (2001) reported the innovative mechanisms of waste disposal being practiced in India. According to them, depending upon the convenience and facilities available at different locations, the waste is disposed off effectively either through composting (aerobic composting or vermi-composting) or it is being converted into useful energy necessarily after proper

segregation. Other methods of disposing solid waste include biomethanation, incineration, pelletisation, pyrolysis etc. and these interventions brought in sizable reduction in otherwise pollutable waste.

Farrel and Jones (2009) identified composting techniques as the most simple and cost effective technology for managing the biodegradable organic fractions of MSW. According to Iacovidou *et al.* (2012), the composting of MSW can effectively be under taken through two prominent methods without any environmental problems. These methods have been listed as windrow composting and vermicomposting.

Pavoni *et al.* (1975) described the process of biomethanation in waste management. According to them, biomethanation is one process which converts organic sources to methane and manure through microbial action in the absence of air through a process called anaerobic digestion where the evolved methane gas is effectively utilized for cooking and burning purposes. Here the organic compounds are broken down by anaerobic microorganisms where they utilize the N, P and other nutrients present in the manure for developing microbial protoplasm at their cellular level.

Navarro *et al.* (2014) described the incineration process, where wastes are burned at very high temperature of 850°C in incinerators. The carbon sources of wastes get converted to carbon dioxide, water and non-combustible materials with solid residues.

Another technology for effective handling of solid waste was pyrolysis and according to Gupta *et al.* (2015), pyrolysis is a thermo chemical process where waste is heated to very high temperature in the absence of air. In this gasification process, toxic materials get encapsulated in vitreous mass, which is relatively much safer to handle than that in incinerators (Kwak *et al.*, 2006).

Varma and Kalamdhad (2013) suggested enrichment of biodegradable part of the MSW by mixing the available waste with cattle manure in the ratio 1.5:1. Such an enriched material provided a nutritional value of 2.16% N and 0.32 % P. Another handy advantage of this compost is that it was ready within 20 days of

enrichment where the entire process was under taken using a rotary drum composter. The total organic carbon (TOC) content of the end product was around 17.04 % with a safe Electrical Conductivity (EC) of 2.78 dS/m which went well for normal crops.

2.6. LANDFILLING

It is well known that in any solid waste management plant that handles the waste effectively, will leave a minimum net residue of 10% unutilized trash which do not find any effective end use and this must be carefully disposed into some secure areas, leading to employment of landfill technology. In every such attempt, it is compulsory that should comply the rules and regulations insisted by Government in the Municipal Solid Wastes (Management and Handling) Rules 2000.

Since these isolated trash while dumping in designated areas, has a potential to contaminate the ground water due to its varying and unknown chemical composition, they need to get secured in specifically selected valley areas surrounded by either large walls or fences hiding the mounds of debris. Obviously, the entire sides both bottom and sides have to be lined with welded tough UV stabilized high density polyethylene (HDPE) plastic films to prevent any possible leakage of leachate from within to the outside or nearby ground water sources.

So a modern secure landfill is a carefully engineered facility used for disposing of solid wastes on selected land without creating any hazards or nuisances to public health, or other problems associated with waste disposal particularly in the case of ground water contamination.

According to Pandey (2004), organic waste available in the environment within a landfill can undergo both aerobic and anaerobic decomposition depending upon the oxygen or moisture availability. Normally the availability of oxygen levels within a landfill should be kept as low as possible to prevent the thrash from breaking down rapidly and maintain the filled in material intact for a very long period of time. These landfill sites also need to have pipe vents for the

landfill gases to escape through at many points to prevent the buildup of incredibly flammable methane gas. Once the landfill areas are filled to its full capacity the dumping site is sealed with plastic linings and covered with several feet of soil except the landfill gas vent areas.

Sarptas *et al.* (2005) reported the production of landfill gases mostly consists of methane and CO_2 with complimentary presence of trace gases like carbon monoxide, hydrogen sulfide, nitrogen and oxygen.

Tadros (2009) insisted that all sites cannot be suitable and cannot be selected for land filling and many factors like local topography, soil erosion risk, the suitability of soils for earthworks, collection of leachate facility from within the landfill, adjacent land use, climate, existing flora and fauna around the site, have to be taken into consideration before deciding the site.

Kumar *et al.* (2008) indicated that site sensitivity indices are to be prepared for identifying suitable sites for land filling. According to them, 34 selected attributes are to be considered based on the available population within 500 meters, distance to nearest drinking-water source, nature of the incoming waste and toxicity, ground water details, soil permeability etc. The final selection of site will be decided on the merit of this score and the ranking process for site selection.

Jeevan and Shantram (1995) reported incidence of deterioration of water quality in neighbourhood areas of landfill sites due to entry of leachates into these water bodies from the landfill sites. They also indicated the imminent possibility of explosion of methane gases that accumulate within the landfill sites unless and until safe provisions for its escape are provided.

2.7. LEACHATE

One of the biggest problems associated with the dumping of solid waste either in open or in landfill is the leachate formation and its management. Once it gets wet, either through precipitation or with the available moisture in the materials, the tendency to absorb and then release the excess moisture in the form

of ooze happens. So, leachate is nothing but contaminated liquid effluent formed by contacting water with the waste materials. Usually the leachates which originate at the upper region of any dump or landfill gradually seeps into the bottom and accumulate in the basal part or sides as the case may be depending on the site features. At one point of time, they ooze out through points of weakness in the construction materials. So in a scientifically made landfill there should be specific provision for pipe systems at the base for collecting and treating the leachate in a pre-designated leachate plant at a lower elevation to avail the advantage of gravity inflow.

According to Asadi *et al.* (2011), the composition of the leachate is normally decided by the extent and nature of soluble ions available in the filled materials along with the product of decomposition of organic matter.

Rout and Sharma (2010) indicated that the contaminant ions present in the leachate offer potential pollution threat not only in the immediate soil system in its vicinity, but also to the surface and ground water systems. Ogundiran and Afolabi (2008) endorsed a similar view and concern in this regard.

Kale *et al.* (2010) examined the leachate originating from Pune municipal waste dumping site and reported exceedingly high value for almost all physico-chemical parameters like pH, EC, TDS, BOD, COD, Ca, Mg and Al. They also recorded the presence of many heavy metals like As, Zn, Mn, Fe, Cu, Pb, Cd, Ni, Co and Hg in higher proportions.

Mor *et al.* (2005) in a similar study in and around the landfill areas in Delhi also observed exceedingly high concentrations of various contaminants like sulphate, nitrate, ammonia, Ca and Mg besides high pH and TDS in the leachate. They also reported high concentration of various heavy metal (Cd, Cr, Cu, Fe, Ni, Pb and Zn) and unacceptable levels of various physico-chemical properties. Further, their microbiological studies conducted on the leachate confirmed the presence of total coliform and faecal coliform not only in the leachate samples but also in the adjacent ground water samples around the landfill sites.

Ghafoor *et al.* (2005) reported that exclusive application of Pb and Cr in land fill soil could not enhance their levels in leachate. But when they are applied in combination there was a synergistic effect which led to enhanced detection of these ions in leachate. Further, they also observed that availability of organic sources in dump sites retarded the presence of Cr in the leachate.

Ramaiah *et al.* (2014) examined certain chemical parameters of leachate originating from landfill at Mavallipura, Bangalore and observed the enhanced presence of various ions like Ca^{2+}, Mg^{2+} and NO_3^-, and accounted this to be a valid reason for pushing TDS levels on the higher side. Their study foresaw an impending deterioration in the soil and ground water quality with the passage of time.

2.7.1. Seasonal influence on leachate

Shivakumar and Srikantaswamy (2012) observed that the ionic concentrations of contaminants in an industrial area were much lower in monsoon season than pre-monsoon or post-monsoon seasons and clearly attributed this observation to the dilution effect brought in by rains.

The observations made by D'souza and Somashekar (2013), on the physico-chemical characteristics of leachate from a landfill area indicated that the reduction in contamination levels was always observed only after the monsoon season. According to them, the delay in observed dilution of contaminants in leachate in the post monsoon season might be due to the time required for the precipitation to move on a heavily packed landfill site.

2.7.2. Land pollution

Either an overcrowded or an ill managed landfill can trigger land pollution. Pollutants coming out of the dumping sites mostly through leachates get direct access or contact with soil leading to adsorption on soil particles.

Since land is static, pollution confines strictly to areas of contact with contaminants unless and until some interventions do happen to mitigate the problems. The extent of land contamination and the spread of contamination within the soil are difficult to assess.

Lal *et al.* (2008) reported that repeated application of sewage introduced heavy metals in soil and their continued accumulation has caused problems of phytotoxicity to plants and even it gets transferred to food chain through cultivated crops. According to them, the phyto-availability and mobility of Cd depended more on its concentration, pH and CEC of the soil.

Loughry (1973) observed that soils with sandy loam texture could be recommended for waste disposal sites but soils with greater than 70 % sand are highly unsuitable for waste disposal. According to him, the permeability in such soils are very high thus they readily permit large quantities of leachate to pass through contaminating ground water sources more easily than soils with more clay content. According to his studies, soil with silt concentration >31 % are also unsuitable for waste disposal since they encourage surface flooding and offer potential pollution from surface run off.

Assessment of heavy metal contamination around SWM sites in the various townships of Kerala had been conducted by Padmalal *et al.* (2002). According to them, various heavy metals like iron, manganese, nickel, cadmium, lead, chromium, copper and zinc have been identified in the immediate vicinity of these dumping sites.

Kjeldsen *et al.* (2002) indicated that land pollution around dumping sites have only been initiated through leachate movement originating from them and at all times the physico-chemical characteristics of leachate depended mostly on the waste composition and moisture availability in the waste.

Bilgili *et al.* (2006) reported that leachate originating from dumping sites account for higher concentration of ions like Na, K, Ca, Mg, Fe, Cl, HCO_3, SO_4, and NH_4 resulting in higher levels of EC, TDS, COD, BOD etc. Further they also

indicated that these conditions might be responsible for the observed alteration in the physico-chemical and biological properties of such soils.

Mulla *et al.* (1980) while assessing the consequence of long term use of sewage effluence for irrigation observed that higher accumulation of heavy metals were seen in both soil and plants in such area and naturally this raised serious concerns since heavy metals are likely to enter into the food chain causing health concerns.

Ghafoor *et al.* (2005) reported that the behaviour of heavy metals in soil mainly depend more on their extent of contamination, soil reaction and clay content.

Adhikari *et al.* (1998) indicated that the behaviour and bioavailability of heavy metals in soil depended on the mineralogy, drainage and vegetation of the land.

According to Singh and Singh (1994), presence of higher organic matter status provided better opportunity for Pb to get complexed and thereby it's concentration decreased in the leachate.

Pillai *et al.* (2014) evaluated physico-chemical characteristics of a soil around MSW disposal site in Thrissur. According to them, the leachate originating from the solid waste disposal site, had provided varying concentrations of heavy metals in soils which remain in contact.

2.7.3. Water pollution

Water pollution around an ill managed or well managed landfill site or dumping site can occur only through the leachates emanating from its source. This is initiated mostly by the precipitation that enters a waste dumping site or landfill area, coupled with moisture availability in the dumped material. Excess availability of moisture within the site results in the quick extraction of water soluble compound and particulate matter of the waste. Such leachates offer

potential threat not only to the surface water but also to the ground water in the immediate vicinity.

According to Jain (2007), water pollutant can be a chemical or physical substance which when present at excessive levels, do cause harm to living organism.

Singh *et al.* (2008) observed that physical contaminants in a water source are the suspended solids and chemical hazards originate from the dissolved fraction of various metals or phosphates or nitrates or other ions.

Ikem *et al.* (2002) related the contamination of ground water invariably with unsanitary land filling with solid waste. According to them, such unscientific disposal always posed major environmental concerns and risk. Raman and Narayanan (2008) had also aired similar concerns.

Bakis and Tuncan (2011) reported that the heavy metals and other chemical leachate originating from dumping sites spoil the water quality and impaired the potability of water. Further, they observed that the physico-chemical quality of well water near the solid waste dumping site were poor with either high EC or hardness or TDS. They could also observe the presence of higher levels of dissolved ions like Ca, Mg, Cl, N, K, SO_4, NO_3 and PO_4.

Cavallaro and McBride (1978) reported that among the toxic ions, Cd is considered to be one of the most potential bio-toxic metal and when the presence of Cd was beyond the permissible limit of 0.1 mg/l around sewage disposal sites in Haryana, many strictures were clamped for cultivation of crops.

The studies conducted by Vasanthi *et al.* (2007), on the quality of ground water around a municipal solid waste disposal site in Chennai revealed that there was unusually high values for TDS, EC, COD, total hardness, chlorides, nitrates and sulphates making its quality highly impaired. A similar observation had been recorded by John *et al.* (2014), while evaluating the physico-chemical properties of ground water adjacent to the MSW dump site in Dehradun city.

Rajkumar *et al.* (2010) evaluated the physico-chemical parameters of ground water near MSW in Erode city and reported that the pH values of all the samples studied were in alkaline range and the major ions present in the water sample were in the order of $Na^{+}>Ca^{2+}> Mg^{2+} >K^{+} = HCO_3^{-} >Cl^{-} >SO_4^{2-} >NO_3^{-} >CO_3^{2-}$.

Studies conducted by Lone *et al.* (2012), for microbiological parameters near MSW site in Bhopal indicated that the leachate originating from the dumping site was responsible for introducing microbial contamination in ground water and the extent of contamination decreased in wells as the distance increased from the source of contamination. Vasanthi *et al.* (2007) also reported similar observations in this regard.

In a study of the ground water contaminated by sewage water from Jabalpur city, Srivastava and Pandey (2012) observed very high EC values possibly due to the presence of high amount of inorganic substance in ionic form. Their assessment on the faecal coliform bacteria in the contaminated water decreased from 84 to zero cfu/100ml as distance of the sampling increased from the source. Apart from bacteria, they also reported the presence of viruses, parasites and other disease causing organisms.

2.7.4. Air pollution

Severe environmental and health issues have been raised on account of air pollution around MSW dumping site in Indian cities. Open dumping sites are common due to low budget for waste disposal and non availability of trained man power. In such sites, the major air pollutants will be dust, particulate matter, oxides of S, N and C, dioxins and furans if open burning is also practiced. However, in other dumping sites which receive wet and moist waste materials of varying origin are found to emit anaerobic odours ranging from reduced sulfur compounds (hydrogen sulfide, dimethyl sulfide, dimethyl disulfide, and methanethiol), volatile fatty acids, aromatic compounds and amines (Chiemchaisri *et al.*, 2012).

Whatever be the case, these pollutants in air are likely to create varying kinds of problems to the human beings in the neighbourhood. Inhalation of such contaminated air is considered to be a route for accumulation of pollutants in the human body (Barman *et al.*, 2010).

Bensy *et al.* (2010) reported that dust or particulate matter originating from the dumping site can produce a spectrum of diseases ranging from a simple cold to deadly diseases like cancer.

Air born particles less than 10 μm in diameter that get suspended in air are referred to as respirable suspended particulate matter (RSPM). Particle < 100 μm in diameter that are suspended in air are referred to as suspended particulate matter (SPM). The common sources of RSPM from dumping sites are plastics, synthetic fibre and domestic items, which can release ions (Zothanzama *et al.*, 2013). The pungent smell and thick smoke generated from the stack of burning waste can create irritation to eyes and nausea, among passengers and drivers in the area.

According to Pulikesia *et al.* (2006), higher concentration of particulate matter in air and its inhalation into lungs can result in acute chronic respiratory disorders which at the end cause fatal lung damage in humans.

According to Jyoti *et al.* (2007), suspended particulate matter in air originating from open dumping site are reported to create higher incidence of cardiovascular diseases and such high incidence have been reported among the population residing in the vicinity of dumping site.

According to Hamer (2003), the methane produced from wet and rotting organic matter in unmanaged landfills is 20 times more effective than carbon dioxide in trapping heat from the sun.

Vieitez and Ghosh (1999) computed the possible quantum of release of CO_2 and methane into atmosphere from one metric tonne of solid waste. According to them, each metric tonne of SW has the potential to release 50±110 m^3 of carbon dioxide (CO_2) and 90±140 m^3 of methane into atmosphere.

Open burning of wastes is a common practice all over India in the absence of proper collection and disposal of waste. This happens to be a common reality

since it is an easy option for disposal. The Statistics provided by Annepu (2012), indicate that 2 % of the uncollected total wastes are burned in streets and 10 % of the MSW collected and dumped at all convenient sites and are later burned in open. According to him, estimated emission of carcinogenic agents like dioxins/furans annually in Mumbai city from open burning was to the tune of 10000 grams.

According to Singh *et al.* (2007), the occurrence of landfill fires is quite common due to the buildup of heat inside the waste beds due to decomposition of organic sources.

Niloufer *et al.* (2014) studied the seasonal emissions of air pollutants in two dumpsites in Vijayawada using a portable onsite multi-gas analyzer. According to their study, methane emission was more during summer season than rainy or winter season. However, emission of CO remained higher in summer season than winter or rainy season. The study further confirmed that summer season promoted more H_2S emission than rainy and winter season. On the contrary, NO_2 emissions were high during winter followed by rainy and summer seasons.

2.8. MOBILITY OF METAL CONTAMINANTS IN SOIL

Among the various contaminated metals identified at the MSW dumping site, majority of them fall under the ambit of heavy metals by virtue of its definition where any metal which touches or crosses the limit of 5 g/cc and atomic number >20 is classified as heavy metal (Adriano, 2001).

Tripathi and Misra (2012) studied the metal load at MSW dumping site in Allahabad and arranged the ions in the order of increased presence. Accordingly, the order of increased presence of heavy metals were Pb>Zn>Fe>Ni>Cu>Cr>Cd.

Spark (1999) reported that the mobility and bioavailability of Ni in soil depends on its concentration at the liquid phase and not on the solid phase. At this situation the element is easily adsorbed and translocated by plants and this will subsequently induct this element into the food chain. The availability of such an

ion in soil and its subsequent non availability are decided by various phenomena like desorption, dissolution, precipitation or complexation. According to him, although all these phenomena can occur simultaneously, adsorption mechanism is known to control the metal availability and solubility in soil.

Violante *et al.* (2010) reported that sorption/desorption reactions as well as chemical complexation with inorganic and organic along with redox reactions play an important role in controlling the bioavailability, leaching and toxicity of heavy metals and metalloids. According to them, these reactions influenced by many factors such as nature of sorbent, presence and concentration of organic and inorganic ligands, pH of media, presence of humic and fulvic acid root exudates and microbial metabolites.

The mobility of Cd^{2+} in soil is identified to be relatively more than that of Cu^{2+}, as the later is more strongly adsorbed than the former in soils (Cavallaro and McBride, 1978).

According to Bingham *et al.* (1984), the relative concentration of chloride was observed to be higher in irrigated soils and in waste disposal sites. These chloride ions are known to form stable complexes with Cd which increased the mobility of Cd in such soils.

According to Khan and Frankland (1983), there was only very little movement of Cd and Pb in soil and for this reason they are largely retained in surface soil. However, a contradictory view on the mobility of Cd had been reported by Alloway and Morgan (1986) where in relative availability of Cd to plants was much greater than that of other potentially harmful heavy metals like Pb in soil.

2.9. EFFECT OF HEAVY METALS ON PLANTS

Jayapragasam (2000) reported that many plants growing in metal polluted sites had resulted in metal accumulation within and consequently they exhibited altered metabolism, growth reduction and finally lower biomass production.

Chakravarthy and Srivastava (1992) observed that physiological and biochemical processes operating in plants were mostly affected by metal absorption. Excessive exposure to heavy metals provided oxidative stress to plants which culminated in cell damage or rendered disturbances in cellular ionic homeostasis.

Pahlsson (1989) studied the metal toxicity of Zn, Cu and Cd in vascular plants and reported that these metals at a concentration of 100-200 µg/l provided disturbances in metabolic processes and growth with Cu and Cd while the same concentration of Zn could not exhibit any toxic symptoms or any disturbances in metabolic process.

According to Prasad (1995), higher levels of Cd initiate membrane damage, inactivates enzyme and reduces the stress tolerance of plants besides reducing the cell wall elasticity. The ultimate manifestation of higher levels of Cd might be the inhibition of plant growth through reduced photosynthesis and transpiration.

Baccouch *et al.* (1998) reported that presence of Ni stimulated the guaiacol peroxidase activity in maize plants resulting in the enhanced membrane lipid peroxidation in the shoot portion.

According to Patra and Sharma (2000), presence of Hg could invite injury to cereal seeds and there by triggering abnormal germination and hypertrophy of roots and coleoptiles. Further this metal is known to interfere with the light and dark reactions of photosynthesis.

Liu *et al.* (2003) reported reduced dry matter accumulation and grain yield in rice cultivars grown in Pb contaminated soils. According to them, Pb has interfered with the yield components like spikelets per panicle, 1000 grain weight, panicles per plant and filled grain percentage.

Parida *et al.* (2003) reported that the presence of Ni affected the growth of fenugreek plants and its influence was mostly manifested through highly stunted growth and reduced branching. According to them, the initial toxicity of Ni in fenugreek was manifested through interveinal yellowing followed by general chlorosis of younger leaves.

Sharma and Dubey (2005) remarked that excessive absorption of Pb by plants had generally caused a wide variety of problems in plants. According to them, blackening of roots, chlorosis of leaves and stunted growth were the common externally manifested symptoms. Further, the reasons for reduced photosynthesis in such plants have been substantiated by poor mineral nutrition and distortion in water balance or a change in the hormonal system brought along with impairment of membrane structure and permeability of cells.

Benavides *et al.* (2005) reported that Cd had inhibited the nitrate reductase activity in the shoots of soybean. According to them, it is perhaps due to the reduced absorption of nitrate and its transport from root to shoot portion. They have also indicated a reduction in the ATPase activity of plasma membrane fraction of wheat and sunflower roots when Cd is present in soil.

Pena *et al.* (2006) observed that in Sunflower Cd toxicity had reduced the leaf area, fresh and dry weights, and relatively lower water content in leaf which induced oxidation of many proteins.

Alam *et al.* (2007) while studying the Ni toxicity in Mustard plants reported that such plants manifested reduced growth, poor photosynthetic efficiency and lower chlorophyll content. However, the nitrate reductase and carbonic anhydrase activities were also on the lower side.

The seedlings of Ground nut (*Arachis hypogea*) when raised in Cd enriched environment, there was an apparent decrease in the activity of antioxidative enzymes (Dinakar *et al.*, 2008).

When rice seedlings were raised in Cd rich environment, there was reduced rate of photosynthesis which according to Rascio *et al.* (2008), might be due to impaired uptake of Mn which is involved in photolysis of water in photosynthetic pathway.

Similarly, when rice plants were grown in Ni enriched nutrient media, the condition was resulted in a severe water stress on plants which according to Llamas *et al.* (2008), might be due to absence of K ions in roots and shoots.

Yadav (2010) concluded that when plants are exposed to higher levels of heavy metal concentration, there was a general reduction in the water uptake and

nutrient uptake which resulted in the photosynthetic efficiency of such plants. However, the visible symptoms observed in such plants were chlorosis, growth inhibition, browning of root tips and finally the death of plants.

According to Yusuf *et al.* (2011), when mustard and wheat were grown in a medium supplied with Ni at a concentration of 100 µM, there was apparent decrease in the photosynthetic rate and chlorophyll content besides, a tendency to lower the protein content in plants within ten days of growth.

Hirve and Bafna (2013) evaluated the germination pattern of Mung bean (*Vigna radiata*) under the influence of varying range of cadmium chloride concentrations. They observed that at all concentrations of cadmium chloride, the root and shoot length of plants were decreased. Further with enhancement of metal concentration in the rooting media there was proportionate reduction in the absorption of water and nutrients which reflected in the water balance, inhibition of enzyme activity, reduction in cell metabolism, retardation in photosynthesis and transpiration.

2.10. HEAVY METAL ACCUMULATION IN PLANTS

Heavy metal accumulation in plants is affected by many factors like variations in plant species, duration of exposure, physiological adaptations, the growth stage of plants and ionic concentration of metals regulate the absorption, accumulation and translocation of metals within the plants (Guilizzoni, 1991).

The study concluded by Shahandeh and Hossner (2000), revealed that Indian mustard (*Brassica juncea*) and Sunflower (*Helianthus annuus*) accumulated more Cr than other agricultural plant species from a comparable concentration. Further, they also indicated that the relative concentration of Cr was more in roots than in shoots.

The studies conducted by Vanisri (2004), revealed that tomato plants failed to fruit when the Cd concentration in the medium was beyond 1.5 mg kg^{-1}. According to her, the successful survival of tomato plants in the contaminated

media was possible only when the concentration was limited to 0.5 and 1 mg kg^{-1} Cd in soil.

Wani *et al.* (2012) reported that Indian mustard and sunflower were found to be effective hyper accumulators for heavy metals.

According to Thayaparan *et al.* (2013), *Azolla pinnata* was able to accommodate more Pb in the tissues with its increasing concentration in the growth media. According to them, there was 83% reduction in the concentration of Pb in medium when *Azolla pinnata* was grown in a period of four days. However, with enhancement in absorption of Pb the relative growth of this plant was considerably reduced.

Prasannakumari *et al.* (2014a) after evaluating the efficiency of many macrophytes in their ability to accumulate heavy metals like Cu, Zn, Cd, Cr and Pb reported that macrophytes like *Cyperus tenuispica, Bacopa monnieri, Mariscus javanicus* and *Acanthus ilicifolius* were effective accumulators of the above heavy metals.

In another study conducted by Prasannakumari *et al.* (2014b), on the absorption potential of heavy metals by few selected ferns identified along the Neyyar dam, Trivandrum revealed that all the selected ferns had high potential for absorption of Cu, Zn, Cd and Pb. Hence these ferns can either be used as bioindicators or phytoremediators in heavy metal pollution studies.

2.11. SELECTIVE RETENTION OF HEAVY METALS BY PLANTS

The uptake of chemicals by plant species from soil solution depends a number of plant factors. They include physical processes such as root intrusion, water and ion fluxes and their relationships to the kinetics of metal solubility in soil, biological parameters, kinetics of membrane transport, ion interactions, the metabolic fate of absorbed ions and finally the ability of the plant to accommodate the adsorbed ion at some part of their biomass (Cataldo and Wildung, 1978). When specific metal ion retention is unique at some part of their biomass in a particular species, it can be regarded as a selective retention of heavy metals and

the site where it gets specifically accumulated can be designated as selective retention site.

Pettersson (1976) assessed the uptake of heavy metal like Cr, Co, Cu, Ni, Cd, Pb, Mn and Zn by a variety of crops like rape, cucumber, wheat, oats and tomato from nutrient solution supplemented with these heavy metals. According to him, in cucumber Mn, Ni and Pb accumulated in the shoot portions and in the case of other plants maximum accumulation is in root portion.

A study conducted by Jidesh and Kurumthottical (2000), revealed that the selective retention of cadmium was more in shoot portion of chilli than the root portions. Among the shoot portion the fruit portions had practically no retention of Cd. According to their study, Pb was more seen to be retained in the root portions of chilli than the shoot portions.

According to Boonyapookana *et al.* (2005), Sunflower (*Helianthus annuus*) plants could accumulate Pb in both leaf and stem particularly at the vascular bundle region with greater amount getting accumulated in leaf portion. However, they had located the presence of Pb in the root tissue also. According to their study sunflower plants could register a 23 fold increase Pb content in shoot portion when plants were grown in soils pretreated with 2.5 mM Pb EDTA.

Abe *et al.* (2008) evaluated ninety-three weed species and eight crop species for a period of 2 months in pots containing sandy loam soil for their ability to phytoremediate under 3 mg kg^{-1} Cd concentration. The study revealed that *Cichorium intybus* and *Matricaria chamomilla* accumulated high shoot Cd concentrations while *Oenothera biennis*, *Calystegia sepium* and *Cassia obtusifolia* accumulated high root Cd concentrations.

According to Danh *et al.* (2009), Vetiver (*Vetiveria zizanioides*) plants were identified to be fairly good accumulators of heavy metals and both shoot and root had the capability to selectively retain both Pb and Zn. According to them, when 1% Pb was retained in root, only 0.3 % metal was retained in shoot. However, in the case of zinc both shoot and root maintained 1% Zn.

According to Revathy *et al.* (2011), the bioaccumulation of Cr in sorghum plants was more in shoot portion than the root portions irrespective of the

concentration of metal. According to them, addition of vermicompost in contaminated media decreases the bioaccumulation percentage.

According to Mohanty and Patra (2012), the aerial parts of Paragrass plant accumulated 10 to 100 fold lesser Cr than roots indicating that selective retention site for Cr in paragrass are the roots.

Zakaria *et al.* (2012) concluded that the selective retention capacity of heavy metals particularly for Cr by globe amaranthus (*Gomphrena globosa*) was depended on the oxidative status of metal. When Cr was present as Cr (VI) the accumulation was more restricted to floral part of the plant while with Cr (III) the accumulation was confined to the root portions.

Signes-Pastor *et al.* (2015) reported that globe amaranthus (*Gomphrena globosa*) can accumulate Arsenic (As) when grown in As containing nutrient media. 72% of the absorbed As was selectively retained in root system, 10% in stem, 12% in leaves and less than 1% in flowers. According to them, the accumulation capacity also depended on the concentration of metals in the nutrient solution.

Tanwar *et al.* (2015) reported maximum accumulation of Cd in root portions of celery plants compared to the shoot portions.

2.12. MECHANISMS OF REMOVAL OF HEAVY METALS

2.12.1. Phytoremediation

Baker (1981) reported that plant species differ in their ability to accumulate metals from contaminated soils and such plants which succeed in the fair accumulation of heavy metal in their biomass are called hyper accumulators particularly when they can accumulate 0.1% Pb, Co or Cr and more than 1% Mn, Ni or Zn when grown in their natural habitat.

Rossel *et al.* (2003) described phytoremediation as an emerging technology that uses plants and their associated rhizospheric microorganisms to remove, degrade, detoxify, or contain contaminants located in the soil, sediments, groundwater, surface water and even the atmosphere.

Khan (2005) categorized phytoremediation under five major sub groups like phytoextraction, phytodegradation, rhizofilteration phytostabilization and phytovolatilization. Phytoextraction is the removal and accumulation of metal concentrations in the harvestable plant parts. Phytodegradation is the degradation of contaminants by plants and their associated microbes. Rhizofilteration is the absorption of metals by plant roots from contaminated waters. Phytostabilization is the immobilization and reduction in the mobility and bioavailability of contaminants by plant roots and their associated microbes. Phytovolatilization is the volatilization of contaminants by plants from the soil into the atmosphere. Yang *et al.* (2005) also endorsed a similar categorization of phytoremediators.

Ghosh and Singh (2005) reported that most of the contaminated sites had good establishment of weed species which are hardy and tolerant. These weed plants are good phytoremediators and are able to restrict the level of contamination in such soils besides preventing them from being introduced into the food web.

Ramanjneyulu and Giri (2006) reported that various types of vegetation which are capable of producing more biomass like trees, grasses and aquatic plants are effectively used for *in situ* decontamination of air, soil, surface and subsurface water systems. According to them, such plants possess unique characteristics like faster growth, ability to accumulate and tolerate higher levels of toxic metals without exhibition of toxicity symptoms.

Jadia and Fulekar (2009) upheld phytoremediation as an emerging technology which is cost effective and having aesthetic advantages is being used for cleaning contaminated soil effectively. According to them, the organic contaminants in the soil can be effectively managed by microorganisms while metal contaminants need immobilization or physical removal as metals at higher concentration are not only toxic but also cause oxidative stress in plants through the formation of free radicals.

Baylock and Huang (2000) concluded that many plants accumulate lead in roots and its translocation to shoot is very low. They also reported that the limiting step for Pb phytoextraction is the long distance transportation from root

to shoot. Thus, according to them, a plant exhibiting significant metal accumulation in roots expresses limited capacity of phytoextraction.

Chowdhury and Tandon (2009) reported that certain varieties of Indian mustard (*Brassica juncea*) have the ability to accumulate metals from solution into the shoot portions. They also have indicated that the Indian mustard has the ability to accumulate toxic metals like Pb, Cu and Ni to an appreciable level when compared to their dried shoot biomass.

Experiment conducted by Wu *et al.* (2004) led to conclusions that when EDTA was added to a soil contaminated with Cu and Pb, the mobilities of these metals were enhanced. According to them, when Indian mustard (*Brassica juncea*) plants were planted in such contaminated soil treated with EDTA, both metal concentrations were found to be very high in shoot portions compared to the same plants grown in non EDTA treated polluted soil.

Ginneken *et al.* (2007) evaluated some of the fast growing species of *Brassica* genus for their ability to have metal accumulation like Cd, Cr, Ni, Pb and Zn under certain conditions which particularly enhance the solubility of metals in the soil. The study revealed that *Brassica juncea* (Indian mustard), *Brassica rapa* (field mustard) and *Brassica napus* (rape) had great capability for higher biomass production. But among them *Brassica juncea* was the only species which is able to accumulate high levels of heavy metals like Cd, Cr, Cu, Ni, Pb and Zn due to higher solubility conditions in soils.

Malarkodi *et al.* (2008) after a field experiment to assess the heavy metal accumulation of Ni from a contaminated soil in Coimbatore district and concluded that castor (*Ricinus communis*) plants could effectively accumulate more Ni than marigold (*Tagetes erecta*). The accumulation was enhanced when the contaminated soils were treated with farmyard manure and poultry manure. Ni had a preferential selective retention in the root portions of both plants than the shoot portions.

Niu *et al.* (2011) monitored the Cd and Pb accumulation by sunflower (*Helianthus annuus* L.) in sand culture for a period of 90 days and concluded that

the ratios of aerial biomass/ root mass for both the metal treatments declined with enhancement in concentration of these metals.

Mani *et al.* (2012) reported that the phytoremediation potential of sunflower (*Helianthus annuus* L.) could be increased by the application of 12% humic acid @ 2 litre per hectare and recommended that this practice can be adopted in the sewage irrigated gangetic alluvial soils of India where Cr accumulation is reported to be high.

According to Pugazholi *et al.* (2013), lower doses of heavy metals like Zn, Cu, Ni, Pb and Cd stimulated the root and shoot elongation of sunflower plants. Further, they reported that this plant had effectively taken up these heavy metals to produce higher biomass and the uptake was proportional to the concentration of these elements in the soil.

Sinha *et al.* (2013) reported higher accumulation of Cr in the shoot portions of chrysanthemum (*Chrysanthemum coronarium*) and marigold (*Tagetes erecta*) than other flowering plants when grown in a Cr contaminated soils. The average values of Cr accumulation in stem, leaf and flower were relatively higher in marigold than chrysanthemum.

The metal tolerance of Zn and Cd and its accumulation capacity in *Gomphrena claussenii* was experimented by Carvalho *et al.* (2013). According to them, the plants could accumulate both Zn and Cd in the shoot portions up to an extent of 5318 μg g^{-1} of Zn and 287 μg g^{-1} of Cd within a period of 30 days exposure. According to them, the plants manifested only slight metal toxic symptoms without any significant decrease in biomass.

2.12.1.1. Phytoremediation by weed flora

Wu *et al.* (2005) examined the ability of 17 weed species for accumulation of Pb from polluted soil under greenhouse conditions. The weed species employed for the study were *Plantago virginica, Trifolium repens, Veronica didyma, Gnaphalium affine, Vicia cracca, Avena fatua, Lolium perenne, Poa annua, Kummerowia striata, Ixeris chinensis, Digitaria ciliaris, Echinochloa crusgalli,*

Oxalis corniculata, Amaranthus viridis, Amaranthus spinosus, Eleusine indica, and *Eragrostis pilosa.* The results indicated that the biomass production of all weed species employed in the experiment was not affected by Pb concentrations in the root zone when compared with unpolluted soil. Most of the weeds accumulated lead in root portions except *Kummerowia striata, Ixeris chinensis, Digitaria ciliaris, Echinochloa crugalli* which accumulate in shoot portions.

According to Abe *et al.* (2008), plants belonging to Compositae family are more able than Gramineae species to translocate Cd from root to shoot. In both plant species biomass and Cd concentration are related to Cd content in soil. They also reported that plants like *Bidens frondosa, Bidens pilosa* and *Amaranthus viridis* had high Cd accumulation capacity along with higher biomass production which is beneficial indices for identifying Cd phytoremediators.

Danh *et al.* (2009) reported that vetiver (*Vetiveria zizanioides*) showed wide range of tolerance to heavy metals like As, Cd, Cr, Cu, Hg, Ni, Pb, Se, and Zn. According to them, this plant was ideally suited for phytostabilisation and phytoextraction as this plant was capable of sizeable quantity of contaminants from soil.

Adie and Osibanjo (2010) identified the potentials of tropical weeds namely, *Nephrolepis biserrata, Panicum maximum, Eleusine indica,* and *Chromolaena odorata* to accumulate Pb and Cd from a soil contaminated with these metals. According to them, these plants were identified to be effective in bringing down the Pb and Cd levels.

According to Mohanty and Patra (2012), the Cr uptake and its accumulation differed significantly with the age of plants in Paragrass. According to them, any paragrass plant growing in Cr contaminated soils with high biomass might be acting as a successful tool of rhizofiltration and phytoextraction.

Subhashini *et al.* (2013) evaluated the Cd accumulation capacity of different plant species viz; *Acalypha indica, Abutilon indicum, Physalis minima, Cleome viscose, Catharanthus roseus, Ruellia tuberose, Canna indica, Perotis indica, Echinocloa colona* and *Cyperus rotundus*. According to them, there was greater translocation of Cd from the growing medium as the applied Cr

concentration increased. Further, they also reported that all the plant species were ineffective in translocating the Cd load from roots to shoot except *Catharanthus roseus*.

Kumar *et al.* (2013) evaluated the scope of phytoremediation in soils contaminated with heavy metals using different weeds. According to them, different weed species like *Amaranthus viridis, Ipomoea spp., Cynodon spp., Amaranthus spinosus, Basella alba, Spinachea oleracea* were able to decrease the pollution load of heavy metals around sewage treatment plant.

According to Lum *et al.* (2014), most of the weeds which they selected for the study (*Cleome rutidosperma, Eleusine indica, Commelina benghalensis, Synedrella nodifolia, Kyllinga erecta, Asystasia gangetica, Dissotis rotundifolia, Axonopus compressus, Paspalum orbiculare, Panicum maximum, Cyperus rotundus* and *Eragrostis tenella*) were capable of mitigating the heavy metal pollution. Further, they indicated that these metals were absorbed and retained either in shoot or root portion in varying concentrations based on the plant species.

2.12.1.2. Mechanism of phytoremediation

For the phenomenon of phytoextraction of metals by plants, the metals must be transported from the rhizosphere to the root and then to the shoot. Because of the existence of charges in metal ions they are not free to move across the cellular membranes which are basically lipophilic in nature. Hence the metal ion transport into the plant particularly through cells must be mediated by membrane proteins which support transport functions. These transmembrane proteins do possess an extracellular binding domain to which the metal ions get attached initially. The transmembrane structures which are normally connected with extracellular and intracellular media facilitate the transfer of bound metallic ions from the extracellular space through the hydrophobic environment of the membrane into the cell (Lasat *et al.*, 1996).

Lasat *et al.* (1998) suggested that when metals are complexed and sequestered in cellular structure (vacoule) they become unavailable for further translocation to shoot portions. According to them, Zn tolerance in the shoots of Zn hyper accumulator *Thlaspi caerulescens* might be due to the sequestration of these metals in vacuole. Chaney *et al.* (1997) also reported similar observation.

According to Steveninck *et al.* (1990), Zn hyper accumulators possess the ability to inactivate Zn in vacuole through its precipitation as Zn phytate. Yet another phenomenon seen in Zn hyper accumulators is the binding of the metal to low molecular weight organic acids (Salt *et al.*, 1999).

Similarly, Ni tolerances in certain plants were explained through its complexation with organic compounds having low molecular weight (Lee *et al.*, 1977).

Cobbett and Goldsbrough (1999) explained the detoxification of Cd, a potentially toxic metal which accumulate in plants from contaminated environment by binding through phytochelatins.

Rauser (1990) explained the detoxification of Cd through its binding with thiol (SH)- rich peptide seen in plant tissue.

Tomsett *et al.* (1992) identified metallothioneins (MT) in plants and bacteria which are protein compounds exhibit capacity for heavy metal binding.

Ho-man *et al.* (2013) suggested several steps in mechanisms that are being operated in a hyper accumulator plant for phytoremediation. These includes solubilization of the metal in the soil media, uptake of the metal by roots and its subsequent detoxification/chelation/sequestration/volatilization results in the sustenance of plants without visual toxic symptoms.

Mandal *et al.* (2014) also reported similar steps and processes at cellular levels within the plant. Further, they have identified more than 400 plant species as hyper accumulators in soil and water medium.

2.12.2. Bioremediation

Bioremediation is a biological intervention made to operate in a metal contaminated soil by employing living organisms, primarily microorganisms, to

degrade the environmental contaminants to non toxic or less toxic form. Microbes though often used to remedy environmental problems have limitations for survival and adaptations since they need infinite combination of electron donors and electron acceptors to drive their metabolic processes which they achieve through redox reactions operated in soil. These microorganisms have other adaptations and strategies to detoxify their targeted pollutant. Bioremediation strategies have been identified to be more practical and useful since *in situ* corrections of environmental contamination can be attempted without much hurdles. The selected microbes can be either indigenous to a contaminated area or they might have been isolated from somewhere and introduced into the contaminated site. If they are isolated from elsewhere and introduced into the contaminated site, then the process is referred to as bio augmentation. On the other hand, if they are indigenously isolated, multiplied under suitable conditions and used, they are referred to as biostimulation.

2.12.2.1. Arbuscular mycorrhizal fungi

Gaur and Adholaya (2004) reported that the arbuscular mycorrhizal fungi (AMF) seen on the roots of plants growing on heavy metal contaminated soils played an important role in facilitating better accumulations of heavy metals and their tolerance in plants.

According to Khan (2005), AMF are unique fungal flora which establishes symbiotic relationships with majority of terrestrial plants to promote nutrient uptake. According to him, these fungi are seen to provide protection to roots from heavy metal toxicity by mediating interactions between metals and plant roots.

Plants which establish symbiotic association with AMF have the potential to take up heavy metals from contaminated soil (Gohre and Paszkwoski, 2006).

Marques *et al.* (2009) indicated that arbuscular mycorrhizal fungi have the ability of enhanced tolerance to biotic and abiotic stresses, caused by the presence of high levels of heavy metals.

According to Teng *et al.* (2010), when alfalfa was inoculated with both *Rhizobium meliloti* and *Glomus caledonium* symbionts and grown in chemical

contaminated area, the shoot biomass, root dry biomass and root nodule dry weight were significantly higher when compared with uninoculated counter parts. The inoculated soils registered lower levels of contamination at the end of the growth period.

Yu *et al.* (2010) conducted inoculation studies with three different arbuscular mycorrhizal fungi (*Glomus etunicatum*, *Glomus constrictum*, and *Glomus mosseae*) on maize roots to see the arsenic (As) accumulation. The study revealed that the root colonization rates by the three fungi were significantly different (*G. mosseae* > *G. etunicatum* > *G. constrictum*) and the colonization was markedly decreased with increasing As concentration in soil.

According to Meier *et al.* (2012), AMF improve the phytostabilisation of metals like Zn, Cd and Cu. According to them, these metals were restricted to the hyphae and roots of the plants without translocating these elements to the shoot portions.

Arbuscular mycorrhizal inoculations conducted by Garg and Bhandari (2012), were beneficial in reducing the harmful effects of Cd in red gram (*Cajanus cajan*). The inoculations help the plant nodules to function properly by reducing nodule senescence.

Audet and Charest (2013) reported that the mycorrhizal symbiosis of AMF reduced the plant stress tolerance normally created by the high metal exposure to plants. According to them, the mycorrhizal symbiosis helps the plant to modulate the metal uptake and its bioavailability in soil. The possible mechanisms suggested for overcoming the plant stress could be metal-binding, metal sequestration and hyphal alkalinization.

Willis *et al.* (2013) reported that some species of AMF (*Glomeromycota*) have been beneficial to many plants growing in heavy metal contaminated soil by preventing its uptake to plant and possible consequences. At the same time other species of AMF was found to encourage a higher rate of heavy metals uptake by plants through symbiotic relationships and this feature of the fungi was employed for detoxification of contaminated soils.

Souza *et al.* (2013) reported that mycorrhizal colonization on the roots of *Canavalia gladiata* could restrict the entrance of Pb in them from a highly Pb contaminated area. But when the inoculation was effected on the same plant under intermediate concentration of Pb accumulation of the metal was seen both in shoot and root portions. Further, they have observed that Pb accumulation was mostly restricted to the root portions in the non-mycorrhizal plants.

Garg and Bhandari (2014) observed that heavy metals were immobilized in plants inoculated with AMF. The possible mechanisms suspected by them were precipitation in the soil matrix, adsorption on to the root surface or accumulation within the roots.

When roots of white clover (*Trifolium repens*) were inoculated with AMF grown in Cu contaminated area, Xiao *et al.* (2015) observed that the plant biomass increased with an attended decrease in Cu content in both shoots and root portions of the plant.

According to Gomes *et al.* (2015), AMF could induce tolerance mechanism to As in *Brachiaria decumbens* . According to them, the shoot and root growth were independent of As concentration and the presence of As retarded the P uptake and AMF inoculation could not help the situation.

Reports of Tanwar *et al.* (2015), on the inoculation of celery plants with *Glomus mosseae* and associated uptake of Cd from soil indicated that addition of EDTA enhanced the accumulation of Cd in plants inoculated with *Glomus mosseae.* Further, they observed that these plants were able to withstand the phytotoxic symptoms and the associated stress conditions only within the plants because of the benefits provided by *Glomus mosseae* through increased P accumulation, chlorophyll content and plant growth. According to them, addition of EDTA in presence of AMF enhances the phytoextraction potential of plant.

Arias *et al.* (2015) reported that the phytoremediation of Pb contaminated soil could be effectively managed by sunflower and barley plants inoculated with AMF as the metal content in both root and shoot portions were quite high in test plants.

Mycorrhizal inoculation of pot marigold (*Calendula officinalis* L.) was reported to enhance the uptake of not only essential nutrient but also Pb and Cd from a contaminated soil. Since both root and shoot portions of the marigold plant recorded fairly high concentration of Pb and Cd. The same plant offer immense potential for phytoremediation in soil (Tabrizi *et al.*, 2015).

Mishra *et al.* (2015) demonstrated the effectiveness of AMF and Plant Growth Promoting Rhizobia (PGPR) in phytoremediation of Fe^{3+} contaminated soils in *Pennisetum glaucum* and *Sorghum bicolor*. Both plants were inoculated individually or in synergestic combination to see the effectiveness in phytoremediation. Results indicated that whenever there was an increase in the absorptive surface area created by the ramifying hyphae of the AMF, there was enhanced uptake of Fe by them but were not permitted to be translocated to the shoot portions since fungal hyphae served as filtration barrier.

According to Bahraminia *et al.* (2015), Pb concentration and its uptake by vetiver roots were more when they were inoculated with mycorrhiza. Mycorrhizal association enhanced the Pb extraction from soil, its uptake and translocation. The translocation of Pb by vetiver plants continued to be on the higher side even when the Pb levels were lower in the rhizosphere.

When marigold (*Tagetes erecta*) was inoculated with AMF, bioavailable heavy metal proportions in soil increased compared to non inoculated plants and the mycorrhizal exudates helped to enhance the absorption of heavy metal (Pb) concentration (Alvarado *et al.*, 2013).

Jarrah *et al.* (2014) conducted an experiment to evaluate the influence of AMF (*Glomus mosseae*) along with the addition of EDTA on phytoremediation of Pb by sunflowers (*Helianthus annuus*) plants in a calcareous soil. Results revealed that inoculation of AMF along with EDTA increased root colonization and absorption of Pb at increased levels of Pb concentration.

2.12.2.2. Other microorganisms

Eleven Cd tolerant bacterial strains from the root zone of Indian mustard (*Brassica juncea* L.) seedlings grown in Cd contaminated soils have been isolated

by Belimov *et al.* (2005). These bacterial strains were tolerant to many metals including Zn, Ni, Co and Cu.

Venkatesan *et al.* (2011) isolated five cadmium tolerant plant growth promoting rhizobacteria (*Proteus* sp., *Bacillus* sp., *Clostridium* sp., *Alcaligenes* sp. and *Coccobacillus* sp.) from the root zone of Indian mustard grown in a contaminated soil. The presence of these microorganisms could not deter the growth of seedlings and hence these microorganisms are considered beneficial in the bioremediation of Cd.

Mohammadzadeh *et al.* (2014) evaluated the effect of bacteria inoculation on Sunflower growth and its phytoremediation capacity from soils contaminated by different levels of nickel. According to them, in the absence of inoculation the growth indices, photosynthetic pigments, shoot Fe concentration, root and shoot Zn concentration, and translocation factor decreased as the Ni concentration in soil increased. But when bacterial inoculation of the plant was successfully carried out there was significant enhancement in the plant growth, development of photosynthetic pigments, and Ni uptake.

Not the least but last, it is concluded that no similar study from an unscientific landfill site in Kerala has been undertaken and hence reviews under Kerala situation could not be included.

Materials and methods

3. MATERIALS AND METHODS

A scientific study on "Impact assessment of landfill on soil health and water quality in a waste disposal site" was conducted at the College of Agriculture, Vellayani during the period 2012 to 2015. For this the waste dumping site of Thiruvananthapuram Corporation located at Vilappilsala panchayath, 16 km away from the city was selected. Incidentally the garbage treatment plant at this site was closed due to heavy protest and agitation from the local people on account of reported environmental problems in soil, water and air.

For a comprehensive study the entire process phased out into four segments.

Segment 1: Monitoring of landfill area and leachate zone for assessing the contamination level.

A detailed peripatetic survey of the garbage treatment plant area, landfill positions, direction of leachate flow from the landfill site, the floral diversity along the leachate path and the available ground water sources outside the waste plant area was conducted to have an overview of the situation and to select various representative sampling points for the collection of samples within and outside the plant area. During the survey it is seen that though there was leachate flow from both landfill sites, the one without capping had created more problem than the other. The leachate flow from the two landfill sites, merge at a common point within the designated plant area and from where it moves further down through private land and finally join the *Meenampally thodu* discharging its contents. In the leachate flow zone outside the plant, the problem of discolouration in drinking water sources could be noticed and hence these sources were also proposed to be selected for the study.

Segment 2: Identification and characterization of common weed flora along the leachate zone

The prominent and profusely growing weed flora present along the leachate flow zone from both landfill sites was monitored and 15 numbers were selected for study. This was so done to validate the common suspicion that these weeds could be potential hyper accumulators of various contaminant metal ion and finally to shortlist the best hyper accumulator from among them.

Segment 3: Sand culture experiment

Sand culture experiment was designed to assess the performance of a few hyper accumulators at relatively high doses of Pb, Cd and Ni. For this, four well known accumulators were selected and grown under different graded doses of heavy metals along with a selected weed species showing maximum hyper accumulator activity from the leachate zone.

Segment 4: Pot culture experiment

Pot culture experiment was conducted in the Department of Soil Science and Agricultural Chemistry using the landfill materials collected from the garbage treatment plant. The landfill materials from the dump site were mixed with virgin soil in varying proportions with and without the inoculation of AMF and the extent of absorption of heavy metals from the landfill materials were assessed using well established hyper accumulators identified from the sand culture experiment

3.1. MONITORING OF LANDFILL AREA AND LEACHATE ZONE FOR ASSESSING THE CONTAMINATION LEVEL

3.1.1. Description of the study area

The study was confined mostly to the two landfill sites of Vilappilsala treatment plant spread in an area of 47.8 acres. Earlier to closure, the plant was

handling nearly 300 tonnes of city garbage per day and technology used for waste management was aerobic windrow composting. The plant has successfully run for nearly 11 years and later due to inadequacies in the running process, the plant has to be physically closed down against the strong protest and agitation from the local people as the effluents and emanating bad odours from the plant has invited environmental issues. It is roughly estimated that by this time the plant had handled 9.67 lakh tonnes of garbage waste from the city. But since the waste was not segregated, the full quantum of waste materials could not be converted to organic manure. In this connection it is estimated that 30% of the waste reaching the site had different origin ranging from plastics to metals and mixed with organic sources and this quantity was diverted for dumping in the valley areas of the treatment plant since this waste cannot be put to any use. The dumping was undertaken without complying any of the essential mandatory requirements required for a scientific landfill. All the dumped materials were levelled and compacted using machinery and once it attained necessary height the surface and sides were covered with welded UV stabilized polythene sheet and upper part capped with a thick layer of soil to give a natural look to the landfill site with necessary vents at different points for the landfill gases to escape. The second landfill site which was progressively getting waste materials from the plant had to be abandoned without getting covered with any polythene sheet or getting capped properly due to local protest and closure orders from Government. This landfill site provided maximum amount of leachate to the environment than the other.

3.1.2. Sample collection

To make the study more meaningful, it was necessary to have continuous monitoring of geo-coded sites over three consecutive seasons representing pre-monsoon, monsoon and post–monsoon period for observing all the possible fluctuations in physical, chemical and biological characteristics induced by seasonal changes.

Accordingly, representative samples of waste materials from landfill sites, leachate samples (at a regular interval of 50 m) along the leachate flow zone up to the *Meenampally thodu* covering both plant area and outside, soil samples from the leachate bed at two depths (0-30 cm and 30-60 cm) from the leachate sampling points within the plant area and well water samples from outside the plant area were collected using standard procedures. The details of the geo-referenced points used for collection of various samples are presented in Table 1.

3.1.2.1. Pre-monsoon season

Pre-designated representative and geo-referenced samples for landfill materials from dump sites, leachate samples, soil samples from leachate bed, well water sources were collected towards the end of May 2014 which coincided with the peak summer seasons. The first leachate sample matched ooze from the lower end of the landfills and subsequent samples from further lower points along the flow till it reached the *Meenampally thodu*. After collecting the leachate, soil samples were also collected from the leachate zone at two depths viz; 0-30 cm and 30-60 cm. Thus in a season 10 landfill materials (5 each from two landfills), 8 leachate samples from within the plant area, 3 leachate samples outside the plant area (flowing through private lands) and 16 soil samples (from two depths, 0-30cm and 30-60 cm) were collected, labelled and transported to the laboratory for processing and subsequent analysis. Water samples from three drinking water sources (well) near the vicinity of the flow zone were also collected, labelled and transported to the laboratory for detailed physical, chemical and biological analysis.

Table 1. Locations selected for collection of landfill materials, soil, leachate and well water samples

Locations	Samples	Latitude	Longitude
Representative locations selected for collection of landfill materials			
1	Landfill material	N 08^0 32' 13.2"	E 077^0 02' 19.9"
2	Landfill material	N 08^0 32' 12.7"	E 077^0 02' 20.4"
3	Landfill material	N 08^0 32' 12.0"	E 077^0 02' 20.7"
4	Landfill material	N 08^0 32' 11.7"	E 077^0 02' 19.9"
5	Landfill material	N 08^0 32' 12.4"	E 077^0 02' 19.3"
6	Landfill material	N 08^0 32' 21.5"	E 077^0 02' 15.7"
7	Landfill material	N 08^0 32' 20.6"	E 077^0 02' 14.9"
8	Landfill material	N 08^0 32' 21.2"	E 077^0 02' 13.7"
9	Landfill material	N 08^0 32' 20.0"	E 077^0 02' 13.7"
10	Landfill material	N 08^0 32' 20.0"	E 077^0 02' 12.9"
Locations selected for soil and leachate sample collection			
11	Soil & leachate (0m*)	N 08^0 32' 12.6"	E 077^0 02' 18.3"
12	Soil & leachate (50m)	N 08^0 32' 13.9"	E 077^0 02' 17.1"
13	Soil & leachate (100m)	N 08^0 32' 15.6"	E 077^0 02' 14.9"
14	Soil & leachate (150m)	N 08^0 32' 18.0"	E 077^0 02' 14.1"
15	Soil & leachate (200m)	N 08^0 32' 18.6"	E 077^0 02' 11.4"
16	Soil & leachate (250m)	N 08^0 32' 19.3"	E 077^0 02' 09.2"
17	Soil & leachate (300m)	N 08^0 32' 20.2"	E 077^0 02' 07.4"
18	Soil & leachate (350m)	N 08^0 32' 22.1"	E 077^0 02' 05.2"
19	Leachate (canal**)	N 08^0 32' 23.7"	E 077^0 01' 59.4"
20	Leachate (canal)	N 08^0 32' 22.8"	E 077^0 01' 54.3"
21	Leachate (canal)	N 08^0 32' 17.1"	E 077^0 01' 51.1"

*Distance from the landfill site

**Outside the garbage treatment plant

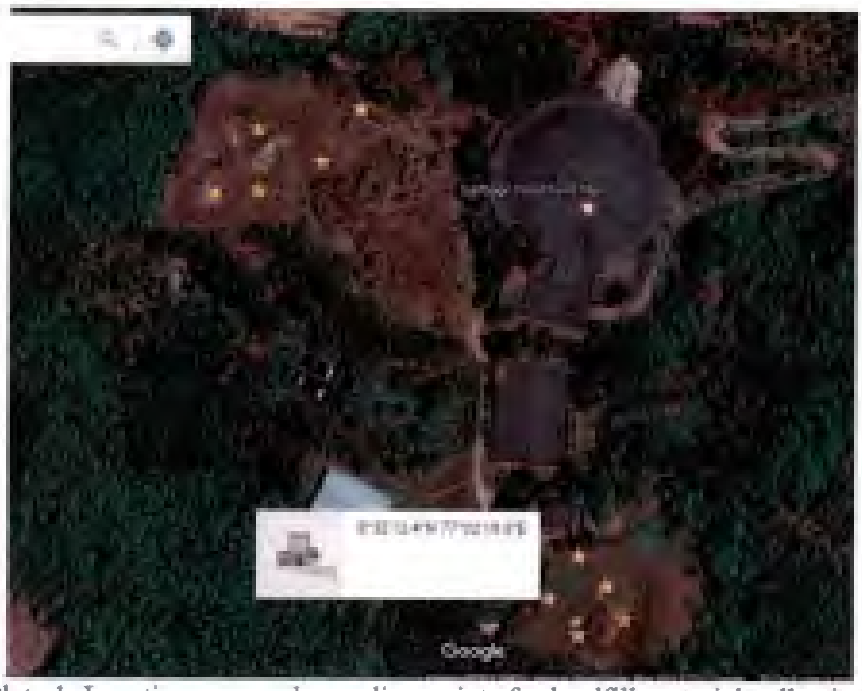

Plate 1. Location map and sampling points for landfill material collection

Plate 2. Location map and sampling points for soil sample collection

Plate 3. Location map and sampling points for leachate sample collection

Plate 4. Leachate out flow from the base of first landfill

Plate 5. Leachate out flow from the base of second landfill

Table 1. Continued

Locations	Samples	Latitude	Longitude
Locations selected outside the plant area for well water collection			
22	Well water 1	N 08^0 32' 24.4"	E 077^0 01' 58.3"
23	Well water 2	N 08^0 32' 19.8"	E 077^0 01' 54.2"
24	Well water 3	N 08^0 32' 17.8"	E 077^0 01' 50.6"

3.1.2.2. Monsoon season

Exactly in similar fashion, geo-referenced landfill materials from two dump sites, soil samples from leachate zone (two depth), leachate samples and well water samples were collected during the mid week of September 2014 which coincide with the peak monsoon season. All samples were labelled appropriately and taken to the laboratory for detailed analysis (physical, chemical and biological).

3.1.2.3. Post-monsoon season

This sampling was done in second week of February 2015 from the predetermined sites as described above with the help of GPS (Garmin GPSMAP 76CSx).

3.2. ASSESSMENT OF WEED FLORA IN THE LEACHATE ZONE FOR POSSIBLE HYPER ACCUMULATION CAPACITY OF CONTAMINANTS

All along the leachate flowing zone profuse growth of varying kinds of weeds could be seen. After surveying the entire zone, 15 different species of weeds popularly noted in the area were identified based on the assumption that these weeds could be better hyper accumulators in the highly contaminated medium than other weeds growing outside the leachate zone. So these profusely growing weed species were identified botanically and collected from the site carefully and bought to

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laboratory for assessing the possible level of suspected accumulation both in root or shoot portions. Hence, in the laboratory they were carefully washed with running water to remove the adhering soil particle or external contaminants and later with distilled water. The root and shoot portions were carefully separated using steel knife and were processed properly for detailed analysis of heavy metals. The details of the major weed flora identified and collected from the leachate flow zone are listed in Table 2.

Table 2. Weed species selected from the leachate zone for evaluating the hyper accumulation capacity

Sl No.	Common Name	Scientific Name	Family
1	Joy weed	*Alternanthera tenella* Colla.	Amaranthaceae
2	Creeping oxeye/ Trailing daisy	*Sphagneticola trilobata* (L.) Hitchc.	Asteraceae
3	Climbing day flower/ Spreading day flower	*Commelina diffusa* N. Burman	Commelinaceae
4	Colocasia	*Colocasia esculenta* (L.) Schott.	Araceae
5	Mile-a-minute plant	*Mikania micrantha* Kunth.	Asteraceae
6	Castor	*Ricinus communis* L.	Euphorbiaceae
7	Siam weed	*Eupatorium odoratum*	Asteraceae
8	Signal grass	*Brachiaria distachya* (L.) Stapf.	Poaceae
9	Centro	*Centrosema pubescens* Benth.	Fabaceae
10	Spreading hog weed	*Boerhavia diffusa* L.	Nyctaginaceae
11	Silver spiked cock's comb	*Celosia argentea* L.	Amaranthaceae
12	Burmuda grass	*Cynodon dactylon* (L.) Pers.	Poaceae
13	Tropical girdle pod	*Mitracarpus verticillatus* (L.) DC.	Rubiaceae
14	Sida	*Sida rhombifolia* L.	Malvaceae
15	Crow foot grass	*Dactyloctenium aegyptium* (L.) Willd.	Poaceae

3.3. SAND CULTURE EXPERIMENT

A sand culture experiment was designed to identify and compare the mining capacity and performance of four well known hyper accumulators under graded doses of Pb, Cd and Ni. For this, acid washed sand was used as the medium for growth,

Plate 6. Leachate flow zone and common weed flora from the landfill site

Plate 7. Leachate flow zone outside the treatment plant area

Plate 8. Joy weed (*Alternanthra tenella*) – Selected hyper accumulator from the leachate flow zone

where four doses of each metal source was provided in the root zone through solution to assess their individual performance. For this, sufficient numbers of uniform sized plastic containers of half kg capacity were used for the study. Four hyper accumulators along with one identified weed plant noted for its best hyper accumulation ability in the leachate zone were used as the test plants in sand culture. The details of the test plants are given in Table 3.

Table 3. Details of the hyper accumulator plants used for sand culture experiment

Sl No.	Plants		Sources of seeds
	Common Name	Scientific Name	
1	Indian mustard	*Brassica juncea* L.	IARI, New Delhi
2	Sunflower	*Helianthus annuus* L.	TNAU, Coimbatore
3	Globe amaranth	*Gomphrena globosa* L.	Dept. of Horticulture, College of Agriculture, Vellayani
4	Marigold	*Tagetes spp.* L.	
5	Joy weed (best hyper accumulator from the leachate zone)	*Alternanthera tenella*	College of Agriculture, Vellayani

For raising the experimental plants for sand culture, two seeds each of test plant were sown and for getting the weeds plant, cuttings of weeds were planted during mid of July in 2015 in containers containing acid washed sand. These mini pots were closely observed for germination and subsequent growth. Since the growth of the plants was very poor, a foliar spray of 19:19:19 was given @ 2g/l at weekly intervals to the foliage to sustain the growth and plants were grown for four weeks. The experiment was conducted in the rain shelter of Department of Plant Physiology, College of Agriculture, Vellayani as Completely Randomized Design with four treatments and three replications separately for each plant species. By the end of second week, when sufficient growth for seedlings have been ensured, pre-calculated quantities of the heavy metals were impregnated in the sand portions of each plant. The performance of each plant species nurtured under the influence of graded doses

of each metal was closely monitored and the plants were carefully uprooted two weeks after the imposition of treatments. The plants were washed with distilled water and weighted separately for root and shoot, then labelled and processed in laboratory for further analysis.

The following levels of metals were provided in the root zone of each plant

1. Pb @ 0, 0.5, 1.0 and 2.5 mg kg^{-1}
2. Cd @ 0, 0.5, 1.0 and 2.5 mg kg^{-1}
3. Ni @ 0, 0.5, 1.0 and 2.5 mg kg^{-1}

Water soluble sources of heavy metals as mentioned below which are chemically pure were used as sources of heavy metals for imposing the treatments.

Pb – Lead (Lead nitrate - $Pb(NO_3)_2$)

Cd - Cadmium (Cadmium nitrate – $Cd(NO_3)_2 .4H_2O$)

Ni - Nickel (Nickel chloride – $NiCl_2 .6 H_2O$)

The different treatment details in sand culture experiment were illustrated in Table 4.

Table 4. Treatment details of sand culture experiment

Treatments	Lead	Cadmium	Nickel	Doses
1. Indian mustard (*Brassica juncea* L.)				
1	L I_1R_1	C I_1R_1	N I_1R_1	0 mg kg^{-1} (Control)
	L I_1R_2	C I_1R_2	N I_1R_2	
	L I_1R_3	C I_1R_3	N I_1R_3	
2	L I_2R_1	C I_2R_1	N I_2R_1	0.5 mg kg^{-1}
	L I_2R_2	C I_2R_2	N I_2R_2	
	L I_2R_3	C I_2R_3	N I_2R_3	
3	L I_3R_1	C I_3R_1	N I_3R_1	1.0 mg kg^{-1}
	L I_3R_2	C I_3R_2	N I_3R_2	
	L I_3R_3	C I_3R_3	N I_3R_3	
4	L I_4R_1	C I_4R_1	N I_4R_1	2.5 mg kg^{-1}
	L I_4R_2	C I_4R_2	N I_4R_2	
	L I_4R_3	C I_4R_3	N I_4R_3	
2. Sunflower (*Helianthus annuus* L.)				
1	L S_1R_1	C S_1R_1	N S_1R_1	0 mg kg^{-1} (Control)
	L S_1R_2	C S_1R_2	N S_1R_2	
	L S_1R_3	C S_1R_3	N S_1R_3	
2	L S_2R_1	C S_2R_1	N S_2R_1	0.5 mg kg^{-1}
	L S_2R_2	C S_2R_2	N S_2R_2	
	L S_2R_3	C S_2R_3	N S_2R_3	
3	L S_3R_1	C S_3R_1	N S_3R_1	1.0 mg kg^{-1}
	L S_3R_2	C S_3R_2	N S_3R_2	
	L S_3R_3	C S_3R_3	N S_3R_3	
4	L S_4R_1	C S_4R_1	N S_4R_1	2.5 mg kg^{-1}
	L S_4R_2	C S_4R_2	N S_4R_2	
	L S_4R_3	C S_4R_3	N S_4R_3	
3. Globe amaranth (*Gomphrena globosa* L.)				
1	L G_1R_1	C G_1R_1	N G_1R_1	0 mg kg^{-1} (Control)
	L G_1R_2	C G_1R_2	N G_1R_2	
	L G_1R_3	C G_1R_3	N G_1R_3	
2	L G_2R_1	C G_2R_1	N G_2R_1	0.5 mg kg^{-1}
	L G_2R_2	C G_2R_2	N G_2R_2	
	L G_2R_3	C G_2R_3	N G_2R_3	
3	L G_3R_1	C G_3R_1	N G_3R_1	1.0 mg kg^{-1}
	L G_3R_2	C G_3R_2	N G_3R_2	
	L G_3R_3	C G_3R_3	N G_3R_3	
4	L G_4R_1	C G_4R_1	N G_4R_1	2.5 mg kg^{-1}
	L G_4R_2	C G_4R_2	N G_4R_2	
	L G_4R_3	C G_4R_3	N G_4R_3	

Plate 9. Sand culture experiment

Plate 10. Sand culture experiment

Table 4. Continued

Treatments	Lead	Cadmium	Nickel	Doses
4. Marigold (*Tagetes spp.* L.)				
1	L M_1R_1	C M_1R_1	N M_1R_1	0 mg kg^{-1} (Control)
	L M_1R_2	C M_1R_2	N M_1R_2	
	L M_1R_3	C M_1R_3	N M_1R_3	
2	L M_2R_1	C M_2R_1	N M_2R_1	0.5 mg kg^{-1}
	L M_2R_2	C M_2R_2	N M_2R_2	
	L M_2R_3	C M_2R_3	N M_2R_3	
3	L M_3R_1	C M_3R_1	N M_3R_1	1.0 mg kg^{-1}
	L M_3R_2	C M_3R_2	N M_3R_2	
	L M_3R_3	C M_3R_3	N M_3R_3	
4	L M_4R_1	C M_4R_1	N M_4R_1	2.5 mg kg^{-1}
	L M_4R_2	C M_4R_2	N M_4R_2	
	L M_4R_3	C M_4R_3	N M_4R_3	
5. Hyper accumulator plant – *Alternanthera tenella*				
1	L H_1R_1	C H_1R_1	N H_1R_1	0 mg kg^{-1} (Control)
	L H_1R_2	C H_1R_2	N H_1R_2	
	L H_1R_3	C H_1R_3	N H_1R_3	
2	L H_2R_1	C H_2R_1	N H_2R_1	0.5 mg kg^{-1}
	L H_2R_2	C H_2R_2	N H_2R_2	
	L H_2R_3	C H_2R_3	N H_2R_3	
3	L H_3R_1	C H_3R_1	N H_3R_1	1.0 mg kg^{-1}
	L H_3R_2	C H_3R_2	N H_3R_2	
	L H_3R_3	C H_3R_3	N H_3R_3	
4	L H_4R_1	C H_4R_1	N H_4R_1	2.5 mg kg^{-1}
	L H_4R_2	C H_4R_2	N H_4R_2	
	L H_4R_3	C H_4R_3	N H_4R_3	

3.4. POT CULTURE EXPERIMENT

Final validation and performance of different well known hyper accumulators using collected landfill materials from landfill site were carried out through a pot culture experiment at the College of Agriculture, Vellayani in an open area near the Department of Soil Science & Agricultural Chemistry. For rendering the required composition of potting mixture, virgin soil were collected from the college campus, sieved (5 mm sieve) and mixed with the collected landfill materials from the dump sites. Sufficient number of grow bags having a capacity of 10 kg were procured and the soil media in the required proportion was constituted using both degradable

landfill materials and virgin soil in different proportions as mandated by treatment requirements. Three plant species which had survived the highest dose of all heavy metals in sand culture experiment were taken forward to this experiment. The plant species selected for pot culture experiment are illustrated in Table 5.

Table 5. The plants and their sources of collection used in pot culture experiments

Sl No.	Plants		Sources of seeds
	Common Name	Scientific Name	
1	Sunflower	*Helianthus annuus* L.	TNAU, Coimbatore
2	Globe amaranth	*Gomphrena globosa* L.	Dept. of Horticulture, College of Agriculture, Vellayani
3	Marigold	*Tagetes spp.* L.	

The experiment was laid out in CRD with three replications for each plant species.

The treatment details are as follows:

T_1-Degradable landfill materials 1 kg + 9 kg virgin soil with AMF inoculation
T_2-Degradable landfill materials 1 kg + 9 kg virgin soil without AMF inoculation
T_3-Degradable landfill materials 2 kg + 8 kg virgin soil with AMF inoculation
T_4-Degradable landfill materials 2 kg + 8 kg virgin soil without AMF inoculation
T_5-Degradable landfill materials 3 kg + 7 kg virgin soil with AMF inoculation
T_6-Degradable landfill materials 3 kg + 7 kg virgin soil without AMF inoculation
T_7-Degradable landfill materials 5 kg + 5 kg virgin soil with AMF inoculation
T_8-Degradable landfill materials 5 kg + 5 kg virgin soil without AMF inoculation
T_9-Control 1:- 10 kg virgin soil with AMF inoculation
T_{10}-Control 2:- 10 kg virgin soil without AMF inoculation

Arbuscular Mycorrhizal Fungi (AMF), *Glomus fasciculatum* procured from Department of Agricultural Microbiology, College of Agriculture, Vellayani was applied @ 5g/grow bag in T_1, T_3, T_5, T_7 and T_9 treatments.

3.4.1. Planting

After filling the grow bags in required proportion, these grow bags were kept in open sun for a period of one month for complete stabilization. After this specified period, short seed holes were made towards middle of grow bag for positioning the seeds and wherever AMF inoculation was warranted, 5g each of AMF was introduced into the holes made in the middle of the grow bags prior to placement of seed. Later this point was covered with a small quantity soil and sufficient moisture was regularly ensured through irrigation for germination and growth. The different treatment combinations of the hyper accumulators tested in pot culture experiment are presented in Table 6.

The germinated seeds were allowed to grow and these plants were maintained for a period of three months. At the end of the third month, the plants were carefully uprooted and roots washed in running water to remove the adhering soil particles. Later the root and shoot portions were separated using steel knife and weighed separately. As part of processing and preserving plant parts for further analysis, all the harvested and separated plant parts were separately weighed for root and shoot portion and these portions were processed for various analyses. In the case of sunflower plants, the flowers were separately harvested and seeds detached and processed separately for detailed analysis of heavy metals since seeds find potential use in sunflower oil production.

Table 6. Different treatment combinations for sunflower, globe amaranth and marigold in pot culture experiment

Sl No.	Sunflower (*Helianthus annuus* L.)	Globe amaranth (*Gomphrena globosa* L.)	Marigold (*Tagetes spp.* L.)	Treatments
1	S_1R_1	G_1R_1	M_1R_1	Degradable waste materials 1 kg + 9 kg virgin soil with AMF inoculation (T_1)
2	S_1R_2	G_1R_2	M_1R_2	
3	S_1R_3	G_1R_3	M_1R_3	
4	S_2R_1	G_2R_1	M_2R_1	Degradable waste materials 1 kg + 9 kg virgin soil without AMF inoculation (T_2)
5	S_2R_2	G_2R_2	M_2R_2	
6	S_2R_3	G_2R_3	M_2R_3	
7	S_3R_1	G_3R_1	M_3R_1	Degradable waste materials 2 kg + 8 kg virgin soil with AMF inoculation (T_3)
8	S_3R_2	G_3R_2	M_3R_2	
9	S_3R_3	G_3R_3	M_3R_3	
10	S_4R_1	G_4R_1	M_4R_1	Degradable waste materials 2 kg + 8 kg virgin soil without AMF inoculation (T_4)
11	S_4R_2	G_4R_2	M_4R_2	
12	S_4R_3	G_4R_3	M_4R_3	
13	S_5R_1	G_5R_1	M_5R_1	Degradable waste materials 3 kg + 7 kg virgin soil with AMF inoculation (T_5)
14	S_5R_2	G_5R_2	M_5R_2	
15	S_5R_3	G_5R_3	M_5R_3	
16	S_6R_1	G_6R_1	M_6R_1	Degradable waste materials 3 kg + 7 kg virgin soil without AMF inoculation (T_6)
17	S_6R_2	G_6R_2	M_6R_2	
18	S_6R_3	G_6R_3	M_6R_3	
19	S_7R_1	G_7R_1	M_7R_1	Degradable waste materials 5 kg + 5 kg virgin soil with AMF inoculation (T_7)
20	S_7R_2	G_7R_2	M_7R_2	
21	S_7R_3	G_7R_3	M_7R_3	
22	S_8R_1	G_8R_1	M_8R_1	Degradable waste materials 5 kg + 5 kg virgin soil without AMF inoculation (T_8)
23	S_8R_2	G_8R_2	M_8R_2	
24	S_8R_3	G_8R_3	M_8R_3	
25	S_9R_1	G_9R_1	M_9R_1	Control 1 – 10 kg virgin soil with AMF inoculation (T_9)
26	S_9R_2	G_9R_2	M_9R_2	
27	S_9R_3	G_9R_3	M_9R_3	
28	$S_{10}R_1$	$G_{10}R_1$	$M_{10}R_1$	Control 2 – 10 kg virgin soil without AMF inoculation (T_{10})
29	$S_{10}R_2$	$G_{10}R_2$	$M_{10}R_2$	
30	$S_{10}R_3$	$G_{10}R_3$	$M_{10}R_3$	

Plate 11. Pot culture experiment – sunflower as test plant

Plate 12. Pot culture experiment – globe amaranth as test plant

Plate 13. Pot culture experiment – marigold as test plant

3.5. ANALYTICAL PROCEDURES

3.5.1. Degradable landfill materials

The degradable landfill materials collected from Vilappilsala garbage treatment plant area in three seasons were shade dried, sieved through 2 mm sieve and processed further for different analysis like bulk density, pH, EC, total N, P, K, organic carbon, and heavy metals (Pb, Cd, Ni, Ca, Mg, Zn, Mn, Cu, Fe, Al, Co, Cr and Hg). The details of the analytical procedures followed for various analyses are given in Table 7.

3.5.2. Soil analysis

The soil samples analyzed in this category fall in two sections

1. Soil samples collected from leachate zone at two depth were appropriately labelled, bought to laboratory, shade dried, sieved through 2 mm sieve and processed and analyzed for bulk density, pH, EC, organic carbon, available N, available P, available K and extractable metals (Pb, Cd, Ni, Ca, Mg, Zn, Mn, Cu, Fe, Al, Co, Cr and Hg)
2. Pre-harvest and post harvest samples of soil media in pot culture experiment were labelled, shade dried, sieved and analyzed for bulk density, pH, EC, organic carbon, available N, available P, available K and extractable metals (Pb, Cd, Ni, Ca, Mg, Zn, Mn, Cu, Fe, Al, Co, Cr and Hg)

The details of the analytical procedures followed for various soil analyses are given in Table 7.

3.5.3. Water analysis (Leachate and well water)

The leachate and well water samples collected during three different seasons were appropriately labelled and taken to laboratory for further studies. Immediately on reaching the laboratory, these samples were tested for pH, EC, total dissolved

solids, BOD, COD, coliforms and heavy metal contents (Pb, Cd, Ni, Ca, Mg, Zn, Mn, Cu, Fe, Al, Co, Cr, Hg and As). The details of the analytical procedures followed for various biological and chemical analyses are given in Table 8.

3.5.4. Plant analysis

The plant samples analyzed in this category fall into three sections

1. Popular weed plants (shoot and root portions) collected from leachate zone.
2. Plant parts (shoot and root portions) from sand culture experiment
3. Plant parts (shoot, root and seeds) from pot culture experiment

All the plant samples and their appropriate plant parts were carefully labelled, air dried for 4-5 days and then kept in hot air oven at a temperature of 70°C till constant weight. Later these plant parts were finely powdered and taken for respective analysis.

1. Weed plants (root and shoot) for Pb, Cd, Ni, Ca, Mg, Zn, Mn, Cu, Co and Cr
2. Plants from sand culture (root and shoot) for Pb, Cd and Ni
3. Plants from pot culture (root, shoot and seeds) for Pb, Cd, Ni, Ca, Mg, Zn, Mn, Cu, Fe, Al, Co, Cr and Hg

The details of the analytical procedures followed for heavy metal analysis are given in Table 7.

Table 7. Analytical methods used for the characterization of landfill materials, soil and plant samples

Parameter	Method	References
1. Landfill materials		
pH	pH meter (1:2.5 soil: water w/v suspension)	Jackson (1958)
Electrical Conductivity	Conductivity meter (1:2.5 suspension)	
Total N	Microkjeldahl digestion and distillation	
Total P	Diacid (HNO_3 : $HClO_4$ in the ratio 9:4) digestion and estimation using spectrophotometer	
Total K	Diacid (HNO_3 : $HClO_4$ in the ratio 9:4) digestion and estimation using flame photometer	
Organic Carbon	Chromic acid wet digestion method	Walkley and Black (1934)
Bulk Density	Laboratory core method for disturbed soil	Black *et al.* (1965)
Heavy metals (total)	Diacid (HNO_3 : $HClO_4$ in the ratio 9:4) digestion and estimation using Inductively Coupled Plasma Optical Emission Spectrometer	Kalra (1998)
Aluminium (total)	Diacid (HNO_3 : $HClO_4$ in the ratio 9:4) digestion and estimation using Inductively Coupled Plasma Optical Emission Spectrometer	Kalra (1998)
2. Soil samples		
Available N	Alkaline permanganate method	Subbiah and Asija (1956)
Available P	Bray extraction and estimation using spectrophotometer	Bray and Kurtz (1945)
Available K	Neutral *N* NH_4OC extraction and estimation using flame photometer	Jackson (1958)
Organic Carbon	Chromic acid wet digestion method	Walkley and Black (1934)
Bulk Density	Laboratory core method for undisturbed soil	Black *et al.* (1965)
Heavy metals	0.5 *N* HCl extraction and estimation using Inductively Coupled Plasma Optical Emission Spectrometer	Kalra (1998)
3. Plant samples		
Heavy metals	Diacid (HNO_3 : $HClO_4$ in the ratio 9:4) digestion and estimation using Inductively Coupled Plasma Optical Emission Spectrometer	Kalra (1998)

Table 8. Analytical methods used for characterization of leachate and well water samples

Parameter	Method	References
pH	pH meter	Jackson (1958)
EC	Conductivity meter	
BOD	Incubation and titration	Gupta (1999)
COD	Titration method	
Total dissolved solids	Filtration	
Coliforms	MPN index method	USDA (2014)
Heavy metals	Filtered- Inductively Coupled Plasma Optical Emission Spectrometer	Kalra (1998)

3.6. STATISTICAL ANALYSIS

The data generated from the experiments were analyzed statistically using analysis of variance techniques (ANOVA) in CRD. Wherever significant differences between treatments were detected through ANOVA critical differences (CD) are provided for effective comparison of treatments. All these statistical analyses were followed the standard procedures described by Panse and Sukhatme (1978).

Results

4. RESULTS

In an attempt to comprehend the existing problems of the waste disposal site of Thiruvananthapuram Corporation in Vilappilsala panchayath which ceased to function in 2011, a study entitled "Impact assessment of landfill on soil health and water quality in a waste disposal site" was conducted. To meet the objectives listed in the present study a phased attempt to quantify the problems during pre-monsoon, monsoon and post-monsoon seasons has been attempted. The study was undertaken at a point after three years of closure of the waste processing plant. Being a sensitive location, sanction to collect different samples and bulk material from within the closed plant area was obtained from Thiruvananthapuram Corporation and for the study outside the plant area; clearance had been taken from Vilappilsala panchayath. The data generated from the various analysis and experiments are presented in this chapter.

4.1. MONITORING OF LANDFILL AREA AND LEACHATE ZONE FOR ASSESSING THE CONTAMINATION LEVEL

4.1.1. Analysis of landfill materials

The chemical parameters of the landfill material available in the disposal site had been monitored for different parameters during three seasons of study are presented in Table 9. The basic data made available under this table also provide an overall ground reality of the existing landfill materials particularly with respect to its physico-chemical status.

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Table 9. Comparative evaluation of the mean physico-chemical properties of landfill materials in the waste disposal site

Parameters	Pre-monsoon	Monsoon	Post-monsoon	Mean
BD (g cc^{-1})	0.83	0.85	0.84	0.84
pH	6.41	5.37	5.60	5.79
EC (dS m^{-1})	1.17	0.41	0.24	0.60
OC (%)	2.85	2.78	2.65	2.76
N (%)	0.11	0.09	0.08	0.09
P (%)	0.13	0.07	0.05	0.08
K (%)	2.55	1.53	1.43	1.83
Al (mg kg^{-1})	15.46	12.95	11.61	13.34
Ca (mg kg^{-1})	12.73	10.45	9.08	10.75
Mg (mg kg^{-1})	25.07	21.59	19.73	22.13
Zn (mg kg^{-1})	13.64	11.74	10.53	11.97
Mn (mg kg^{-1})	13.27	12.35	11.05	12.22
Cu (mg kg^{-1})	11.45	10.47	10.19	10.71
Fe (mg kg^{-1})	10.14	8.34	6.61	8.36
Pb (mg kg^{-1})	10.22	10.16	10.14	10.17
Cd (mg kg^{-1})	3.32	3.27	2.95	3.18
Ni (mg kg^{-1})	4.63	4.31	3.97	4.30
Co (mg kg^{-1})	2.57	2.52	2.37	2.49
Cr (mg kg^{-1})	5.05	4.78	4.79	4.88
Hg (mg kg^{-1})	5.58	4.47	1.54	3.86

4.1.1.1. Bulk density

An assessment of the bulk density of the landfill material was conducted for three consecutive seasons (pre-monsoon, monsoon and post-monsoon) during the study period. The results which are presented in Table 9 indicated that the bulk density of landfill materials were relatively very low compared to normal values and

seasonal effect was not much pronounced in altering the bulk density. The mean bulk density values of landfill materials observed during pre-monsoon, monsoon and post-monsoon seasons were 0.83, 0.85 and 0.84 g cc^{-1}, respectively.

4.1.1.2. pH

Table 9 provides a comparison of pH of landfill materials during the study period in the three adjacent seasons. Though there was a marginal variation in pH of landfill materials they remained mostly in acidic range (5.37 to 6.41) with a mean value of 5.79. However, the individual mean values of pH of landfill materials in pre-monsoon, monsoon and post-monsoon seasons were 6.41, 5.37 and 5.60, respectively.

4.1.1.3. Electrical conductivity

The mean electrical conductivity (EC) values observed in the landfill materials during pre-monsoon, monsoon and post-monsoon seasons (Table 9) are 1.17, 0.41 and 0.24 dS m^{-1}, respectively during the year 2014. The EC values were observed to be in the safe range in all the three seasons and comparatively higher mean value (1.17 dS m^{-1}) was observed in the pre-monsoon period.

4.1.1.4. Organic carbon

Not much variations in the organic carbon content were noted in the landfill materials between pre-monsoon, monsoon and post-monsoon seasons and the respective values were 2.85, 2.78 and 2.65 per cent (Table 9).

4.1.1.5. Nitrogen

The mean total nitrogen content noted from the landfill materials during pre-monsoon, monsoon and post-monsoon season were 0.11, 0.09 and 0.08 per cent, respectively (Table 9).

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4.1.1.6. Phosphorus

The mean total phosphorus content in the landfill material at Vilappilsala is presented in Table 9. Samplings conducted during pre-monsoon, monsoon and post-monsoon seasons provided 0.13, 0.07 and 0.05 per cent phosphorus, respectively.

4.1.1.7. Potassium

The mean values for total potassium content in the landfill materials during pre-monsoon, monsoon and post-monsoon season are presented in Table 9 and the respective values in these three seasons were 2.55, 1.53 and 1.43 per cent, respectively.

4.1.1.8. Aluminium

Analysis of the landfill materials for total aluminium content revealed the content of 15.46, 12.95 and 11.61 mg kg^{-1} during pre-monsoon, monsoon and post-monsoon periods, respectively with a mean of 13.34 mg kg^{-1}.

4.1.1.9. Calcium

Sampling conducted for total calcium content in the landfill materials at Vilappilsala yielded 12.73, 10.45 and 9.08 mg kg^{-1} calcium during pre-monsoon, monsoon and post-monsoon seasons, respectively (Table 9). Pre-monsoon samples recorded comparatively higher values of calcium compared to the other two seasons. However, the lowest calcium content was registered in the post monsoon period of sampling.

4.1.1.10. Magnesium

Data on the total magnesium content in the landfill material collected and analyzed during pre-monsoon, monsoon and post-monsoon seasons indicated that pre-monsoon sampling values (25.07 mg kg^{-1}) were relatively higher than the other

two seasons. The lowest magnesium content of 19.73 mg kg^{-1} was recorded from post-monsoon sampling. Monsoon samples registered a total magnesium content of 21.58 mg kg^{-1}. The total average content of magnesium of the landfill material was 22.13 mg kg^{-1} (Table 9).

4.1.1.11. Zinc

Analysis of the landfill materials for total zinc content during pre-monsoon, monsoon and post-monsoon seasons revealed a concentration of 13.64, 11.74 and 10.53 mg kg^{-1}, respectively. The pre-monsoon sample and the post-monsoon samples recorded the highest and lowest values of total zinc (Table 9).

4.1.1.12. Manganese

The mean total manganese content in the landfill material observed during pre-monsoon, monsoon and post-monsoon seasons were 13.27, 12.35 and 11.05 mg kg^{-1}, respectively with a mean total of 12.22 mg kg^{-1}. Like other observations the pre-monsoon samples recorded higher values and post-monsoon samples recorded lower value.

4.1.1.13. Copper

The mean total copper content in the landfill materials analyzed during pre-monsoon, monsoon and post-monsoon seasons were 11.45, 10.47 and 10.19 mg kg^{-1}, respectively. The same trend as observed in total zinc and total manganese were visible in this case also.

4.1.1.14. Iron

The mean total iron content observed in the landfill materials at Vilappilsala during the pre-monsoon, monsoon and post-monsoon seasons were 10.14, 8.34 and 6.61 mg kg^{-1}, respectively indicating higher levels of iron content during pre-monsoon season and comparatively lower iron content in post-monsoon season.

4.1.1.15. Lead

Analysis of the landfill material for lead revealed a mean content of 10.22, 10.16 and 10.14 mg kg^{-1} in pre-monsoon, monsoon and post-monsoon seasons, respectively. Here also the mean lead content was higher during pre-monsoon followed by monsoon season and post-monsoon season.

4.1.1.16. Cadmium

Table 9 depicts the total cadmium content available in the landfill material at Vilappilsala during pre-monsoon, monsoon and post-monsoon seasons during the year 2014. The respective cadmium content in the three seasons was 3.32, 3.27 and 2.95 mg kg^{-1}, respectively. The computation of total mean content of cadmium in three seasons was 3.18 mg kg^{-1}.

4.1.1.17. Nickel

The mean total nickel content in the landfill material at Vilappilsala during 2014 particularly over pre-monsoon, monsoon and post-monsoon season were 4.63 4.31 and 3.97 mg kg^{-1}, respectively with a total average content of 4.30 mg kg^{-1} over various seasons.

4.1.1.18. Cobalt

The cobalt content available in different seasons in the landfill material is presented in Table 9. The mean values for pre-monsoon, monsoon and post-monsoon seasons were 2.57, 2.52 and 2.37 mg kg^{-1} cobalt, respectively with a total mean content of 2.49 mg kg^{-1}. The metal fluctuations as influenced by the seasonal changes were very much similar as in the case of other metals like Pb, Cd or Ni.

4.1.1.19. Chromium

Though the total mean content of chromium over a period of three seasons in landfill materials at Vilappilsala was 4.87 mg kg^{-1}, there were individual variations in the mean metal content between pre-monsoon, monsoon and post-monsoon seasons. The mean values for chromium presented in Table 9 indicate presence of 5.05, 4.78 and 4.79 mg kg^{-1} in pre-monsoon, monsoon and post-monsoon seasons, respectively.

4.1.1.20. Mercury

The landfill material at Vilappilsala provided total mean mercury content of 5.58, 4.47 and 1.54 mg kg^{-1} in pre-monsoon, monsoon and post-monsoon seasons, respectively. A computation of the total mean content of mercury in landfill material over three seasons was 3.86 mg kg^{-1}. Pre-monsoon samples provided relatively higher values of total mercury than the other two seasons.

4.1.2. Analysis of soil samples

Table 10, 11 and 12 provide the details of physico-chemical properties of the geo-referenced soil samples collected along the leachate flowing zone within the plant area during pre-monsoon, monsoon and post-monsoon seasons. The soil samples have been collected at regular intervals of 50 m, at two depths (0-30 and 30-60 cm) from the landfill area till it joined the outside stream. By the time it reached the fourth sampling site, there was a convergence of leachate emanating from another immediately adjacent landfill site providing higher values for majority of the chemical parameters at this point.

Table 10. Physico-chemical properties of soil samples along the leachate zone within the treatment plant area (pre-monsoon period)

Samples	Depth (cm)	BD (g cc^{-1})	pH	EC (dS m^{-1})	OC (%)	Av. N	Av. P	Av. K
						(kg ha^{-1})		
Site 1 (0 m*)	0-30	1.27	5.05	0.97	0.66	275.97	32.82	190.73
	30-60	1.35	4.44	0.63	0.28	137.99	29.24	171.70
Site 2 (50 m)	0-30	1.23	5.29	0.89	0.56	263.42	28.12	180.77
	30-60	1.36	4.53	0.67	0.20	150.53	18.93	140.60
Site 3 (100 m)	0-30	1.24	5.66	0.72	0.61	188.19	24.74	149.57
	30-60	1.44	5.04	0.39	0.23	175.64	16.36	145.37
Site 4 (150 m)	0-30	1.23	5.42	0.97	0.83	401.41	43.83	233.83
	30-60	1.37	4.34	0.55	0.18	175.62	32.68	219.67
Site 5 (200 m)	0-30	1.32	5.57	0.93	0.56	351.23	37.86	224.50
	30-60	1.42	4.64	0.44	0.14	240.10	28.82	191.67
Site 6 (250 m)	0-30	1.27	6.09	0.94	0.65	338.68	34.01	204.67
	30-60	1.34	5.31	0.33	0.17	200.71	26.41	194.73
Site 7 (300 m)	0-30	1.22	6.12	0.68	0.62	301.06	29.28	135.67
	30-60	1.34	5.52	0.30	0.13	200.71	22.51	80.67
Site 8 (350 m)	0-30	1.29	6.19	0.46	0.78	225.80	26.87	90.80
	30-60	1.37	5.86	0.34	0.17	213.43	22.07	75.50
Range	0-30	1.22-1.32	5.05-6.19	0.46-0.97	0.56-0.83	188.19-401.41	24.74-43.83	90.80-233.83
	30-60	1.34-1.44	4.34-5.86	0.30-0.67	0.13-0.28	137.99-240.10	16.36-32.68	75.50-219.67

*Distance from landfill site

Table 11. Physico-chemical properties of soil samples along the leachate zone within the treatment plant area (monsoon period)

Samples	Depth (cm)	BD (g cc^{-1})	pH	EC (dS m^{-1})	OC (%)	Av. N	Av. P	Av. K
						(kg ha^{-1})		
Site 1 (0 m*)	0-30	1.27	6.26	1.03	0.56	175.62	29.24	118.73
	30-60	1.34	6.05	0.99	0.08	137.99	11.32	68.53
Site 2 (50 m)	0-30	1.29	6.77	0.75	0.62	175.62	21.53	103.47
	30-60	1.36	5.92	0.68	0.05	75.27	17.37	101.83
Site 3 (100 m)	0-30	1.27	7.52	1.53	0.75	112.83	17.37	97.63
	30-60	1.33	6.72	0.89	0.17	87.81	12.21	71.60
Site 4 (150 m)	0-30	1.33	4.17	1.88	0.65	275.97	32.82	190.73
	30-60	1.43	5.23	1.08	0.16	150.18	29.17	140.57
Site 5 (200 m)	0-30	1.38	4.72	0.99	0.69	250.91	29.99	95.37
	30-60	1.43	5.97	0.40	0.10	163.43	22.75	58.57
Site 6 (250 m)	0-30	1.35	4.77	0.19	0.71	238.34	29.95	88.60
	30-60	1.38	5.04	0.12	0.06	125.46	23.25	57.50
Site 7 (300 m)	0-30	1.25	6.53	0.13	0.75	163.08	26.66	79.67
	30-60	1.29	5.53	0.24	0.20	137.99	21.77	71.70
Site 8 (350 m)	0-30	1.34	6.81	0.32	0.26	125.44	24.34	73.73
	30-60	1.36	5.34	0.43	0.06	112.90	16.17	71.70
Range	0-30	1.25-1.38	4.17-7.52	0.13-1.88	0.26-0.75	112.83-275.46	17.37-32.82	73.73-190.73
	30-60	1.29-1.43	5.04-6.72	0.12-1.08	0.05-0.17	75.27-163.43	11.32-29.17	57.5-140.57

*Distance from landfill site

Table 12. Physico-chemical properties of soil samples along the leachate zone within the treatment plant area (post-monsoon period)

Samples	Depth (cm)	BD (g cc^{-1})	pH	EC (dS m^{-1})	OC (%)	Av. N	Av. P	Av. K
						(kg ha^{-1})		
Site 1 (0 m*)	0-30	1.23	5.91	0.90	0.71	250.89	29.69	138.77
	30-60	1.29	6.03	0.89	0.18	75.27	13.33	97.63
Site 2 (50 m)	0-30	1.31	6.07	0.74	0.63	175.30	22.07	137.73
	30-60	1.33	5.06	0.38	0.12	100.36	18.18	82.77
Site 3 (100 m)	0-30	1.30	6.94	0.69	0.14	163.08	14.45	123.67
	30-60	1.34	6.24	0.45	0.11	75.62	11.32	101.63
Site 4 (150 m)	0-30	1.38	6.93	0.93	0.70	250.89	32.26	185.53
	30-60	1.44	6.13	0.34	0.40	100.36	22.21	170.67
Site 5 (200 m)	0-30	1.32	6.72	0.97	0.66	213.25	28.52	86.57
	30-60	1.37	5.94	0.33	0.50	100.71	20.99	129.57
Site 6 (250 m)	0-30	1.28	6.44	0.63	0.68	163.08	28.05	77.70
	30-60	1.34	5.43	0.53	0.15	125.46	22.01	88.60
Site 7 (300 m)	0-30	1.27	6.10	0.53	0.47	150.53	23.16	76.43
	30-60	1.31	6.04	0.40	0.17	163.08	22.52	67.53
Site 8 (350 m)	0-30	1.31	6.07	0.58	0.53	112.90	22.36	73.67
	30-60	1.32	6.82	0.49	0.08	137.99	16.16	53.50
Range	0-30	1.23-1.38	5.91-6.94	0.53-0.97	0.14-0.70	112.90-250.89	14.45-32.26	73.67-185.53
	30-60	1.29-1.44	5.06-6.82	0.33-0.89	0.08-0.50	75.27-163.08	11.32-22.52	53.50-170.67

*Distance from landfill site

4.1.2.1. Bulk density

The bulk density values observed along the sampling path during pre-monsoon period is presented in Table 10 did not show much variation to indicate any specific influence of leachate or it's dissolved contents in altering this parameter. In the upper layer of soil, the bulk density ranged between 1.22 and 1.32 g cc^{-1}.

Similarly at the lower depth of 30-60 cm there was a general enhancement in the bulk density values all through the sampling points. At this depth the range of values remained between 1.34 and 1.44 g cc^{-1}.

During monsoon season, the bulk density of the surface soil samples (0-30 cm) along the leachate zone also didn't show apparent variations. However, at the lower depth (30-60 cm) the bulk densities of soils registered marginal enhancement in the value particularly when compared to its corresponding upper layer bulk density. The range of values in the upper layer and lower layers of sampling were between 1.25-1.38 g cc^{-1} and 1.29-1.43 g cc^{-1}, respectively.

During the post-monsoon season sampling, the range of bulk density (Table 12) observed at 0-30 cm depth was between 1.23 and 1.38 g cc^{-1}. However, at the second depth there was a marginal enhancement in the bulk density at each point of sampling compared to its corresponding upper samples. The range of values in the upper layer and lower layers of sampling were between 1.23-1.38 g cc^{-1} and 1.29-1.44 g cc^{-1}, respectively.

4.1.2.2. pH

The soil reactions at these geo-referenced sampling points generally maintained an acidic pH in surface soils during pre-monsoon period. However, there was a slight enhancement in pH as it came to the last sampling point compared to initial reference site. At the second depth of sampling it is seen that all the soil samples maintained comparatively lower pH value than its corresponding upper sample. The range of pH observed in soil samples collected between 0-30 cm was in the range of 5.05 to 6.19; while that from 30-60 cm were 4.34 to 5.86.

The variations in pH of soil samples along the leachate zone as influenced by the distance from the landfill site as well as its corresponding values at lower depth (30-60 cm) during monsoon season are presented in Table 11. In general, these

values, when compared with the pre-monsoon period were generally higher in pH at both depths particularly in the first three sampling points. However, at the fourth sampling points and other subsequent sampling points thereof had maintained more acidic nature. The range of values in upper and lower layer samples during monsoon period remained between 4.17-7.52 and 5.04-6.72, respectively.

Soil reactions in the samples along the sampling site generally remained in slightly acidic range in post-monsoon season also, with pH values ranging between 5.91 and 6.94 in surface layers and at the second depth the soil reactions maintained more or less similar trend with slightly lesser pH values. Compared to pre-monsoon or monsoon season, post-monsoon values were marginally higher. The range of pH values observed during post-monsoon season at the lower depth was 5.06 to 6.82 and at the upper layer, pH ranged between 4.17 and 7.52.

4.1.2.3. Electrical conductivity

The electrical conductivity observed during the pre-monsoon period in the soil samples collected from two depths at the sampling points indicated normal values (Table 10). However, there was a relative decline in the EC values recorded in the lower depths compared to its corresponding upper layer values. The EC values at 0-30 cm and 30-60 cm were in the range 0.46 to 0.97 and 0.30 to 0.67 dS m^{-1}, respectively.

The electrical conductivity values in the soil samples collected during the monsoon season also remained normal at the two depths of study (Table 11). Though normal, there was a tendency in showing decreased EC values as the sampling points moved towards the periphery of the treatment plant. Compared to pre-monsoon values, erratic fluctuations in the EC values could be noted during the monsoon period. The EC values at 0-30 cm and 30-60 cm were in the range 0.13-1.88 dS m^{-1} and 0.12-1.08 dS m^{-1}, respectively.

The electrical conductivity values in post-monsoon season at both depths also remained normal and safe (Table 12). The range of EC values existed over the samples was 0.53-0.97 dS m^{-1} in 0-30 cm depth and that for 30-60 cm depth were 0.33-0.89 dS m^{-1}. Compared to monsoon period there was stabilization observed in EC values during post-monsoon period at both depths.

4.1.2.4. Organic carbon

The organic carbon levels at two depths of soil along the leachate zone of Vilappilsala treatment plant during the pre-monsoon period of 2014 is depicted in Table 10. The result indicated that the organic carbon in upper sampling zone appeared to be normal and the values ranged between 0.56 to 0.83 per cent. However, the organic carbon levels at the lower layers (30-60 cm) were considerably lower than upper layer values. The range was maintained between 0.13 and 0.28 per cent at this depth.

The organic carbon content in the upper layers of leachate zone during the monsoon period ranged between 0.26 and 0.75 per cent and at the lower depth of sampling the range was between 0.05 and 0.17 per cent. Marginal fluctuations in organic carbon values were noted between surfaces samples while the amount of organic carbon in lower depth of sampling was considerably lower at all point of comparison.

The variations in the organic carbon content in the soil samples along the leachate zone at fixed distance particularly between two soil depths during post-monsoon season are presented in Table 12. The data indicated that these values generally represent low status in majority of the samples and medium status in isolated sampling points. The range of values in 0-30 cm and 30-60 cm depths were 0.14-0.70 per cent and 0.08-0.50 per cent, respectively. The organic carbon levels were generally lower at the sampling points both in upper and lower layers.

4.1.2.5. Available nitrogen

The available nitrogen status in the leachate zone at two depths namely 0-30 and 30-60 cm during pre-monsoon season are provided in Table 10. The results indicated that there was a general decline in the available nitrogen status in all the lower layer sampling compared to its corresponding upper layers. The available nitrogen status appeared to have decreased with the distance from the landfill site till the fourth sampling point where there was convergence of effluents from the adjacent landfill site which incidentally recorded the highest available nitrogen content of 401.41 kg ha^{-1}. The subsequent surface sampling site from this point recorded a decrease in the available nitrogen status up to the last sampling site. However, this trend observed in the surface samples cannot be visualized at the lower depth though the range varied between 137.99 to 240.10 kg ha^{-1}.

The available nitrogen status in the soil samples collected and analyzed at two depths along the leachate zone during the monsoon period (Table 11) were generally lower when compared with the corresponding samples in pre-monsoon period. The fourth soil sample which incidentally recorded comparatively higher available nitrogen status was collected from the convergence point of effluent emanating from an adjacent landfill within the plant area. Thereafter in the soil samples the available nitrogen status registered a steady decline. At any lower depth the available nitrogen status maintained lower values (ranged between 75.27 and 163.43 kg ha^{-1}) compared to its corresponding upper layer available nitrogen status (ranged between 112.83 and 275.46 kg ha^{-1}).

The available nitrogen status in the soil samples analyzed at two depths during post-monsoon period maintained low status of available nitrogen with a range of 112.90 to 250.89 kg ha^{-1} in the 0-30 cm depth and 75.27 to 163.08 kg ha^{-1} in 30-60 cm depth. Compared to monsoon period, post-monsoon period could not register

much variation in the available nitrogen status. However, there was a marginal decrease in the available nitrogen status at the lower depth of the study area.

4.1.2.6. Available phosphorus

The available phosphorus status in the upper layer soil samples during pre-monsoon period registered a decrease in the available phosphorus content up to the fourth sampling point which registered the maximum value of 43.83 kg ha^{-1}. Subsequent sampling values when compared with the observed fourth sampling point registered a gradual decline in the available phosphorus content. The soil samples collected from 30-60 cm depth recorded comparatively lower values than its upper counterpart. The range of available phosphorus at this depth varied between 16.36 to 32.68 kg ha^{-1}. The range of available phosphorus at the surface soils ranged between 24.74 to 43.83 kg ha^{-1}.

The data on the available phosphorus status at the two depths of study along the leachate zone at specific intervals during the monsoon period indicated that these values were generally lower than its corresponding value during the pre-monsoon period (Table 11). There was a general decrease in the available phosphorus status at the lower depth as compared to the upper layer as indicated in Table 11. The range of values in the upper layer ranged between 17.37 and 32.82 kg ha^{-1} and that in lower layer was between 11.32 and 29.17 kg ha^{-1}. The fourth soil samples which incidentally represent the confluence point recorded the highest available phosphorus status (32.82 kg ha^{-1} and 29.17 kg ha^{-1} in the upper and lower layers, respectively).

There had been fluctuations in the available phosphorus status along the sampling points in the surface layer samples of 0-30 cm depth during post-monsoon period (Table 12). Higher phosphorus status at the first sampling site near the landfill area recorded a value of 29.69 kg ha^{-1} which gradually declined till the third sampling point and there after registered a spurt in the available phosphorus status touching a level of 32.26 kg ha^{-1} which coincided with the merger of effluents from an adjoining

landfill. Later samples collected along the leachate line registered succeedingly lower values with subsequent sampling. The lower depth of sampling maintained comparatively lower levels of available phosphorus and did not reflect any particular trend.

4.1.2.7. Available potassium

The available potassium status at two depths along the leachate zone of the Vilappilsala landfill site observed during the pre-monsoon period is prescribed in Table 10. There was a comparative decrease in available potassium status at the lower layers than its corresponding upper layer values. The available potassium status in the upper layers showed a decrease in trend till the fourth sampling points which incidentally recorded the highest value of 233.83 kg ha^{-1}. Later on at the subsequent sampling points of upper layers, there was a gradual decline. The range of available potassium in upper layers was 90.80 to 233.83 kg ha^{-1} and that for the lower layers were in the range 75.50 to 219.67 kg ha^{-1}.

Compared to pre-monsoon period all the samples collected and analyzed in monsoon period recorded generally lower values at both depths (Table 11). The tendency to record lower available potassium status with enhancement in distance of sampling from the landfill site was evident in this case also except in the case of fourth sampling point. Like other parameters the soils at lower depth recorded comparatively lower values than its corresponding upper layer values. The range of available potassium in upper layers was 73.73 to 190.73 kg ha^{-1} and that for the lower layers were in the range 57.5 to 140.57 kg ha^{-1}.

The available potassium status in the surface soils along the leachate zone during the post-monsoon period gradually decreased with increase in distance from the landfill site up to the third point of sampling and later increased to 185.53 kg ha^{-1} at the fourth sampling point. Thereafter, a gradual decline in available potassium status was noted all along the subsequent sampling points. At the second depth of

sampling a similar trend was visible but the individual potassium status at any point of sampling was comparatively lesser than its corresponding upper layer sample. The potassium status at both levels was observed to be in the low to medium range.

The available status of secondary nutrients and various heavy metals content along the leachate zone within the plant area at regular interval of 50 m during pre-monsoon, monsoon and post-monsoon periods at two depths of study are presented in Table 13, 14 and 15.

4.1.2.8. Available calcium

The available status of calcium in pre-monsoon season was very low at both depths, with lower depth recording marginally lower values than its corresponding upper layer. The range of available calcium status in 0-30 cm depth was 1.91 to 2.76 mg kg^{-1} and that in 30-60 cm depth was 0.96 to 1.94 mg kg^{-1}.

During monsoon period it is seen that both upper layer and lower layer status of available calcium were very low. Compared to upper layer, the lower layer incidentally registered marginally lower concentration of calcium at all sampling site. The range of available calcium status in 0-30 cm depth was 1.26-2.15 mg kg^{-1} and that in 30-60 cm depth was 0.77-1.85 mg kg^{-1}. Compared to pre-monsoon period, monsoon period registered comparatively lower calcium status at both depths of study.

The available calcium content in post-monsoon season samples ranged between 1.04-1.94 mg kg^{-1} and 0.74-1.66 mg kg^{-1} in upper and lower layer samples, respectively. Compared to pre-monsoon and monsoon period, the available calcium status during post-monsoon was relatively lower at both depths. Compared to upper layer, lower layer samples maintained lower content of available calcium.

Table 13. Depth wise variation in extractable level of secondary nutrients and other metals of soil samples (pre-monsoon period)

Samples	Depth (cm)	Ca	Mg	Zn	Mn	Cu	Fe	Al	Pb	Cd	Ni	Co	Cr	Hg
		mg kg^{-1}												
Site 1 (0 m*)	0-30	2.18	6.85	5.83	18.75	0.39	11.22	20.93	0.85	0.22	0.28	0.60	0.52	1.50
	30-60	1.07	5.37	1.95	5.13	0.20	5.16	5.21	0.42	0.01	0.13	0.33	0.22	1.01
Site 2 (50 m)	0-30	2.12	6.54	2.69	17.18	0.35	10.36	15.12	0.73	0.11	0.24	0.41	0.40	1.39
	30-60	0.96	4.87	2.12	2.58	0.15	2.29	3.28	0.19	0.10	0.11	0.28	0.19	1.13
Site 3 (100 m)	0-30	1.91	6.08	2.04	12.50	0.34	9.27	13.59	0.71	0.09	0.13	0.30	0.33	1.17
	30-60	0.97	4.07	2.19	2.22	0.12	2.40	1.29	0.30	0.01	0.13	0.13	0.18	1.09
Site 4 (150 m)	0-30	2.76	6.85	6.79	19.13	1.28	12.29	22.41	1.58	0.25	0.41	0.60	0.57	4.42
	30-60	1.94	5.75	2.94	4.21	0.30	4.29	5.83	0.82	0.09	0.20	0.47	0.21	3.42
Site 5 (200 m)	0-30	2.37	6.08	5.47	18.05	0.42	9.39	15.37	1.12	0.24	0.26	0.32	0.39	3.37
	30-60	1.86	5.57	1.83	2.45	0.27	3.23	3.24	0.44	0.05	0.14	0.44	0.14	3.08
Site 6 (250 m)	0-30	2.20	5.67	3.13	9.87	0.41	9.70	13.10	0.99	0.19	0.24	0.31	0.39	1.45
	30-60	1.76	5.10	1.43	2.41	0.25	2.17	1.18	0.43	0.06	0.11	0.30	0.13	1.05
Site 7 (300 m)	0-30	2.15	5.29	3.12	7.90	0.35	5.95	10.29	0.93	0.11	0.24	0.24	0.33	1.35
	30-60	1.65	5.16	1.90	2.21	0.23	1.09	1.01	0.29	0.06	0.11	0.22	0.22	0.95
Site 8 (350 m)	0-30	2.08	4.86	2.50	3.61	0.33	4.60	5.12	0.52	0.02	0.22	0.22	0.25	1.29
	30-60	1.55	4.56	1.53	2.03	0.21	0.70	1.00	0.23	0.01	0.15	0.21	0.22	0.82
Range	0-30	1.91-2.76	4.86-6.85	2.04-6.79	3.61-19.13	0.33-1.28	4.60-12.29	5.12-22.41	0.52-1.58	0.02-0.25	0.13-0.41	0.22-0.60	0.25-0.57	1.17-4.42
	30-60	0.96-1.94	4.07-5.75	1.43-2.94	2.03-5.13	0.12-0.30	0.70-5.16	1.00-5.83	0.19-0.82	0.01-0.10	0.11-0.20	0.13-0.47	0.13-0.22	0.82-3.42

*Distance from landfill site

Table 14. Depth wise variation in extractable level of secondary nutrients and other metals of soil samples (monsoon period)

Samples	Depth (cm)	Ca	Mg	Zn	Mn	Cu	Fe	Al	Pb	Cd	Ni	Co	Cr	Hg
		mg kg^{-1}												
Site 1 (0m*)	0-30	1.67	4.46	1.65	11.73	0.40	9.17	8.26	0.15	0.02	0.11	0.17	0.05	0.34
	30-60	0.96	3.96	1.52	2.89	0.11	3.02	2.20	0.21	ND	0.05	0.13	0	0.21
Site 2 (50m)	0-30	1.56	4.16	1.10	11.45	0.31	8.30	8.20	0.11	0.01	0.10	0.15	0.03	0.21
	30-60	0.77	3.56	1.13	1.83	0.06	0.69	0.95	0.07	ND	0.04	0.05	0.03	0.05
Site 3 (100m)	0-30	1.26	3.85	0.49	9.67	0.24	6.56	6.20	0.09	0.01	0.09	0.08	ND	0.08
	30-60	0.86	3.06	0.33	1.41	0.13	0.34	0.64	0.13	ND	0.06	0.06	ND	0.06
Site 4 (150m)	0-30	2.15	4.96	2.75	16.67	0.62	9.31	12.87	0.65	0.05	0.17	0.27	0.22	2.08
	30-60	1.85	3.28	2.03	1.78	0.25	2.86	2.17	0.29	0.04	0.06	0.11	0.21	0.31
Site 5 (200m)	0-30	2.08	4.09	2.32	15.23	0.31	5.29	10.64	0.51	0.05	0.14	0.15	0.01	1.21
	30-60	1.74	3.23	1.32	1.36	0.21	0.87	0.42	0.21	0.03	0.05	0.02	ND	0.09
Site 6 (250m)	0-30	1.96	3.95	1.79	2.47	0.20	5.18	6.91	0.31	0.05	0.13	0.12	ND	0.67
	30-60	1.66	3.48	0.99	0.21	0.10	0.35	0.43	0.28	ND	0.01	0.06	0.09	0.13
Site 7 (300m)	0-30	1.87	3.06	1.09	1.89	0.15	2.44	4.13	0.26	0.05	0.11	0.06	ND	0.49
	30-60	1.46	2.59	0.82	0.55	0.11	0.25	0.35	0.13	0.02	0.02	0.06	0.01	0.24
Site 8 (350m)	0-30	1.76	2.50	0.47	0.87	0.11	1.31	1.27	0.19	0.01	0.06	0.02	ND	0.22
	30-60	1.26	2.17	0.14	0.11	0.22	0.22	0.17	0.22	ND	0.03	0.06	0.02	0.14
Range	0-30	1.26-2.15	2.50-4.96	0.47-2.75	0.87-16.67	0.11-0.62	1.31-9.31	1.27-12.87	0.09-0.65	0.01-0.05	0.03-0.17	0.02-0.27	0-0.22	0.08-2.08
	30-60	0.77-1.85	2.17-3.96	0.14-2.03	0.11-2.89	0.06-0.25	0.22-3.02	0.17-2.20	0.07-0.29	0-0.04	0.01-0.06	0.02-0.13	0-0.21	0.05-0.31

*Distance from landfill site, ND-Not Detected

Table 15. Depth wise variation in extractable level of secondary nutrients and other metals of soil samples (post-monsoon period)

Samples	Depth (cm)	Ca	Mg	Zn	Mn	Cu	Fe	Al	Pb	Cd	Ni	Co	Cr	Hg
		mg kg^{-1}												
Site 1 (0 m*)	0-30	1.08	4.15	0.45	8.29	0.32	10.33	15.35	0.13	0.04	0.17	0.28	0.02	0.67
	30-60	0.85	3.08	1.13	4.25	0.13	3.31	4.40	0.07	0.04	0.11	0.19	0.01	1.19
Site 2 (50 m)	0-30	1.05	4.07	0.17	2.41	0.30	10.23	12.55	0.09	0.03	0.12	0.17	0.01	0.44
	30-60	0.74	2.97	0.17	1.31	0.11	1.99	1.29	0.15	0.02	0.04	0.16	0.01	0.42
Site 3 (100 m)	0-30	1.04	3.49	0.14	1.29	0.24	7.36	11.28	0.04	0.02	0.06	0.10	0.01	0.23
	30-60	0.75	2.47	1.17	1.79	0.07	1.12	0.85	0.05	0.01	0.04	0.09	0.01	0.24
Site 4 (150 m)	0-30	1.94	4.08	3.06	12.95	0.44	10.45	18.30	1.07	0.12	0.23	0.36	0.44	4.02
	30-60	1.66	3.15	1.82	4.15	0.24	3.15	4.00	0.18	0.06	0.16	0.28	0.10	2.38
Site 5 (200 m)	0-30	1.58	3.86	2.42	8.93	0.40	8.60	12.49	1.05	0.05	0.16	0.26	0.13	2.18
	30-60	1.58	2.69	1.41	2.10	0.19	1.35	1.29	0.12	0.05	0.13	0.24	0.05	2.00
Site 6 (250 m)	0-30	1.57	3.27	2.32	5.25	0.34	8.57	10.01	0.99	0.04	0.16	0.18	0.10	0.95
	30-60	1.52	3.08	1.33	1.23	0.14	1.49	0.99	0.05	0.03	0.10	0.13	0.02	0.63
Site 7 (300 m)	0-30	1.28	3.21	1.93	4.68	0.19	4.86	9.26	0.57	0.03	0.13	0.15	0.10	0.52
	30-60	1.27	2.48	1.53	1.37	0.22	0.59	0.72	0.02	0.02	0.09	0.12	0.01	0.22
Site 8 (350 m)	0-30	1.13	2.45	1.85	2.52	0.19	2.22	3.92	0.43	0.01	0.10	0.12	0.05	0.46
	30-60	1.21	2.16	1.32	1.01	0.20	0.20	0.26	0.03	0.02	0.09	0.11	0.05	0.07
Range	0-30	1.04-1.94	2.45-4.15	0.17-3.06	1.29-12.95	0.19-0.44	2.22-10.45	3.92-18.30	0.04-1.07	0.01-0.12	0.10-0.23	0.12-0.36	0.01-0.44	0.23-4.02
	30-60	0.74-1.66	2.16-3.15	0.17-1.82	1.01-4.25	0.07-0.24	0.20-3.31	0.26-4.40	0.02-0.18	0.01-0.06	0.04-0.16	0.10-0.28	0.01-0.10	0.07-2.38

*Distance from landfill site

4.1.2.9. Available magnesium

Along the designated sampling points and at both depths of study, secondary nutrients like available calcium and the available magnesium status too remained very low with lower depth samples maintaining marginally low values than its corresponding upper counterpart. It is seen that the range of available magnesium in the leachate zone was between 4.86- 6.85 mg kg^{-1} in the upper layer and 4.07-5.75 mg kg^{-1} in the lower layer, respectively.

During the monsoon season, also soils at both depths maintained lower values of available magnesium (Table 14) especially when compared with that of the other two seasons of study. It is seen that the range of available magnesium in the leachate zone was between 2.50-4.96 mg kg^{-1} in the upper layer and 2.17-3.96 mg kg^{-1} in the lower layer respectively.

The available magnesium status of soil samples provided in Table 15 ranged between 2.45-4.15 mg kg^{-1} and 2.16-3.15 mg kg^{-1} in upper and lower layers respectively. All the soil samples in surface layer and lower layer were deficient in magnesium content when classified under the fertility status of the soil.

4.1.2.10. Available zinc

The available zinc status depicted in Table 13 representing the soil samples collected at regular intervals and at two depths of study showed a range of 2.04-6.79 mg kg^{-1} in upper layer and 1.43-2.94 mg kg^{-1} lower layers. Though zinc can be considered both as a heavy metal and as a micronutrient, it's content in the leachate zone tantamount to sufficiency range in majority of the surface samples. However, at the lower depth it indicates deficiency range in majority of the sampling points.

The available zinc status observed during the monsoon period along the leachate zone at two depths of study is depicted in Table 14. Available zinc status in upper layer ranged between 0.47-2.75 mg kg^{-1} and in second depth of sampling

ranged between 0.14-2.03 mg kg^{-1}. Most of the samples falls under sufficiency range in both upper and lower layers as far as zinc is concerned. Further it was observed that as the distance of sampling points increased from the landfill site there was a corresponding decrease in availability if zinc at the two depths of study. Compared to pre-monsoon status of available zinc the monsoon period registered marginally lower values in the other two seasons.

The available zinc status when monitored during post monsoon period at two depths of study revealed that the entire metallic status maintained lower concentration than pre-monsoon and monsoon seasons. The zinc load in soil was found to decline with enhancement in distance from the landfill area except at the fourth sampling point. When the zinc status was rated according to the fertility status the range could be fixed into sufficiency range both in upper and lower layers.

4.1.2.11. Available manganese

The available manganese status in soil samples along the leachate zone during pre-monsoon season maintained a range between 3.61-19.13 mg kg^{-1} in upper layer samples and 2.03-5.13 mg kg^{-1} in lower layer samples. The higher values of 18.75 and 19.13 mg kg^{-1} were reported from the 1^{st} and 4^{th} sampling point which incidentally coincided with border of landfill site and later at the convergence point of the effluent from the second adjacent landfill. At the second depth of sampling there was a considerable reduction in available manganese status at all points compared to its corresponding upper layer.

The available manganese status in soil samples along the leachate zone in monsoon season maintained a range between 0.87-16.67 mg kg^{-1} in upper layer samples and 0.11-2.89 mg kg^{-1} in the lower layer samples (Table 14). At the second depth of sampling there was a considerable reduction in available manganese status at all points compared to its upper layer samples. All monsoon season samples recorded low manganese status in comparison with pre-monsoon samples.

The available manganese status in soil samples along the leachate zone during post-monsoon period maintained a range between 1.29-12.95 mg kg^{-1} in upper layer and 1.01-4.25 mg kg^{-1} in the lower layer. At the second depth of sampling, there was a considerable reduction in available manganese status at all points compared to its corresponding upper layer. The manganese status range observed during post-monsoon season was lower when compared to pre-monsoon and monsoon period.

4.1.2.12. Available copper

The available copper content at all sampling points irrespective of the depth of sampling, maintained very low values during pre-monsoon season. When this status of metal if equated to the status of a micronutrient, the rating will tip these contents to the deficiency level except in the 4th sampling site (upper layer). The range of values in upper layer samples and lower layer samples were 0.33-1.28 mg kg^{-1} and 0.12-0.30 mg kg^{-1}, respectively.

The available copper status during the monsoon season in two depths of study is provided in Table 14. The available copper status in the upper layer ranged between 0.11-0.62 mg kg^{-1} and that in lower layer ranged between 0.06-0.25 mg kg^{-1}. As observed for other heavy metals, the trend in availability seemed to be lower in monsoon season compared to pre-monsoon period.

The available copper status which represented the post-monsoon seasons at different points particularly at two depths is given in Table 15. The available copper values ranged between 0.19-0.44 mg kg^{-1} and 0.07-0.24 mg kg^{-1} in upper and at lower layer samples, respectively. As in case of the manganese, the copper content also remained low in post-monsoon season than the pre-monsoon and monsoon seasons.

4.1.2.13. Available iron

In general, during pre-monsoon the iron content of surface samples maintained a sufficiency level particularly when it is viewed as a micronutrient.

However, majority of the iron status observed from the lower layer samples maintained deficiency range while equating its status as micronutrient. Range of iron content in samples from 0-30 cm depth was 4.60-12.29 mg kg^{-1} and that from 30-60 cm depth were 0.70-5.16 mg kg^{-1}.

During the monsoon period, the iron content in the upper layer soil samples maintained comparatively higher values than the corresponding lower layer. Iron content of samples was marginally lesser in the pre-monsoon period at all sampling points. At 0-30 cm depth the available iron content ranged between 1.31-9.31 mg kg^{-1} and that at 30-60 cm depth was 0.22-3.02 mg kg^{-1}.

During post-monsoon season also, the iron content in soil samples from the upper layer maintained comparatively higher values than the corresponding lower layer samples. Though most of the samples in upper layer are sufficient in available iron status, the lower layer indicates a deficiency range. Range of iron content in samples at 0-30 cm depth was 2.22-10.45 mg kg^{-1} and that at 30-60 cm depth was 0.20-3.31 mg kg^{-1}.

4.1.2.14. Extractable aluminium

The aluminium status in the leachate zone within the plant area maintained comparatively higher values in the upper layer of sampling than the corresponding lower layer. The range of aluminium observed between upper and lower layers were 5.12-22.41 mg kg^{-1} and 1.00-5.83 mg kg^{-1}, respectively. Like other observations the confluence point of the effluent at the 4^{th} sampling point maintained the highest value of 22.41 mg kg^{-1} aluminium in the upper layer. Similarly, its corresponding lower layer maintained one of the highest values of 5.83 mg kg^{-1} among the other lower layer samples.

During monsoon season also, the aluminium status in the upper layer of sampling maintained comparatively higher values than the corresponding lower layer.

The range of aluminium in upper layer from the study area varied between 1.27-12.87 mg kg^{-1} while that in the lower layer was between 0.17 and 2.20 mg kg^{-1}. The highest content of aluminium noted at the 4th sampling point was a confluence point of another effluent leachate path from the adjacent landfill area.

The post-monsoon status also maintained similar trend with the upper layer samples maintaining comparatively higher values than the corresponding lower layer. The range of aluminium values remained between 3.92-18.30 mg kg^{-1} and 0.26-4.40 mg kg^{-1} in upper layer and lower layer, respectively. Unlike other ions, the general content of aluminium was increased in post-monsoon season both in upper and lower layer than the monsoon season samples. The highest content of aluminium (18.30 mg kg^{-1}) was observed at the 4th sampling point.

4.1.2.15. Extractable lead

The extractable lead status in the surface soils in the leachate zone during pre-monsoon period maintained a range of 0.52 to 1.58 mg kg^{-1}. The corresponding lead status at respective lower layer sampling site was much lesser at all points and the metal content was within a range of 0.19-0.82 mg kg^{-1}.

During monsoon period, the extractable lead status in the upper and lower layer soils maintained a range between 0.09-0.65 mg kg^{-1} and 0.07-0.29 mg kg^{-1}, respectively. Monsoon season registered comparatively lower values than the pre-monsoon samples.

The lead status during post-monsoon season registered marginally higher values in upper layer samples than the monsoon period. The observed range of the metal in upper layer was between 0.04-1.07 mg kg^{-1} and that in the lower layer between 0.02-0.18 mg kg^{-1}.

4.1.2.16. Extractable cadmium

The extractable cadmium status in the soil samples of leachate zone at two depths of study were within the safe limit in pre-monsoon period. The range of values in upper layer and lower layer were 0.02-0.25 mg kg^{-1} and 0.01-0.10 mg kg^{-1}, respectively. The highest cadmium content, both in upper and lower layer soils were registered in the fourth sampling point.

Though the extractable cadmium status in the upper layer soils in the leachate zone of Vilappilsala during monsoon season ranged between 0.01 and 0.05 mg kg^{-1}, many of its corresponding lower layer samples failed to detect the presence of cadmium. This is particularly true at the tail end samples in the leachate flow zone. However, the maximum content of cadmium was observed in fourth point (0.05 mg kg^{-1} in upper layer and 0.04 mg kg^{-1} in lower layer).

The extractable cadmium status in the upper layer soils in the leachate flow zone during post-monsoon season ranged between 0.01-0.12 mg kg^{-1} and that in lower layer soils were 0.01-0.06 mg kg^{-1}. Here also the content of cadmium was observed to be relatively higher in the post-monsoon season than the monsoon season samples. The cadmium content in the lower layer were marginally lower than its upper layer and these values showed a decline in content in the lower layer towards the tail end of the leachate flow.

4.1.2.17. Extractable nickel

The nickel status in the soil samples of leachate zone at two depths of study during pre-monsoon season were within the safe limit. The range of values in upper layer and lower layer were 0.13-0.41 mg kg^{-1} and 0.11-0.20 mg kg^{-1}, respectively.

The nickel status in upper layer samples during monsoon season ranged between 0.03-0.17 mg kg^{-1} and in lower layer the concentrations ranged between

0.01-0.06 mg kg^{-1}. These range of values observed at both depths were comparatively lower than the values recorded during pre-monsoon period.

The nickel status in upper layer samples during post-monsoon period ranged between 0.10-0.23 mg kg^{-1} and that in lower layer ranged between 0.04-0.16 mg kg^{-1} which is higher than the monsoon season samples with the highest value of 0.23 mg kg^{-1} in upper layer and 0.16 mg kg^{-1} in lower layer in the fourth sampling site. After the fourth sampling point the trend in availability of nickel was seen to decrease with advancement in distance towards the tail end portion.

4.1.2.18. Extractable cobalt

The range of values in upper layer and lower layer during pre-monsoon period were 0.22-0.60 mg kg^{-1} and 0.13-0.47 mg kg^{-1}, respectively. In surface soil samples the highest value of 0.60 mg kg^{-1} recorded in first and fourth sampling points. However, in lower layer samples, the highest value (0.47 mg kg^{-1}) was recorded in fourth sampling point.

The range of cobalt status in the soil samples of leachate zone at two depths of study during monsoon season were 0.02-0.27 mg kg^{-1} and 0.02-0.13 mg kg^{-1} in upper and lower layers, respectively (Table 14).

The cobalt status in upper layer soils during post-monsoon period enhanced and ranged between 0.12-0.36 mg kg^{-1} and 0.10-0.28 mg kg^{-1} in upper and lower layer soils, respectively (Table 15).

4.1.2.19. Extractable chromium

The range of chromium status in the soil samples of leachate zone at two depths of study in upper layer and lower layer during pre-monsoon period were 0.25-0.57 mg kg^{-1} and 0.13-0.22 mg kg^{-1}, respectively. In case of surface soils, the highest

value of 0.57 mg kg^{-1} was registered in fourth sampling point while in lower layer samples the highest value, 0.22 mg kg^{-1} was observed in the first sampling point.

Though the chromium values ranged between 0 to 0.22 mg kg^{-1} in upper layer during the monsoon season, the maximum value was recorded in 4th sampling point. There after it is seen that the chromium content could not be detected in any further surface samples. However, the lower layer samples maintained chromium metals at all points of sampling irrespective whether its upper counterpart contained chromium or not. Monsoon season maintained lower concentration of chromium compared to pre-monsoon season.

Unlike the monsoon season, the presence of chromium could be ensured at all sampling points in the upper and lower soil layers. The range of chromium in upper layer soils ranged between 0.01-0.44 mg kg^{-1} while its range in lower layer was 0.01-0.10 mg kg^{-1}.

4.1.2.20. Extractable mercury

Compared to lead, cadmium, nickel, cobalt and chromium, the mercury levels in the soil samples were quite high generally at all surface sampling points. But the lower layer samples also indicated a similar trend with marginally lower values. The mercury range in surface samples during pre-monsoon period was observed to be between 1.17 and 4.42 mg kg^{-1} and that in lower layer were 0.82-3.42 mg kg^{-1} (Table 13). The highest mercuric content in upper (4.42 mg kg^{-1}) and lower (3.42 mg kg^{-1}) layer samples were observed in fourth sampling point.

Compared to pre-monsoon period, monsoon period registered a lower presence of mercury in all the surface layer samples. Compared to upper layer values, the lower layers maintained relatively lower concentration of mercury at all points of study. The highest value of 2.08 mg kg^{-1} mercury was reported from the 4th sampling point and there after its level decreased towards the tail end of the leachate zone. The

range of mercury in upper layer samples were 0.08-2.08 mg kg^{-1} and that in lower layer samples was 0.05-0.31 mg kg^{-1}.

The concentration of mercury in the leachate zone was found to generally increase during the post-monsoon season in both the layers compared to monsoon season. The range of mercury varied in the upper layer between 0.23-4.02 mg kg^{-1} and that in the lower layer between 0.07-2.38 mg kg^{-1}. Compared to upper layers, the lower layers presented relatively lower values.

4.1.3. Analysis of leachate samples

The main social problem that existed in and around the Vilappilsala garbage treatment plant during the functional period was from two counts; one is the bad quality of air and the other is the indiscriminate flow of leachate from the landfill area to lower regions contaminating the canals (*Meenampally thodu*) and the adjacent drinking water sources on either side of the canal, particularly outside the plant area, where human inhabitation is high. It is in this background that detailed chemical and biological examination of this leachate was attempted three years after the closure of the plant. Details on pH, EC and TDS of the leachate at geo-referenced points identified at successive 50 m distance from the landfill area towards a distance of half a km through the plant area is presented in Table 16.

Table 16. Seasonal variations in chemical properties of leachates along the leachate zone

Samples	pH			EC (dS m^{-1})			TDS (g L^{-1})		
	Pre	Mon	Post	Pre	Mon	Post	Pre	Mon	Post
Site 1 (0*m)	7.97	8.04	6.17	9.79	0.76	2.42	0.25	0.10	0.14
Site 2 (50 m)	8.47	7.97	6.92	2.28	0.73	0.89	0.05	0.07	0.08
Site 3 (100 m)	8.17	8.05	6.96	1.07	0.73	0.31	0.03	0.06	0.06
Site 4 (150 m)	7.95	8.66	6.87	9.86	1.81	5.79	0.52	0.12	0.17
Site 5 (200 m)	8.08	8.07	6.96	3.07	1.49	1.81	0.08	0.10	0.08
Site 6 (250 m)	8.19	7.79	6.96	2.32	1.46	0.99	0.05	0.07	0.08
Site 7 (300 m)	8.12	7.57	6.47	2.02	1.36	0.73	0.04	0.07	0.06
Site 8 (350 m)	8.16	8.02	6.51	1.91	0.92	0.54	0.04	0.06	0.06
Site 9 (400 m)	7.58	8.06	6.25	1.43	0.33	0.54	0.04	0.06	0.06
Site 10 (450 m)	7.36	5.74	6.10	0.99	0.12	0.44	0.03	0.06	0.06
Site 11 (500 m)	7.24	5.36	5.91	0.83	0.11	0.24	0.03	0.06	0.06
Mean	7.94	7.58	6.55	3.23	0.80	1.34	0.11	0.08	0.08
Range	7.24-8.47	5.36-8.66	5.91-6.96	0.83-9.86	0.11-1.81	0.24-5.79	0.03-0.52	0.06-0.12	0.06-0.17
Standard**	5.5-9.0			4.00			2.1		

*Distance from the landfill site **As per Solid Waste Management rules 2016

4.1.3.1. pH

It can be seen that the pH of the leachate in the pre-monsoon and the monsoon period were exclusively alkaline within the plant area. But outside the plant area the pH was seen to decline towards acidic range during the monsoon period. The post-monsoon samples were acidic in reaction irrespective of the samples collected from inside the treatment plant or outside. During the pre-monsoon period the range of pH observed within the plant area particularly between site 1 and site 8 with a distance of 300 m ranged between 7.97 and 8.47. But as the distance increased and effluent

started moving outside the plant area, the samples offered a shift towards lesser pH values which ranged between 7.24 and 7.58.

During the monsoon period, the pH values of most of the leachate samples within the plant area particularly between sites 1 and 8 remained more or less alkaline and as the effluent gradually drifted outside the plant area, the pH shifted to acidic range. Accordingly, the range of pH value observed between sites 1 to 8 within a distance of 350 m was between 7.57 and 8.66 while the pH between site 9 and 11 outside the plant area ranged between 5.36 and 8.06. The pH of leachate samples examined during the post-monsoon period maintained comparatively lesser values in the near neutral range between site 1 and site 8 (within the plant area) and thereafter, the pH shifted towards a still lower value. In general, it was observed that the monsoon and post-monsoon samples registered acidic pH particularly outside the plant area.

4.1.3.2. Electrical conductivity

The EC of the leachate in the pre-monsoon period was quite high in many of the samples, particularly in the ones closer to the landfill area. At the 4^{th} sampling site, where the effluent from the adjoining landfill also increase the conductivity to the highest value of 9.86 dS m^{-1} and thereafter at every succeeding sampling points a decline in EC values could be observed. However, all the samples collected outside the plant area have low EC values. There was drastic reduction in EC values during the monsoon period in almost all the samples within the plant area and still further reduction in EC values in samples outside the plant area. The observed mean range of EC values varied between 0.11 and 9.86 dS m^{-1}. Compared to monsoon period, post-monsoon samples of leachate maintained relatively higher EC values in majority of the samples and only few samples were not in safe range.

4.1.3.3. Total dissolved solids

The total dissolved solid (TDS) content in the leachate sample during the pre-monsoon, monsoon and post-monsoon seasons were very low and the values were lesser in monsoon period. During pre-monsoon season, except for the 4th sampling point, all TDS values ranged between 0.03-0.52 g L^{-1}. During monsoon and post-monsoon period the TDS values ranged between 0.06-0.12 and 0.06-0.17 g L^{-1}, respectively in which the values were quite below the minimum standard of safe disposal under the Solid Waste Management rules 2016 (GOI, 2016).

The biological parameters of leachate samples like biological oxygen demand (BOD), chemical oxygen demand (COD) and coliform count were monitored during the three consecutive seasons and the data presented in Table 17.

4.1.3.4. Biological oxygen demand

BOD is the amount of dissolved oxygen needed by aerobic organisms to breakdown the organic material present in a given water sample at a particular temperature over a specific period of time. The BOD values observed at all points of study during pre-monsoon, monsoon and post-monsoon period were quite high both within and outside the plant area. There was slight reduction in BOD values during monsoon and post-monsoon periods compared to its corresponding pre-monsoon values. The range of values observed during pre-monsoon, monsoon and post-monsoon periods were 99.60-179.27, 68.76-160.44 and 91.68-171.27 mg L^{-1}, respectively against the minimum standard of safe disposal into a surface water source of 30 mg L^{-1}.

Table 17. Seasonal variation in the biological characteristics of leachate samples along the leachate flow zone

Samples	BOD (mg L^{-1})			COD (mg L^{-1})			Coliforms (MPN index mL^{-1})		
	Pre	Mon	Post	Pre	Mon	Post	Pre	Mon	Post
Site 1 (0*m)	142.01	130.43	140.85	670.15	710.27	662.18	0.24	0.12	8.87
Site 2 (50 m)	137.52	117.93	130.85	680.35	683.33	651.84	8.87	1.43	4.03
Site 3 (100 m)	121.68	115.43	124.60	630.33	660.65	605.27	0.71	0.87	2.47
Site 4 (150 m)	179.27	160.44	171.27	747.95	760.96	721.81	8.87	0.11	8.87
Site 5 (200 m)	158.35	155.02	153.77	690.34	690.88	672.29	0.87	0.15	1.43
Site 6 (250 m)	158.27	145.85	143.77	680.31	684.28	621.61	8.87	0.27	0.07
Site 7 (300 m)	141.27	134.18	132.52	577.76	670.47	586.52	0.23	2.47	0.07
Site 8 (350 m)	138.76	136.34	122.09	620.59	640.80	570.65	8.87	8.87	0.07
Site 9 (400 m)	124.60	122.93	113.76	276.27	355.28	110.26	6.73	0.38	0.25
Site 10 (450 m)	144.18	75.01	117.93	133.46	174.26	170.19	4.60	0.09	0.09
Site 11 (500 m)	99.60	68.76	91.68	44.19	100.23	40.33	0.09	0.09	0.09
Mean	140.50	123.85	131.19	522.88	557.40	492.09	4.45	1.34	2.39
Range	99.6-179.27	68.76-160.44	91.68-171.27	44.19-747.95	100.23-760.96	40.33-721.81	0.09-8.87	0.09-8.87	0.07-8.87
Standard**	30			250			0.5		

*Distance from landfill site

**As per Solid Waste Management rules 2016

4.1.3.5. Chemical oxygen demand

COD is the milligram of oxygen required for one litre of water for the complete oxidation of organic substances contained in it. The mean COD values during the pre-monsoon, monsoon and post-monsoon period were 522.88, 557.40 and 492.09 mg L^{-1}, respectively. As per Solid Waste Management rules 2016 the minimum standard for safe disposal in to a surface water source is 250 mg L^{-1}. The range of COD observed during the monsoon period indicates the higher requirement

of oxygen followed by pre-monsoon season and lowest need of oxygen in post-monsoon samples.

4.1.3.6. Coliforms

The usual method employed to detect the presence of pathogens in a water source is by assessing the coliform count. The contamination is tested by assessing the number of colonies of coliform (*Escherichia coli*) per 100 mL of water and the result is expressed as coliform microbial density through most probable number dilution culture method (MPN method). The coliform count observed during the pre-monsoon period was generally higher than monsoon and post-monsoon period. Range of values observed during pre-monsoon, monsoon and post-monsoon periods were 0.09-8.87, 0.05-8.87 and 0.07-8.87 MPN index mL^{-1}. The samples taken from the monsoon period recorded lower count than pre-monsoon and post-monsoon period.

The seasonal variations in the mean calcium, magnesium, zinc and manganese content in leachate samples collected and analyzed at a regular interval of 50 m within and outside the plant area up to a distance of 500 m are presented in Table 18.

4.1.3.7. Calcium

The range of calcium content observed during pre-monsoon, monsoon and post-monsoon periods of 2014 were 10.03-24.69, 0.09-15.19 and 9.11-22.19 mg L^{-1}, respectively. It is seen there the relative concentration of calcium in the leachate samples during the monsoon period were much lower than the pre-monsoon and post-monsoon period.

Table 18. Seasonal variations in Ca, Mg, Zn and Mn status in leachate samples, mg L^{-1}

Samples	Ca			Mg			Zn			Mn		
	Pre	Mon	Post	Pre	Mon	Post	Pre	Mon	Post	Pre	Mon	Post
Site 1 (0*m)	22.84	11.43	22.19	94.06	9.36	61.59	0.14	0.02	0.02	6.97	0.09	2.32
Site 2 (50 m)	12.07	10.44	10.29	51.65	9.76	26.51	0.03	0.02	0.01	3.59	0.06	0.25
Site 3 (100 m)	11.98	8.86	10.11	21.44	11.16	16.22	0.02	0.02	0.02	0.52	0.02	0.10
Site 4 (150 m)	24.69	15.19	20.49	83.40	16.85	35.17	0.85	0.03	0.12	7.53	1.95	4.88
Site 5 (200 m)	13.19	10.72	11.47	41.11	7.60	44.30	0.83	0.03	0.12	3.45	1.31	1.68
Site 6 (250 m)	12.24	9.80	10.93	29.84	8.69	26.02	0.77	0.03	0.11	1.77	1.23	1.32
Site 7 (300 m)	10.15	5.53	10.02	20.49	5.66	19.08	0.74	0.04	0.11	1.58	0.87	1.01
Site 8 (350 m)	10.17	5.79	10.02	9.40	6.68	6.49	0.42	0.03	0.03	1.56	1.01	0.23
Site 9 (400 m)	10.24	1.02	10.44	8.41	3.61	4.34	0.04	0.02	0.02	1.33	0.06	0.11
Site 10 (450 m)	10.22	0.31	9.29	8.55	3.82	3.47	0.03	0.02	0.02	1.31	0.09	0.09
Site 11 (500 m)	10.03	0.09	9.11	6.89	1.34	2.42	0.03	0.02	0.02	1.16	0.05	0.08
Mean	13.44	7.20	12.21	34.11	7.68	22.33	0.35	0.03	0.05	2.80	0.61	1.10
Range	10.03-24.69	0.09-15.19	9.11-22.19	6.89-94.06	1.34-16.85	2.42-61.59	0.02-0.85	0.02-0.04	0.01-0.12	0.52-7.53	0.02-1.95	0.08-4.88
Standards**	75.00			30.00			5.00			0.10		

*Distance from landfill site

** As per Solid Waste Management rules 2016

4.1.3.8. Magnesium

Similarly, the magnesium content during the pre-monsoon period ranged between 6.89-94.06 mg L^{-1} with a mean value of 34.11 mg L^{-1}. The mean content of magnesium during monsoon season drastically reduced to 7.68 mg L^{-1} with a range from 1.34 to 16.85 mg L^{-1} existing over a distance of 500 m from the main landfill site. However, the post-monsoon values for magnesium though lesser than pre-monsoon period, maintained a range of 2.42 to 61.59 mg L^{-1} with a mean value of 22.33 mg L^{-1}.

4.1.3.9. Zinc

The zinc content of leachate samples ranged between 0.02-0.85 mg L^{-1} during pre-monsoon, 0.02-0.04 mg L^{-1} during monsoon period and 0.01-0.12 during the post-monsoon period. The lowest mean value of 0.03 mg L^{-1} zinc was noted in monsoon period and the highest mean value of 0.35 mg L^{-1} was observed during pre-monsoon period. An assessment of zinc concentration in the entire leachate samples across all the seasons of study indicated that all the values were below the minimum standard of safe disposal.

4.1.3.10. Manganese

A similar trend was noted in manganese content of leachate samples as observed for zinc. The lowest mean value of manganese 0.61 mg L^{-1} was recorded during monsoon period and the highest mean content of 2.80 mg L^{-1} during the pre-monsoon period. The post-monsoon values remained in between pre-monsoon and monsoon period.

The fluctuations in the aluminium content in the leachate zone within a distance of 500 m from the prominent landfill site during pre-monsoon, monsoon and post-monsoon period is presented in Table 19, along with the results of copper, iron and lead.

Table 19. Seasonal variations in Al, Cu, Fe and Pb content in leachate samples, mg L^{-1}

Samples	Al			Cu			Fe			Pb		
	Pre	Mon	Post	Pre	Mon	Post	Pre	Mon	Post	Pre	Mon	Post
Site 1 (0*m)	35.17	25.16	33.49	0.43	0.03	0.13	24.13	15.25	26.30	0.20	0.06	0.14
Site 2 (50 m)	28.30	23.73	26.19	0.03	0.03	0.02	29.22	20.16	25.33	0.09	0.07	0.07
Site 3 (100 m)	29.47	22.28	27.32	0.03	0.02	0.01	28.27	22.79	24.19	0.09	0.09	0.07
Site 4 (150 m)	38.22	32.47	36.45	0.64	0.09	0.52	32.56	24.39	31.55	0.28	0.08	0.16
Site 5 (200 m)	29.10	22.01	28.17	0.22	0.07	0.20	28.17	21.17	24.09	0.17	0.08	0.16
Site 6 (250 m)	30.08	25.51	26.51	0.19	0.03	0.07	24.56	20.12	22.79	0.08	0.07	0.09
Site 7 (300 m)	28.71	24.45	26.66	0.09	0.02	0.05	22.96	15.14	21.01	0.09	0.07	0.08
Site 8 (350 m)	22.77	20.26	23.32	0.03	0.02	0.02	20.17	13.05	20.35	0.07	0.05	0.09
Site 9 (400 m)	15.52	12.65	16.83	0.02	0.01	0.02	9.30	4.29	6.30	0.08	0.04	0.06
Site 10 (450 m)	16.11	9.41	11.45	0.02	0.02	0.02	5.29	1.23	4.30	0.07	0.06	0.03
Site 11 (500 m)	5.51	5.01	1.41	0.02	0.01	0.02	1.10	0.14	1.21	0.06	0.06	0.06
Mean	25.36	20.26	23.43	0.15	0.04	0.09	20.53	14.33	18.85	0.11	0.06	0.10
Range	5.51-38.22	5.01-32.47	1.41-36.45	0.02-0.64	0.01-0.09	0.01-0.52	1.10-32.56	0.14-24.39	1.21-31.55	0.06-0.28	0.04-0.09	0.03-0.16
Standard**	0.30			3.00			0.30			0.10		

*Distance from landfill site

**As per Solid Waste Management rules 2016

4.1.3.11. Aluminium

It is observed that the aluminium concentration in the leachate samples recorded during monsoon period is in the range of 5.01-32.47 mg Al per litre. Among the three seasons of study pre-monsoon period offered highest mean of 25.36 mg Al per litre of leachate followed by a mean of 23.43 mg L^{-1} Al during the post-monsoon period. All the leachate samples in all the three seasons of study crossed the minimum standards for safe disposal of leachates into a surface water source.

4.1.3.12. Copper

As observed for other metals the lowest copper content (0.04 mg L^{-1}) was observed again during the monsoon period. During the pre-monsoon period, the range of copper over a distance of 500 m from the landfill site towards outside ranged between 0.02-0.64 mg L^{-1}. This was comparatively higher than monsoon and post-monsoon period. The respective mean values of the copper content during pre-monsoon, monsoon and post-monsoon seasons were 0.15, 0.04 and 0.09 mg L^{-1}.

4.1.3.13. Iron

The variations in the iron content that existed in the leachate samples from site 1 to 11 extending over a distance of 500 m indicated that the mean values of iron were 20.53, 14.33 and 18.85 mg L^{-1} during pre-monsoon, monsoon and post-monsoon period, respectively (Table 19). As observed in other cases, the monsoon period recorded lowest concentration and pre-monsoon period the highest concentration of the metal in the leachate.

4.1.3.14. Lead

The lead status in the leachate samples monitored during three seasons of the year 2014 over the same georeferenced sampling points offered more or less similar trend with the lowest mean value (0.06 mg L^{-1}) being observed during monsoon period and the highest value (0.11 mg L^{-1}) during the pre-monsoon period. The mean lead content (0.10 mg L^{-1}) in the post-monsoon period though much higher than the monsoon period, was almost similar as that of the pre-monsoon period. The range of values observed during pre-monsoon, monsoon and post-monsoon period were 0.06-0.28 mg L^{-1}, 0.04-0.09 mg L^{-1} and 0.03-0.16 mg L^{-1}, respectively.

Fluctuations in the content of cadmium, nickel and cobalt in the leachate zone of the Vilappilsala garbage treatment plant which extent to the outside through the plant area has been monitored at a regular interval of 50 m up to a distance of 500 m from the main landfill area over three consecutive seasons of 2014 are presented in Table 20.

4.1.3.15. Cadmium

Among the three seasons of study monsoon seasons offered the lowest mean cadmium content of 0.04 mg L^{-1} while the pre-monsoon period offered the mean highest value of 0.11 mg L^{-1}. The mean cadmium content observed during the post-monsoon period remained 0.09 mg L^{-1}. A reflection of this was evident in the range of values over these corresponding periods of study. The range of values observed during pre-monsoon, monsoon and post-monsoon were 0.01-0.26, 0.01-0.07 and 0-0.18 mg L^{-1}, respectively. It is to be noted that during the post-monsoon period the content of cadmium was beyond detectable limit at a distance of 500 m from the initial sampling site.

Table 20. Seasonal variations in Cd, Ni and Co content in leachate samples along the flow zone, mg L^{-1}

Samples	Cd			Ni			Co		
	Pre	Mon	Post	Pre	Mon	Post	Pre	Mon	Post
Site 1 (0*m)	0.16	0.05	0.06	0.43	0.05	0.18	0.15	0.11	0.15
Site 2 (50 m)	0.06	0.04	0.06	0.12	0.03	0.12	0.06	0.02	0.01
Site 3 (100 m)	0.05	0.01	0.02	0.08	0.02	0.04	0.02	0.02	0.01
Site 4 (150 m)	0.26	0.07	0.18	0.54	0.09	0.29	0.20	0.05	0.21
Site 5 (200 m)	0.19	0.04	0.17	0.34	0.04	0.23	0.18	0.02	0.13
Site 6 (250 m)	0.16	0.04	0.16	0.14	0.03	0.12	0.17	0.02	0.10
Site 7 (300 m)	0.15	0.03	0.16	0.13	0.01	0.11	0.09	0.02	0.06
Site 8 (350 m)	0.12	0.03	0.06	0.13	0.01	0.11	0.05	0.01	0.05
Site 9 (400 m)	0.08	0.02	0.04	0.03	0.01	0.01	0.02	0.01	0.02
Site 10 (450 m)	0.03	0.02	0.02	0.02	ND	0.01	0.02	0.01	0.01
Site 11 (500 m)	0.01	0.01	ND	0.02	ND	ND	0.02	0.01	0.01
Mean	0.11	0.04	0.09	0.18	0.02	0.12	0.08	0.02	0.06
Range	0.01-0.26	0.01-0.07	0-0.18	0.02-0.54	0-0.09	0-0.29	0.02-0.20	0.01-0.11	0.01-0.21
Standard**	2.00			3.00			Not Specified		

ND-Not Detected, *Distance from landfill site, **As per Solid Waste Management rules 2016

4.1.3.16. Nickel

The same trend as observed for cadmium was evident for nickel content also during the three seasons of study. During the monsoon period it is seen that the nickel content in the sampling sites scaled down to virtually non-detectable limits in site at 450 m while the non-detectable level of nickel was noted at the 500 m during the post monsoon period. However, at 450 and 500 m distance, nickel was detectable during the pre-monsoon period. The mean nickel concentration during pre-monsoon, monsoon and post-monsoon seasons were 0.18, 0.02 and 0.12 mg L^{-1}, respectively.

4.1.3.17. Cobalt

Though there were marginal fluctuations between georeferenced sampling points with respect to cobalt, the lowest mean value (0.02 mg L^{-1}) was again recorded during the monsoon season. The highest mean level (0.08 mg L^{-1}) of cobalt was observed during the pre-monsoon season. The mean cobalt content observed during post-monsoon period was 0.06 mg L^{-1}.

Variations in the chromium, mercury and arsenic level in the leachate samples observed during three consecutive seasons of the year 2014-15 at regular interval of 50 m in the leachate flow directions up to a distance of 500 m was monitored and the data presented in Table 21.

4.1.3.18. Chromium

There had been fluctuations in the chromium content between sampling sites and between seasons of study. The chromium content was generally seen to decrease with increase in distance from the site of contamination in all the sampling periods. The maximum mean value of 0.04 mg L^{-1} of chromium was observed during the pre-monsoon period and the lowest chromium content of 0.01 mg L^{-1} was observed during monsoon period. The mean chromium content during the post-monsoon period remained between 0 and 0.05 mg L^{-1}. During the pre-monsoon period, the level of detectable chromium was present only up to a distance of 350 m from the landfill area. However, during the monsoon period majority of the sampling sites failed to offer detectable level of chromium even from the 50 m distance. However, there was an isolated observed enhancement of chromium (0.02 mg L^{-1}) in the fourth sampling site whose influence is not seen at any subsequent sampling sites. The level of non-detectable chromium during the post-monsoon period was evident at 300 m onwards from the first sampling site.

Table 21. Seasonal variations in Cr, Hg and As content in leachate samples along the flow zone, mg L^{-1}

Samples	Cr			Hg			As		
	Pre	Mon	Post	Pre	Mon	Post	Pre	Mon	Post
Site 1 (0*m)	0.07	0.01	0.01	2.02	1.96	2.14	0.01	0.01	ND
Site 2 (50 m)	0.02	ND	0.01	2.01	1.48	1.25	ND	ND	ND
Site 3 (100 m)	0.01	ND	0.01	1.96	1.23	1.01	ND	ND	ND
Site 4 (150 m)	0.09	0.02	0.05	2.59	1.98	2.26	0.01	0.01	ND
Site 5 (200 m)	0.06	ND	0.03	2.11	1.82	1.25	0.01	ND	ND
Site 6 (250 m)	0.05	ND	0.01	1.26	1.01	0.96	0.01	ND	ND
Site 7 (300 m)	0.03	ND	0.01	1.22	0.97	0.84	ND	ND	ND
Site 8 (350 m)	0.03	ND	ND	0.97	0.52	0.65	ND	ND	ND
Site 9 (400 m)	0.02	ND	ND	0.59	0.39	0.22	ND	ND	ND
Site 10 (450 m)	ND	ND	ND	0.50	0.30	0.22	ND	ND	ND
Site 11 (500 m)	ND	ND	ND	0.39	0.28	0.22	ND	ND	ND
Mean	0.04	0.01	0.02	1.42	1.08	1.01	0.004	0.002	ND
Range	0-0.09	0-0.02	0-0.05	0.39-2.59	0.28-1.98	0.22-2.26	0-0.01	0-0.01	
Standard**	2.00			0.01			0.20		

ND-Not Detected, *Distance from landfill site, **As per Solid Waste Management rules 2016

4.1.3.19. Mercury

The levels of mercury observed during the three seasons crossed the minimum standard value of leachate for disposing to a surface water source (0.01 mg L^{-1}). The mercury range in the pre-monsoon season was 0.39 to 2.59 mg L^{-1}, while the monsoon period had a much lower range of 0.28-1.98 mg L^{-1} mercury. A range of 0.22-2.26 mg L^{-1} of mercury was detected along the sampling sites during the post-monsoon season. A consideration of the mean values of mercury made available over the three seasons indicated that the pre-monsoon period supported the maximum mean concentration of 1.42 mg L^{-1} followed by 1.08 during the monsoon period and

there after decreased but with a marginal value of 1.01 mg L^{-1} during post-monsoon period.

4.1.3.20. Arsenic

The arsenic metal concentration in the leachate zone of study which extended over a period of 500 m indicated the total inability to detect as in the post-monsoon period at all sampling points. However, both pre-monsoon and monsoon seasons maintained an average value of 0.004 and 0.002 mg L^{-1} in the samples, respectively. The influence of distance in scaling down the concentrations of arsenic in samples was clear on the analysis of data made available in pre-monsoon and monsoon periods. The influence of an adjacent landfill site in marginally adding the arsenic to the stream of effluents though visualized from the content at site 4 failed virtually during the monsoon period in the subsequent samples (from 200 m onwards). However, the influence of an adjacent landfill in providing arsenic to the leachate stream was slightly visible during the pre-monsoon period up to a distance of 100 m from the confluence point of the stream at 4^{th} site and there after the level of arsenic was below the detectable limit.

4.1.4. Analysis of ground water samples

It is seen that the landfill sites within the treatment plant area of Vilappilsala had inadvertently released leachates to the outside areas particularly the low lying portions which have been identified as the leachate flow zone where detailed investigations have been carried out and results presented in previous tables (Table 16, 17, 18, 19, 20 and 21) at a regular distance of 50 m within the plant area till it reach the *Meenampally thodu* where the leachate has joined with the general water stream which flowed further downward through private properties in the vicinity. During the active periods of treatment plant, there was good reflection in the quality of the leachate emanating from within the plant area in the adjacent drinking water sources (wells) contaminating them both physically, chemically and biologically

restricting the use of these water sources by the local people. However, when this particular study was conducted three years after the closure of garbage treatment plant the gravity of the problems though scaled down considerably even though it did not bring back the well water quality to its original level. The chemical and biological properties of three well water sources identified outside the plant area much ahead of the *Meenampally thodu* have been subjected to detailed analysis in three consecutive seasons during the year 2014-15 and presented in Table 22.

Table 22. Seasonal variations in the chemical and biological characteristics of ground water

Parameters	Well water 1			Well water 2			Well water 3			Acceptable level (BIS)
	Pre	Mon	Post	Pre	Mon	Post	Pre	Mon	Post	
pH	6.15	6.26	5.36	6.07	6.04	4.86	5.85	6.55	4.85	6.5-8.5
EC ($dS\ m^{-1}$)	0.61	0.33	0.42	0.71	0.56	0.20	0.53	0.68	0.37	0.75
TDS ($g\ L^{-1}$)	0.03	0.06	0.06	0.06	0.07	0.07	0.06	0.08	0.06	0.5
BOD ($mg\ L^{-1}$)	23.34	25.84	26.26	15.84	16.76	18.76	21.67	20.42	19.59	30
COD ($mg\ L^{-1}$)	30.26	80.05	10.37	80.92	40.19	10.60	60.08	30.19	40.96	250
Coliforms (MPN index mL^{-1})	0.04	0.07	0.20	0.04	0.04	0.03	0.03	0.06	0.03	0.1
Ca ($mg\ L^{-1}$)	0.38	0.22	0.13	1.40	2.43	0.15	0.58	0.86	0.22	75.00
Mg ($mg\ L^{-1}$)	4.59	1.88	1.48	5.38	3.34	1.68	8.56	1.39	3.72	30.00
Al ($mg\ L^{-1}$)	2.02	2.26	3.23	2.47	0.59	1.55	1.65	1.33	1.55	0.03

In general, the observed variation in pH ranged from 4.85 to 6.55 over the three periods of study. Pre-monsoon sampling of well water provided a range of 5.85-

6.15 with the farthest well water source from the plant area registering 5.85 and the closest well water registering in 6.15. However, this trend reversed during monsoon period with the farthest well water registering 6.55 and the nearest well water registering 6.26. The post-monsoon sampling of these well water sources for pH indicated that except for the close well water source, the other two water sources had scaled down to still lower acidic pH. None of the water sample sources except the third well water during monsoon season presented the acceptable level of pH as per Bureau of Indian Standards (BIS).

The electrical conductivity of well water samples when compared over the three seasons it is seen that all the values during the pre-monsoon season offered safe limit. An assessment of the total dissolved solids in well water over the three seasons of study did not bring any unacceptable level of dissolved salts and all the values were within the acceptable limit.

The BOD values made available from the three water sources over the three seasons of study indicated that the BOD values were less than the acceptable limit indicated by BIS standards for potable water. However, on comparison of mean values across a particular season it is seen that the BOD values were comparatively higher during the monsoon season than the other two seasons. The COD values observed in well water at different points of sampling indicated a range of 10.37 to 80.92 mg L^{-1} and these values were much below the acceptable limit of 250 mg L^{-1} insisted by BIS. The coliform bacterial count observed in the well water sources across three seasons of study indicated a range between 0.03 and 0.07 MPN index per mL.

While comparing the calcium and magnesium status in the well water, it is seen that the magnesium status were comparatively much higher than the calcium status at any point of comparison. The range of calcium observed in the well water samples over the three seasons of study ranged between 0.13 to 2.43 mg L^{-1} which is

far less than the acceptable limits prescribed by BIS standards for drinking water quality. Similarly, the range of magnesium over the three consecutive periods of study was between 1.39 to 8.56 mg L^{-1}. These ranges were again far less than the acceptable limit set by BIS for drinking water sources.

An assessment of the aluminium content in the well water sources across three seasons of study indicated that all samples carried much higher values of aluminium than the acceptable level insisted by BIS for drinking water sources making it totally unfit for human consumption. The well water sample presented a range of 0.59 to 3.23 mg L^{-1} of aluminium over the three period of study.

The analysis of well water samples for various heavy metal contents like zinc, manganese, copper, iron, lead, cadmium, nickel, cobalt, chromium and mercury across three consecutive seasons are presented in Table 23.

Table 23. Seasonal variations in the heavy metal status of ground water samples

Heavy metals (mg L^{-1})	Well water 1			Well water 2			Well water 3			Acceptable limit (BIS)
	Pre	Mon	Post	Pre	Mon	Post	Pre	Mon	Post	
Zn	0.025	0.054	0.043	0.119	0.139	0.089	0.096	0.086	0.028	5.00
Mn	0.001	0.012	0.001	0.001	0.086	0.074	0.004	0.376	0.046	0.10
Cu	0.015	0.014	0.015	0.010	0.012	0.016	0.017	0.017	0.014	0.05
Fe	1.029	0.255	1.237	1.985	0.966	1.858	0.463	0.116	0.774	0.30
Pb	0.036	0.053	0.054	0.060	0.067	0.060	0.076	0.095	0.087	0.01
Cd	0.003	0.006	0.005	0.007	0.009	0.006	0.004	0.006	0.004	0.003
Ni	0.006	0.007	0.002	0.008	0.008	0.002	ND	ND	ND	0.02
Co	0.007	0.013	0.015	0.005	0.009	0.005	0.003	0.007	0.007	Not specified
Cr	ND	ND	ND	0.001	ND	ND	0.015	ND	ND	0.05
Hg	0.005	ND	0.002	0.009	ND	0.009	0.005	ND	0.003	0.001

In general the levels of zinc assayed in the three well water sources across the pre-monsoon, monsoon and post-monsoon periods of study during the year 2014 offered much lesser values than the acceptable limit of 5.00 mg L^{-1} insisted by BIS making it safe as far as this element is concerned.

It is seen that the manganese content in the well water were much lesser than the acceptable limit of 0.10 mg L^{-1} during the pre-monsoon and post-monsoon season. However, during the monsoon seasons the well water samples at the farthest end had crossed this acceptable limit to a content of 0.376 mg L^{-1}.

The copper levels that was monitored across three seasons in the identified well water sources could not present higher levels of copper at any point particularly when compared with the acceptable limit of copper (0.05 mg L^{-1}) insisted by BIS standards.

Fluctuations in the iron content were more visible during the monsoon period than the pre-monsoon and post-monsoon period. The range of iron content existed in the well water samples over three consecutive seasons were ranged between 0.116 and 1.985 mg L^{-1} with majority of the samples crossing the acceptable limit of 0.30 mg L^{-1} insisted by BIS for potable water.

The level of lead content in all the well water samples was beyond the acceptable limits, irrespective of the seasons of study. The observed range of lead in the well water samples across the three seasons were in between 0.036 to 0.095 mg L^{-1} and this was much higher than the acceptable limit offered by BIS. On perusal of the data it is seen that both post-monsoon and monsoon season values were marginally higher for lead content over the corresponding pre-monsoon values.

The cadmium content observed in the well water samples across the three periods of study indicated that all the samples have crossed the acceptable limit of 0.003 mg L^{-1} making these sources a potentially contaminated source of cadmium.

The nickel content during the three seasons of study in the well water samples revealed its presence over a range of values existing between non detectable limit to 0.008 mg L^{-1} which is well within the acceptable limit insisted by BIS. The marginal presence of this element in well water, close to the plant area and as the distance increased, the content of nickel drop down to below detectable limits irrespective of the seasons of study.

The cobalt level observed in the well water sample ranged from 0.003 to 0.009 mg L^{-1}. For sake of comparison of its safety its acceptable limit has not been determined. Analysis of well water for possible dissolved chromium content revealed that its presence ranged from non detectable limit to 0.015 mg L^{-1} which when compared with the BIS standards was well within the acceptable limit (0.05 mg L^{-1}). Monsoon and post-monsoon samples virtually provided non-detectable limits at all points of study.

The mercury content in the well water samples across three seasons provided a range from non-detectable limit to a maximum of 0.009 mg L^{-1}. All well water samples during the monsoon period failed to provide any detectable limit of this metal while the other two seasons offered levels of this metal much above the acceptable level making it highly unfit for human consumption.

4.2. ASSESSMENT OF WEED FLORA IN THE LEACHATE ZONE FOR THEIR HYPER ACCUMULATION CAPACITY

4.2.1. Shoot accumulation

The content of calcium and magnesium along with eight other heavy metals viz; zinc, manganese, copper, lead, cadmium, nickel, cobalt and chromium were assessed in the shoot portions of the major weed species identified along the leachate zone within the plant area and these results are presented in Table 24.

Table 24. Heavy metal accumulation status of major weed species identified along the leachate zone in shoot portion

Sl No.	Plants	Ca	Mg	Zn	Mn	Cu	Pb	Cd	Ni	Co	Cr
		mg kg^{-1}									
1	*Alternanthera tenella* Colla.	2.29	4.24	70.94	366.02	51.52	66.82	1.76	16.04	11.00	11.04
2	*Sphagneticola trilobata* (L.) Hitchc.	1.28	2.68	84.61	106.59	42.33	53.18	2.29	12.63	7.36	9.15
3	*Commelina diffusa* N. Burman	1.29	3.69	96.98	164.71	54.56	59.42	1.19	9.50	8.16	8.90
4	*Colocasia esculenta* (L.) Schott.	1.32	2.74	64.29	211.01	32.24	46.58	1.46	13.79	5.13	9.27
5	*Mikania micrantha* Kunth.	1.26	2.42	57.22	120.63	3.81	42.79	2.65	10.85	8.23	8.09
6	*Ricinus communis* L.	1.72	4.16	48.99	211.45	35.90	56.39	1.37	11.65	5.46	0.80
7	*Eupatorium odoratum*	2.02	2.39	92.11	111.43	41.38	20.58	0.67	8.16	9.08	4.14
8	*Brachiaria distachya* (L.) Stapf.	1.20	2.43	112.54	172.46	27.70	37.48	1.39	11.27	8.24	6.37
9	*Centrosema pubescens* Benth.	1.67	2.48	12.50	123.96	33.34	30.70	0.98	9.01	3.96	4.17
10	*Boerhavia diffusa* L.	1.31	1.91	47.77	130.67	11.67	23.43	0.98	6.33	3.19	3.29
11	*Celosia argentea* L.	1.27	1.30	33.86	133.83	22.78	50.70	1.13	11.03	6.28	8.13
12	*Cynodon dactylon* (L.) Pers.	0.81	1.02	9.19	21.22	10.14	17.67	0.17	7.08	0.98	2.98
13	*Mitracarpus verticillatus* (L.) DC.	2.41	1.82	63.84	103.35	40.67	23.36	0.85	10.37	8.16	1.13
14	*Sida rhombifolia* L.	1.52	1.91	51.67	123.53	27.43	29.54	1.35	9.82	9.49	2.41
15	*Dactyloctenium aegyptium* (L.) Willd.	2.61	2.21	38.24	117.68	46.39	41.19	1.30	11.88	9.10	3.27
CD (0.05)		0.046	0.041	1.012	1.613	1.702	1.883	0.304	0.971	0.431	0.375

Among the 15 species of weeds identified as profusely growing along the leachate zone and supposed to be hyper accumulators of heavy metals were screened. The details of analysis revealed that the content of elements remained significantly different from one another particularly when compared within the 15 weed plant species.

The extent of calcium content in shoot portion within the 15 plant species ranged from 0.81-2.61 mg kg^{-1}. As far as magnesium is concerned, the range in general remained higher over the calcium content with values existing between 1.02-4.24 mg kg^{-1}. Incidentally the shoot portions of *Dactyloctenium aegyptium* recorded maximum calcium content of 2.61 mg kg^{-1} and *Alternanthera tenella* recorded maximum content of magnesium 4.24 mg kg^{-1} in the shoot portion while the lowest content both in calcium (0.81 mg kg^{-1}) and magnesium (1.02 mg kg^{-1}) was recorded in shoot portions of *Cynodon dactylon*. *Alternanthera tenella*, a major weed species identified along the leachate zone had maximum accumulation of manganese (366.02 mg kg^{-1}) in the shoot portions compared to other weed species. As far as copper is concerned, this plant was the second best plant when its accumulation in shoot portion is concerned. *Commelina diffusa* had been identified to accumulate the highest level of copper (54.56 mg kg^{-1}) in the shoot portion while the same plant has been ranked as the second best accumulator of zinc and lead with a content of 96.98 and 59.42 mg kg^{-1}, respectively. Analysis of the shoot portions of *Mikania micrantha* indicated that this plant was supposed to be the best among the other species of weeds considered for the study in accumulating the highest content of 2.65 mg kg^{-1} of cadmium. *Sphagneticola trilobata* commonly known as trailing daisy was identified to be the second best accumulator of cadmium and chromium in the shoot portions with 2.29 and 9.15 mg kg^{-1} of the metal, respectively when compared with the other counter parts. However, the shoot portion accumulated the third best content of nickel when compared to its counter parts. *Colocasia esculenta* when analyzed for the various heavy metal content in the shoot portions, it is seen that the shoot portion had

accumulated the second largest content of nickel and chromium with 13.79 and 9.27 mg kg^{-1} respectively. This shoot portion incidentally was found to have the third largest (211.01 mg kg^{-1}) content of manganese.

Ricinus communis commonly known as Castor had accumulated the second and third accumulator of manganese (211.45 mg kg^{-1}) and lead (56.39 mg kg^{-1}) respectively in the shoot portions. *Brachiaria distachya* was qualified for holding the maximum zinc content of 112.54 mg kg^{-1} in the shoot portion. The relative content of other metals in this plant (shoot portion) were comparatively lesser than that of the other plants described above. The extent of heavy metals in the shoot of *Eupatorium odoratum* was not high with respect to different metals except zinc where its position has been described as the third (92.11 mg kg^{-1}) best accumulator. *Dactyloctenium aegyptium* offered the third highest content of copper (46.39 mg kg^{-1}) and cobalt (9.10 mg kg^{-1}) in the shoot portions when compared to its counter parts taken for the study. *Sida rhombifolia* when analyzed for different heavy metals in the shoot portion was found to perform the second best accumulator of cobalt with a content of 9.49 mg kg^{-1}. The presence of other metals included in the study was far below than its counter parts.

4.2.2. Root accumulation

The content of calcium and magnesium along with eight heavy metals were assessed for their accumulation in the root portions of 15 major weeds identified to be profusely growing along the leachate path within the plant area are presented in Table 25.

Table 25. Heavy metal accumulation status of major weed species identified along the leachate zone in root portion

Sl No.	Plants	Ca	Mg	Zn	Mn	Cu	Pb	Cd	Ni	Co	Cr
		mg kg^{-1}									
1	*Alternanthra tenella* Colla.	2.41	3.61	108.36	260.79	62.44	98.44	7.69	43.04	61.20	20.933
2	*Sphagneticola trilobata* (L.) Hitchc.	1.17	1.04	47.08	130.92	27.19	46.47	2.33	6.31	8.14	11.890
3	*Commelina diffusa* N. Burman	1.09	2.11	156.28	170.74	67.44	55.85	2.84	18.89	20.01	12.616
4	*Colocasia esculenta* (L.) Schott.	1.02	1.63	96.37	232.43	47.78	76.01	2.36	44.94	20.82	20.073
5	*Mikania micrantha* Kunth.	1.03	2.04	95.71	241.69	39.30	65.24	3.32	20.76	18.51	4.266
6	*Ricinus communis* L.	1.22	3.63	43.47	86.74	42.64	57.08	1.42	8.63	5.380	0.803
7	*Eupatorium odoratum*	2.19	2.92	120.28	167.33	52.87	32.72	2.03	10.72	11.180	9.930
8	*Brachiaria distachya* (L.) Stapf.	1.19	6.51	81.27	187.18	68.43	55.12	3.15	30.91	23.460	7.893
9	*Centrosema pubescens* Benth.	2.14	1.62	73.47	133.54	42.41	40.48	2.14	10.96	22.846	5.106
10	*Boerhavia diffusa* L.	1.92	2.49	31.56	141.77	23.49	35.79	4.12	7.87	30.990	5.003
11	*Celosia argentea* L.	1.67	3.03	42.76	111.43	42.54	62.29	3.40	23.28	25.706	18.866
12	*Cynodon dactylon* (L.) Pers.	0.99	0.88	23.50	37.00	26.27	31.92	2.08	10.27	18.133	5.280
13	*Mitracarpus verticillatus* (L.) DC.	2.30	1.87	58.88	121.54	57.79	41.70	3.28	11.09	21.166	5.950
14	*Sida rhombifolia* L.	1.82	2.32	60.25	140.84	59.21	43.42	2.03	10.85	34.313	12.173
15	*Dactyloctenium aegyptium* (L.) Willd.	2.42	3.04	67.38	127.09	51.20	43.48	4.96	12.84	24.786	10.146
CD (0.05)		0.036	0.053	1.461	1.985	2.380	1.529	0.310	0.909	1.278	0.596

When the first three highest root concentration of every plant was considered, it remained significantly different to one another with respect to every metal analyzed except for calcium, magnesium and copper.

On perusal of data in Table 25, the extent of calcium and magnesium contents in the root portions of 15 weed plants indicated that the level of magnesium was generally higher compared to the corresponding calcium content in every weed plant studied. Among the root portions the highest content of calcium was recorded in *Dactyloctenium aegyptium* followed by *Alternanthera tenella* with 2.42 and 2.41 mg kg^{-1}, respectively. The third highest level of calcium (2.30 mg kg^{-1}) was identified within the root portions of *Mitracarpus verticillatus*. The highest, second highest and third highest level among the root portion of magnesium was identified in *Brachiaria distachya*, *Ricinus communis* and *Alternanthera tenella*, respectively with a content of 6.51, 3.63 and 3.61 mg kg^{-1}. Incidentally it is observed that the root portions of *Cynodon dactylon* was found to have the lowest content of calcium and magnesium with 0.99 and 0.88 mg kg^{-1}, respectively. Rest of the plants maintained intermediary values for both calcium and magnesium.

Among the 15 species of weeds selected for study, *Alternanthera tenella* offered the highest levels of manganese (260.79 mg kg^{-1}), lead (98.44 mg kg^{-1}), cadmium (7.69 mg kg^{-1}), cobalt (61.20 mg kg^{-1}) and chromium (20.93 mg kg^{-1}). With respect to zinc and copper this plant part was adjudged as the third best accumulator having a content of 108.36 and 62.44 mg kg^{-1}, respectively.

Colocasia esculenta was found to harness the highest level of nickel (44.94 mg kg^{-1}) in the root portion. The same root portion had been identified to be the second best hyper accumulator of lead (76.01 mg kg^{-1}) and chromium (20.07 mg kg^{-1}) and third best accumulator of manganese (232.44 mg kg^{-1}).

Commelina diffusa had the highest level of zinc accumulation (156.28 mg per kg) and the second best accumulation of copper (67.44 mg kg^{-1}) in the root portions.

Mikania micrantha registered the second highest content of manganese (241.69 mg kg^{-1}) and the third highest level of lead (65.24 mg kg^{-1}) in the root portions. *Eupatorium odoratum* was adjudged as the second highest accumulator of zinc (120.28 mg kg^{-1}) in the root portions in the analytical study conducted for the heavy metals particularly in comparison with 15 different weed species identified for the study. The highest content of copper (68.43 mg kg^{-1}) and the third highest level of nickel (30.91 mg kg^{-1}) was identified in the root portions of *Brachiaria distachya*. *Boerhavia diffusa* upheld the status of third largest accumulator of cadmium (4.12 mg kg^{-1}) and cobalt (30.99 mg kg^{-1}) in the root portion compared to its counter parts identified in the study.

Celosia argentea maintained the third highest level of chromium status (18.87 mg kg^{-1}) in the root portion. The root portions of *Dactyloctenium aegyptium* was identified to harbor the second highest level of cadmium (4.96 mg kg^{-1}) compared to other weed plants employed in the study. The root portions of *Sida rhombifolia* maintained the second highest level of cobalt (34.31 mg kg^{-1}).

It is interesting to note that *Cynodon dactylon* was an exclusive weed plant identified along the leachate zone which incidentally maintained the lowest level of zinc, manganese, copper and lead. Another weed plant *Ricinus communis* had also shown a similar trend in recording the lowest values of cadmium, cobalt and chromium in the root portions. Further it is observed that the lowest content of nickel (6.31 mg kg^{-1}) was identified with the root portions of *Sphagneticola trilobata*.

4.3. SAND CULTURE EXPERIMENT

Considering the presence of various heavy metals in both the root and shoot portions at significantly higher proportions compared to other weed plants evaluated in the study, *Alternanthra tenella* commonly known as Joy weed was found to be a best hyper accumulator and tried as one of the treatment plant in the sand culture experiment. The other hyper accumulator plants employed as treatments in the sand

culture experiment were Indian mustard (T_1), Sunflower (T_2), Globe amaranth (T_3) and Marigold (T_4).

4.3.1. Shoot accumulation

In an attempt to assess the extent of uptake of three metals namely lead, cadmium and nickel in shoot portions under graded doses by five identified hyper accumulators is provided in Table 26.

Table 26. Extent of percentage uptake of heavy metals from sand culture experiment in the shoot portions of hyper accumulators under graded doses of heavy metals

Treatments	Lead (%)			Cadmium (%)			Nickel (%)		
	0.5	1.5	2.5	0.5	1.5	2.5	0.5	1.5	2.5
T_1	1.53	1.70	4.90	1.67	4.30	3.60	1.33	2.40	5.10
T_2	1.23	1.90	8.03	1.07	4.17	9.30	2.10	3.93	9.23
T_3	2.13	4.80	8.30	2.03	4.13	9.30	1.77	4.20	9.57
T_4	1.67	3.27	9.67	2.17	4.00	9.60	1.63	3.60	9.63
T_5	0.53	0.77	0.80	0.33	1.87	2.67	1.03	1.57	4.07
CD (0.05)	0.721	0.688	0.687	0.441	0.473	0.979	0.337	0.797	0.772

T_1 - Indian mustard (*Brassica juncea* L.)

T_2 - Sunflower (*Helianthus annuus* L.)

T_3 - Globe amaranth (*Gomphrena globosa* L.)

T_4 - Marigold (*Tagetes spp.* L.)

T_5 - Identified best hyper accumulator from field (*Alternanthera tenella*)

4.3.1.1. Lead

As far as the uptake of lead is concerned it is seen that globe amaranth (T_3) supported maximum uptake (2.13 per cent) when compared to other hyper accumulators at 0.5 mg kg^{-1} in the medium with no significant difference. At 1.5 mg

kg^{-1} concentration of lead in the media globe amaranth (T_3) maintained the highest uptake of 4.80 per cent with significant difference between its competitors. At the highest concentration of 2.5 mg kg^{-1} lead in the media, marigold (T_4) was identified as the best accumulator with an uptake of 9.67 per cent which is significantly higher over the other hyper accumulators. However, at the lower concentration of 0.5 and 1.5 mg kg^{-1} this plant provided an uptake of 1.67 and 3.27 per cent, respectively and only the uptake at 1.5 mg kg^{-1} remained significantly different from its competitors. Though sunflower (T_2) was adjudged as the third best accumulator of lead at 1.5 and 2.5 mg kg^{-1} concentration in the media, there was significant difference only at 1.5 mg kg^{-1} and not at the highest concentration between its immediate competitors. The respective uptakes of lead at 1.5 and 2.5 mg kg^{-1} in sunflower were 1.90 and 8.03 per cent. The weed plant *Alternanthera tenella* (T_5) which was tagged as one of the best performing hyper accumulator in the leachate zone of garbage treatment plant when taken forward in the sand culture study consistently reported the lowest uptake and remained significantly inferior to its competitors at all concentration except with sunflower (T_2) at the lowest concentration of 0.5 mg kg^{-1} lead in the media. In general and irrespective of the plant species there was comparatively higher uptake at succeedingly higher concentrations of metal in the media.

4.3.1.2. Cadmium

The data on the uptake of cadmium by five different hyper accumulators from three successively higher concentrations of cadmium is presented in Table 26. Though marigold (T_4), globe amaranth (T_3) and Indian mustard (T_1) secured the first, second and third positions with respect to the uptake of cadmium in 0.5 mg kg^{-1} media, statistically there was no difference in the quantum of uptake held by the shoot portions of T_4 and T_3. Similarly the uptake of cadmium in 1.5 mg kg^{-1} media recorded in the shoot portion of Indian mustard, sunflower and globe amaranth though marginally different from one another when ranked in the descending order statistically they remained on par. The performance of marigold, globe amaranth,

sunflower and Indian mustard were marked by higher levels of uptake of cadmium at 2.5 mg kg^{-1} of the metal in the media. Though T_4 remained marginally higher with the highest uptake of 9.60 per cent over T_3 and T_2 (both sharing the same value of 9.30 per cent uptake) and were statistically on par. However Indian mustard (T_1) indicated an uptake of 3.60 per cent cadmium bagging the third position in uptake among its competitors and remained significantly different. *Alternanthera tenella* (T_5) the best hyper accumulator weed recorded the lowest uptake of cadmium at all concentrations and remained significantly inferior to all its competitors. Like lead, there was comparatively higher uptake at succeedingly higher concentrations of metal in the media observed irrespective of the plant species.

4.3.1.3. Nickel

The uptake of nickel in the shoot portions of different hyper accumulators were assessed at three levels of nickel in the media and this data is presented in Table 26. The shoot portions of sunflower (T_2), globe amaranth (T_3) and marigold (T_4) recorded the first (2.10 per cent), second (1.77 per cent) and third (1.63 per cent) positions with respect to nickel uptake in their shoot portions when grown in sand media having a nickel concentration of 0.5 mg kg^{-1} nickel. Though there were marginal differences in uptake between globe amaranth and marigold, there was no significant difference between the treatments. At 1.5 mg kg^{-1} concentration of nickel in medium globe amaranth (T_3), sunflower (T_2) and marigold (T_4) were adjudged as the first (4.20 per cent), second (3.93 per cent) and third (3.60 per cent) best accumulator when considered in the descending order with no statistical difference between them. At the highest concentration of 2.5 mg kg^{-1} nickel in the media the performance of marigold, globe amaranth and sunflower were adjudged as the first (9.63 per cent), second (9.57 per cent) and third (9.23 per cent) best hyper accumulator when their corresponding uptake percentage was considered in descending order. As seen for lead and cadmium, the uptake of nickel by the shoot portion of *Alternanthera tenella* (T_5) was the lowest at all concentrations when

compared with its competitors. Though this weed plant maintained the lowest uptake the uptake values were significantly different between the competitors at all concentrations of nickel.

4.3.2. Root accumulation

Table 27 presents the uptake pattern of heavy metals particularly lead, cadmium and nickel in the root portions of four well known hyper accumulators and one weed plant at three different concentrations *viz*; 0.5, 1.5 and 2.5 mg kg^{-1} of the respective metals from sand culture media.

Table 27. Extent of percentage uptake of heavy metals from sand culture experiment in the root portions of hyper accumulators under graded doses of heavy metals

Treatments	Lead (%)			Cadmium (%)			Nickel (%)		
	0.5	1.5	2.5	0.5	1.5	2.5	0.5	1.5	2.5
T_1	1.50	2.00	5.33	1.70	4.93	4.03	2.00	2.73	6.33
T_2	1.40	1.90	8.83	2.17	4.77	12.37	2.17	5.20	9.80
T_3	2.50	5.10	8.57	2.20	4.67	9.83	1.90	4.57	10.07
T_4	1.63	5.50	10.20	2.50	4.50	11.17	2.67	4.53	9.83
T_5	1.30	2.07	1.20	0.53	1.83	3.17	1.77	1.40	4.50
CD (0.05)	0.787	1.262	1.094	0.557	0.922	2.615	0.586	0.564	1.070

T_1 - Indian mustard (*Brassica juncea* L.)

T_2 - Sunflower (*Helianthus annuus* L.)

T_3 - Globe amaranth (*Gomphrena globosa* L.)

T_4 - Marigold (*Tagetes spp.* L.)

T_5 - Identified best hyper accumulator from field (*Alternanthera tenella*)

4.3.2.1. Lead

In the case of lead, though globe amaranth (T_3) was ranked as the best accumulator of lead in the root portion with a content of 2.50 per cent, it was statistically different from marigold (T_4) which was found to have 1.63 per cent uptake. The root portions of Indian mustard (T_1) harboured the third largest uptake of lead (1.50 per cent) from a media which provided 0.5 mg kg^{-1} lead which has no statistical difference with T_4. The lowest uptake of 1.30 per cent from this media was reported in the root portions of the weed *Alternanthera tenella.*

Marigold (T_4) and globe amaranth (T_3) maintained more or less similar uptake of lead in the root portions with no statistical difference with respect to treatment containing 1.5 mg kg^{-1} lead. The root portions of the weed plant *Alternanthera tenella* (T_5) maintained the third position (2.07 per cent) in uptake and remained significantly inferior as compared to marigold and globe amaranth. The lowest uptake of 1.90 per cent was identified in the root portions of sunflower (T_2) from the above media.

The uptake of lead by the root portions of different hyper accumulators from a media providing 2.5 mg kg^{-1} of lead indicated that marigold (T_4) harnessed the highest uptake of 10.20 per cent which is significantly different from the corresponding uptake in sunflower (T_2) and globe amaranth (T_3). The uptake of T_2 and T_3 though marginally different could not bring in any significant difference in the content of their uptake. The lowest uptake of 1.20 per cent lead from this media was identified with the root portions of the weed plant, *Alternanthera tenella* (T_5). In general it is seen that there was successive enhancement in the uptake pattern of lead in the root portions of all the hyper accumulators and weed plant with corresponding enhancement of metal concentration in the growing media.

4.3.2.2. Cadmium

The cadmium uptake by the root portions of hyper accumulators and selected weed plant indicated that there was consistent increase in the metal uptake in the root portions with enhancement in concentration of the metal ions in the growing media. From the growing media with 0.5 mg kg^{-1} cadmium the maximum uptake was seen in marigold (T_4) followed by globe amaranth (T_3) and sunflower (T_2) when the best three uptakes were assessed. Though there were marginal variations in the uptake between these plants in the root portions, statistically they could not show off any significant difference between them. The lowest uptake 0.53 per cent cadmium was reported in the root portions of the weed *Alternanthera tenella* (T_5).

At the concentrations of 1.5 mg kg^{-1} cadmium in the growing media the highest (4.93 per cent) root uptake was shown by Indian mustard (T_1), followed by sunflower (T_2) and globe amaranth (T_3). Though there is marginal variations observed in the first three treatments there were no significant difference between the treatments. The lowest (1.83 per cent) root uptake was registered in T_5 which was inferior to all the treatments.

At the highest concentration of 2.5 mg kg^{-1} cadmium in the medium, the order of retention changed when compared with its lower concentrations. Though the best three hyper accumulators of cadmium in the root portions were ranked as sunflower (12.37 per cent), marigold (11.17 per cent) and globe amaranth (9.83 per cent) there were no practical significant variations between them in the back drop of statistical analysis. At this concentration also the weed plant (T_5) continued to maintain the status of the lowest (3.17 per cent) accumulator of cadmium.

4.3.2.3. Nickel

The performance of hyper accumulators and weed plant employed in the sand culture experiment under three successively high concentration of nickel *viz*; 0.5, 1.5

and 2.5 mg kg^{-1} were assessed for the uptake of this metal in their root portions, the study revealed that there was successive enhancement in uptake of this metal with enhancement of metal concentration in the media. At 0.5 mg kg^{-1} nickel in the media marigold (T_4) was adjudged as the best accumulator with an uptake of 2.67 per cent and remained with out significant difference to the next best hyper accumulator plant sunflower (T_2). Root portions of sunflower (T_2) and Indian mustard (T_1) maintained the second (2.17 per cent) and third (2.00 per cent) positions with respect to nickel uptake in the root portions. Though there was marginal difference in the uptake values between them they were on par.

At 1.5 mg kg^{-1} nickel concentration in the media, the best uptake in the root portions was performed by sunflower (5.20 per cent) followed by globe amaranth (4.57 per cent) and marigold (4.53 per cent). The statistical analysis of this data indicated that the uptake by sunflower (T_2) was significantly different to that from globe amaranth (T_3) and marigold (T_4). The marginal difference reckoned between globe amaranth and marigold with respect to uptake could not reflect any level of statistical difference.

At the highest concentration of 2.5 mg kg^{-1} nickel in the medium, the order of performance in the uptake by the root portions of hyper accumulators turned different from the corresponding lower concentrations. Though the highest uptake of 10.07 per cent nickel was identified with the root portions of globe amaranth (T_3) followed by 9.83 per cent in marigold (T_4) and 9.80 per cent in sunflower (T_2). All these values could not make any statistical difference between them. It is also observed that the root portions of the weed *Alternanthera tenella* (T_5) maintained one of the lowest uptakes of this metal compared to its counter parts at all the three levels of metal in the media.

4.4. POT CULTURE EXPERIMENT

Considering the appreciable uptake of metals and its retention in the root and shoot portions of hyper accumulators from the sand culture experiment it is seen that sunflower, globe amaranth and marigold were faithful plants in qualifying them as hyper accumulators. For this reason these three plants were carried forward for experimentation in pot culture experiment.

4.4.1. Assessment of potting mixture before experiment

The physico-chemical characteristics of the potting mixture constituted by mixing landfill material at different proportions with uncontaminated soil are presented in Table 28.

4.4.1.1. Bulk density

The Potting mixture when constituted at different proportions, bulk density ranged from 1.23 to 1.46 g cc^{-1}. A decrease in bulk density was noted with enhancement in the proportion of landfill materials in the pots. The lowest bulk density of 1.23 g cc^{-1} was associated with T_7 and T_8 where equal quantity of landfill materials and uncontaminated soil were mixed. The marginal variations in bulk density observed between treatments were significant only in treatments where the proportion of land fill materials additions were higher. The significance was more valid when bulk densities from treatments receiving higher quantity of land fill material were compared with either control or those treatments maintaining very low proportion of landfill materials.

Table 28. Physico-chemical characteristics of the pre-treatment potting mixture

Treatments	BD (g cc^{-1})	pH	EC (dS m^{-1})	OC (%)	Av. N (kg ha^{-1})	Av. P (kg ha^{-1})	Av. K (kg ha^{-1})	Al (mg kg^{-1})
T_1	1.42	4.18	0.07	1.67	171.93	13.66	167.60	9.69
T_2	1.43	4.19	0.08	1.72	179.14	11.51	159.62	9.83
T_3	1.44	4.16	0.17	2.47	227.33	24.25	232.88	10.17
T_4	1.44	4.12	0.19	2.23	229.47	26.11	243.06	10.27
T_5	1.31	4.57	0.51	2.61	278.20	37.57	267.80	11.49
T_6	1.32	4.60	0.50	2.75	267.71	38.34	272.13	12.56
T_7	1.23	6.90	0.53	3.88	338.51	47.62	308.44	13.69
T_8	1.23	6.91	0.75	3.79	346.51	48.38	314.25	13.71
T_9	1.46	4.12	0.05	0.83	165.49	8.16	150.18	6.24
T_{10}	1.46	4.13	0.04	0.76	160.90	7.14	142.45	6.28
CD (0.05)	0.009	0.085	0.002	0.057	3.076	1.762	3.202	1.266

T_1-Degradable landfill materials 1 kg + 9 kg virgin soils with AMF inoculation

T_2-Degradable landfill materials 1 kg + 9 kg virgin soils without AMF inoculation

T_3-Degradable landfill materials 2 kg + 8 kg virgin soils with AMF inoculation

T_4-Degradable landfill materials 2 kg + 8 kg virgin soils without AMF inoculation

T_5-Degradable landfill materials 3 kg + 7 kg virgin soils with AMF inoculation

T_6-Degradable landfill materials 3 kg + 7 kg virgin soils without AMF inoculation

T_7-Degradable landfill materials 5 kg + 5 kg virgin soils with AMF inoculation

T_8-Degradable landfill materials 5 kg + 5 kg virgin soils without AMF inoculation

T_9.Control 1 – 10 kg virgin soil with AMF inoculation

T_{10}.Control 2 – 10 kg virgin soil without AMF inoculation

4.4.1.2. pH

The pH value of the potting mixture varied from 4.12 to 6.91. Comparatively higher pH (6.90 and 6.91) was observed with higher proportions of the landfill materials use (T_7 and T_8). The uncontaminated soil (T_9) recorded the lowest pH value of 4.12. Compared to control, marginal variations in pH were observed in pots using different proportions of landfill, but significant differences were discerned only in T_5, T_6, T_7 and T_8 where the proportions of landfill material were comparatively higher.

4.4.1.3. Electrical conductivity

EC values of the potting mixture ranged from 0.04-0.75 dS m^{-1} and higher EC values were noted with the enhancement in the quantity of use of landfill materials. The values of EC in general remained within the safe limits even for a sensitive crop. There was significant difference in EC between every set of treatments. The lowest value of (0.04 dS m^{-1}) EC is identified with the control (T_{10}).

4.4.1.4. Organic carbon

The organic carbon content varied between 0.76-3.88 per cent. The highest per cent organic carbon was identified in T_7 where there was equal proportion of landfill materials and uncontaminated virgin soil. There was constant increase in organic carbon content with enhancement in the quantity of landfill material in the potting mixture. Between many treatments which accommodated different proportion of landfill materials, there were significant differences in organic carbon content.

4.4.1.5. Available nitrogen

There was significant difference in the available nitrogen status basically on account of the varied quantities in use of land fill materials. With enhancement in the quantity of landfill materials in the pots, the available nitrogen status also varied accordingly. The highest nitrogen content (346.51 kg ha^{-1}) was recorded in T_8 and the lowest nitrogen (160.90 kg ha^{-1}) was recorded in T_{10}.

4.4.1.6. Available phosphorus

The available phosphorus status observed between the different treatments and indicated significant variations. The available phosphorus status ranged from 7.14 (control) to 48.38 kg ha^{-1} in treatment 8 where in the maximum amount of landfill materials was added.

4.4.1.7. Available potassium

The available potassium status in the pot culture varied from 142.45 to 314.25 kg ha^{-1}. The highest available potassium (314.25 kg ha^{-1}) was associated with T_8 and the lowest available potassium (142.45 kg ha^{-1}) was associated with T_{10} (control). With enhancement in the use of land fill materials, there was proportionate and significant increase in available potassium.

4.4.1.8. Aluminium

Lowest value of aluminium content 6.24 mg kg^{-1} was identified with virgin soil and all other treatments were significantly different in the content of soil aluminium. The observed range of aluminium in the treatments varied between 6.24 to 13.71 mg kg^{-1}.

Table 29. Pre-treatment status of heavy metals in potting mixture

Treatments	Zn	Mn	Cu	Fe	Pb	Cd	Ni	Co	Cr	Hg
	mg kg^{-1}									
T_1	3.66	3.38	2.09	5.39	2.57	1.11	1.57	0.57	1.59	3.25
T_2	3.02	3.21	2.13	5.23	2.46	1.04	1.46	0.68	1.64	3.25
T_3	5.11	5.10	4.39	6.14	4.59	1.82	2.32	1.17	2.83	4.25
T_4	5.05	5.13	4.40	6.28	4.55	1.85	2.54	1.04	2.78	4.22
T_5	8.64	8.64	7.42	7.45	6.83	2.55	3.01	1.54	3.67	4.63
T_6	8.64	8.73	7.43	7.49	6.82	2.52	3.03	1.58	3.65	4.69
T_7	11.38	11.68	10.49	8.93	8.22	3.33	3.98	2.55	4.86	5.56
T_8	11.50	11.83	10.51	9.04	8.58	3.34	4.02	2.62	4.88	5.53
T_9	0.97	1.24	0.64	3.85	0.09	0.04	0.04	0.03	0.02	0.02
T_{10}	0.93	1.22	0.68	3.93	0.10	0.02	0.04	0.04	0.02	0.03
CD (0.05)	0.097	0.546	0.687	0.129	0.164	0.117	0.115	0.129	0.114	0.134

T_1-Degradable landfill materials 1 kg + 9 kg virgin soils with AMF inoculation

T_2-Degradable landfill materials 1 kg + 9 kg virgin soils without AMF inoculation

T_3-Degradable landfill materials 2 kg + 8 kg virgin soils with AMF inoculation

T_4-Degradable landfill materials 2 kg + 8 kg virgin soils without AMF inoculation

T_5-Degradable landfill materials 3 kg + 7 kg virgin soils with AMF inoculation

T_6-Degradable landfill materials 3 kg + 7 kg virgin soils without AMF inoculation

T_7-Degradable landfill materials 5 kg + 5 kg virgin soils with AMF inoculation

T_8-Degradable landfill materials 5 kg + 5 kg virgin soils without AMF inoculation

T_9-Control 1 – 10 kg virgin soil with AMF inoculation

T_{10}-Control 2 – 10 kg virgin soil without AMF inoculation

4.4.1.9. Heavy metals

Heavy metal status availability in different treatments after constituting the potting mixture is provided in Table 29. The initial zinc status in potting mixture prior to rising the hyper accumulators were much lower, specifically when compared after mixing with different proportions of land fill materials. With successive

enhancement in use of landfill materials in pots, there was attendant increase in the availability of the metals. Every treatment envisaging the use of higher land fill materials, maintained significantly superior in the metal level from every previous lower level of addition. The lowest zinc content 0.93 mg kg^{-1} zinc was reported in the control (T_{10}). A similar trend was observed for the rest of the heavy metal like manganese, copper, iron, lead, cadmium, nickel, cobalt, chromium and mercury. The range of values for zinc and manganese were 0.93-11.50 mg kg^{-1} and 1.22-11.83 mg kg^{-1}, respectively for T_{10} and T_8. The highest level of copper content (10.51 mg kg^{-1}) was detected in T_8, where maximum quantity of landfill material have been incorporated while the lowest (0.64 mg kg^{-1}) recorded in T_9. The variations in iron content ranged between 3.85 and 9.04 mg kg^{-1} with T_9 (control) and T_8 registering lower and higher values respectively.

Variations in the lead content were observed between treatments and ranged from 0.09 to 8.58 mg kg^{-1}. Similarly the cadmium content in the potting soil mixtures, varied between 0.02 and 3.34 mg kg^{-1}. The observed variation in nickel and copper in the potting mixture samples were between 0.04 and 4.02 and 0.04 and 2.62 mg kg^{-1}, respectively. Chromium and mercury content also varied between 0.02 and 4.88 mg kg^{-1} and 0.02 and 5.56 mg kg^{-1}, respectively.

4.4.2. Sunflower

4.4.2.1. Post harvest assessment of potting mixture

Table 30 depicts the physico-chemical characteristics of the post harvest soil samples made available in each pot.

Compared to pre-treatment samples, every post harvest soil samples maintained marginally higher bulk density. Compared to control and treatment with lowest proportion of land fill materials (T_9 and T_{10}), there was significant decrease in

bulk density was noted with higher levels of usage of landfill materials (T_7 and T_8) in the post harvest samples.

Table 30. Physico-chemical characteristics of post harvest soils after sunflower

Treatments	BD (g cc^{-1})	pH	EC (dS m^{-1})	OC (%)	Av. N (kg ha^{-1})	Av. P (kg ha^{-1})	Av. K (kg ha^{-1})	Al (mg kg^{-1})
T_1	1.43	4.37	0.12	1.55	137.72	13.19	113.63	7.42
T_2	1.46	4.43	0.11	1.57	125.21	14.64	114.55	7.24
T_3	1.45	4.35	0.20	2.21	163.54	15.47	124.34	8.67
T_4	1.48	4.15	0.17	2.12	151.22	16.55	127.33	8.48
T_5	1.36	7.93	0.18	2.52	221.72	21.74	161.47	9.75
T_6	1.32	5.07	0.23	2.62	217.80	26.52	182.58	9.57
T_7	1.25	7.33	0.20	3.25	255.50	27.37	201.96	10.70
T_8	1.21	6.68	0.15	3.38	248.79	32.96	223.07	10.45
T_9	1.51	3.15	0.25	0.59	113.67	6.64	82.22	5.84
T_{10}	1.48	3.98	0.12	0.46	110.29	8.54	85.78	5.65
CD (0.05)	0.010	0.628	0.031	0.045	4.450	2.479	3.934	0.795

T_1-Degradable landfill materials 1 kg + 9 kg virgin soils with AMF inoculation

T_2-Degradable landfill materials 1 kg + 9 kg virgin soils without AMF inoculation

T_3-Degradable landfill materials 2 kg + 8 kg virgin soils with AMF inoculation

T_4-Degradable landfill materials 2 kg + 8 kg virgin soils without AMF inoculation

T_5-Degradable landfill materials 3 kg + 7 kg virgin soils with AMF inoculation

T_6-Degradable landfill materials 3 kg + 7 kg virgin soils without AMF inoculation

T_7-Degradable landfill materials 5 kg + 5 kg virgin soils with AMF inoculation

T_8-Degradable landfill materials 5 kg + 5 kg virgin soils without AMF inoculation

T_9.Control 1 – 10 kg virgin soil with AMF inoculation

T_{10}.Control 2 – 10 kg virgin soil without AMF inoculation

The pH of the post harvest soil samples indicated a range between 3.15 and 7.33. Compared to corresponding pre-treatment soils there was marginal

enhancement in pH wherever landfill materials have been used. However in the case of control pots there was a tendency to decrease the pH. Soil reaction of the postharvest soil samples recorded significant variations between treatments particularly when higher proportions of the landfill materials (T_7 and T_8) have been accommodated in the potting mixture. There was significant difference in pH between treatments using AMF along with lower and higher levels of landfill materials. Similarly between those treatments using same level of landfill materials with and without AMF, had indicated tendencies to enhance soil reaction with the incorporation of AMF

Compared to pretreatment values, there were marginal variations in the EC in many post harvested soil samples, significant variations in EC were noted between treatments and since the maximum noted EC value was 0.25 dS m^{-1}, there was no reason for any concern for soil health or issues for plant growth and every value was well within the safe limits of EC in soil.

The organic carbon content in the post harvest samples were generally lower compared to its corresponding values in the pretreatment. Majority of the higher organic carbon status vested with higher levels of usage of landfill material remained significantly different from control or with any another treatment using lowest level of landfill materials. The influence of AMF in altering the organic carbon content within a particular treatment is not clear. The range of organic carbon values varied between 0.46 and 3.38 per cent.

The available nitrogen status in the post harvest soil samples was generally lower than the corresponding pretreatment values. Significant difference in the available nitrogen status existed between treatments and within treatments except T_5 and T_6. The lowest available nitrogen status (110.29 kg ha^{-1}) was associated with the control pot (T_{10}).

The available phosphorus status in the postharvest soils after raising sunflower was generally lower compared to corresponding pretreatment values. However, the influence of AMF in rendering better availability of phosphorus from treatments using it was very clear particularly when compared with its counterpart treatment where AMF is not used. Successive enhancement of levels of usage of landfill materials in the treatments had yielded significant and higher levels of available phosphorus. The status of available phosphorus in all treatment remained significantly superior when compared with control.

The available potassium status in post harvest soil samples offered lower levels in all treatments when compared to its counterpart in the pretreatment. In the post harvest soil samples, significance in the available potassium status was evident only with those treatment using higher levels of landfill materials. With the use of AMF in treatments, the available potassium status in post harvest soil samples decreased. The range of available potassium observed in treatments was between 82.22 to 223.07 kg ha^{-1}.

The aluminium status in postharvest samples ranged from 5.65-10.70 mg kg^{-1} with the lowest value getting recorded in control (T_{10}) without AMF combination and the highest value in T_7 where maximum quantity of degradable landfill material have been incorporated . At all points of incorporation of AMF in potting mixture the levels of aluminium continued remain higher compared to its pairing treatment without AMF.

Table 31. Post harvest status of heavy metals in potting mixture after raising sunflower, mg kg^{-1}

Treatments	Zn	Mn	Cu	Fe	Pb	Cd	Ni	Co	Cr	Hg
T_1	3.23	2.78	1.97	3.42	1.54	0.25	0.28	0.24	0.93	1.48
T_2	3.19	2.64	1.78	3.24	1.37	0.16	0.17	0.15	0.78	1.44
T_3	4.63	4.44	3.25	5.35	3.28	0.57	0.67	0.39	1.78	2.66
T_4	4.45	4.35	3.15	5.28	3.05	0.44	0.48	0.28	1.57	2.47
T_5	7.66	7.25	5.48	6.12	4.84	0.99	0.96	0.87	2.27	3.24
T_6	7.54	7.12	5.33	5.92	4.65	0.86	0.84	0.75	2.17	3.13
T_7	8.83	9.15	8.44	7.08	6.89	1.27	1.37	1.67	3.69	4.28
T_8	8.65	8.94	8.25	6.84	6.75	1.07	1.19	1.47	3.54	3.88
T_9	1.48	1.09	0.59	3.57	0.04	0.04	0.03	0.02	0.01	0.01
T_{10}	1.44	1.04	0.55	3.32	0.02	0.02	0.01	0.01	ND	ND
CD (0.05)	0.160	0.127	0.126	0.124	0.124	0.145	0.131	0.165	0.156	0.146

ND-Not Detected

T_1-Degradable landfill materials 1 kg + 9 kg virgin soils with AMF inoculation

T_2-Degradable landfill materials 1 kg + 9 kg virgin soils without AMF inoculation

T_3-Degradable landfill materials 2 kg + 8 kg virgin soils with AMF inoculation

T_4-Degradable landfill materials 2 kg + 8 kg virgin soils without AMF inoculation

T_5-Degradable landfill materials 3 kg + 7 kg virgin soils with AMF inoculation

T_6-Degradable landfill materials 3 kg + 7 kg virgin soils without AMF inoculation

T_7-Degradable landfill materials 5 kg + 5 kg virgin soils with AMF inoculation

T_8-Degradable landfill materials 5 kg + 5 kg virgin soils without AMF inoculation

T_9.Control 1 – 10 kg virgin soil with AMF inoculation

T_{10}.Control 2 – 10 kg virgin soil without AMF inoculation

The post harvest status of heavy metal in the soil samples where different quantities of land fill materials containing contaminants were provided for raising sunflower, a successful hyper accumulator for a period of three months is provided in table 31. In general, the different heavy metal status in soil samples offered more or

less similar trend particularly when compared with treatments receiving lower and higher quantities of land fill materials in the growing media. With enhancement in the levels of incorporation of contaminated and degradable landfill materials, the availability of all metal concentration remained high and this was in tune with enhancement in quantity of land fill used. Every metal offered its lowest level in the control pots and every metal status from other treatments when compared with control, remained significantly superior. In majority of the cases, maximum metal contamination was identified in Treatment 7 where the highest quantities of landfill materials have been incorporated along with AMF inoculation. The results highlight the fact that wherever AMF has been incorporated in the potting mixture, the availability of heavy metal in soil has been increased to a significantly higher level compared to its counterpart avoiding its use.

The highest level (8.83 mg kg^{-1}) of zinc content was noted in T_7 where maximum quantity of landfill material has been incorporated while the lowest (1.44 mg kg^{-1}) recorded in T_{10}. The range of values for manganese and copper were 1.04-9.15 and 0.55-8.44 mg kg^{-1}, respectively. The lowest iron content (3.32 mg kg^{-1}) was reported in T_{10} and the highest (7.08 mg kg^{-1}) recorded in T_7. The variations in the content of lead and cadmium levels in soils ranged between 0.02-6.89 mg kg^{-1} and 0.02-1.27 mg kg^{-1}, respectively for T_{10} (lowest value) and T_7 (highest value). The nickel values in the treatments varied between 0.01-1.37 mg kg^{-1} in which lowest value recorded in T_{10} and highest value in T_7. Similarly the variations in cobalt, chromium and mercury were 0.01-1.67, 0.003-3.69 and 0.003-4.28 mg kg^{-1}, respectively. In general, compared to pretreatment values, all the post harvest heavy metal status remained apparently lower in all the treatments.

4.4.2.2. Selective retention of metals

After raising sunflower for a period of three months in a series of designated treatment pots, the plant parts (root, shoot and seed) have been separately analyzed

for different metal contents like aluminium, zinc, manganese, copper, iron, lead, cadmium, nickel, cobalt, chromium and mercury. The respective content of different metals in the root, shoot and seeds are presented in Table 32, 33 and 34 respectively along with their biomass.

A close perusal of the data on root and shoot biomass indicated that treatments differences were clearly and significantly reflected in the biomass production. Treatment T_7, in which equal quantity of landfill material and virgin soil were mixed to constitute the potting mixture along with AMF registered highest root (33.60 g) and shoot (260.46 g) mass.

In general, it is seen that the root portion of sunflower maintained the maximum load of majority of heavy metals followed by the shoot portion and the least in the seeds. Among all treatments, T_8, which received the maximum quantity of degradable land fill materials without AMF inoculation maintained the maximum content of aluminium (2.05 mg kg^{-1}), copper (1.74 mg kg^{-1}), iron (1.05 mg kg^{-1}), cadmium (1.65 mg kg^{-1}), nickel (1.92 mg kg^{-1}), cobalt (0.65 mg kg^{-1}), chromium (0.86 mg kg^{-1}) and mercury (0.92 mg kg^{-1}) in the root portions. At the same, among all treatments, the maximum content of lead (1.07 mg kg^{-1}) was held by the shoot portion of the sunflower from the same T_8. On the contrary, the control pot (T_9) which received no addition of land fill materials but media inoculated with AMF, recorded the lowest content of various heavy metal in the root and shoot portions of sun flower compared to any other treatments. On comparison of metal load in different plant parts, from different treatments, it is seen that every treatment brought significant difference in the retention of various metal load in root and shoot portions of sunflower. But this significance was totally absent in the metal content retained by the seed portion from any treatment since the metal load was very low.

Table 32. Selective retention of different metal status in roots portion of sunflower under the influence of different treatments, mg kg^{-1}

Treatments	Weight (g)	Al	Zn	Mn	Cu	Fe	Pb	Cd	Ni	Co	Cr	Hg
T_1	3.11	0.44	0.43	0.28	0.22	0.05	0.06	0.18	0.16	0.04	0.04	0.02
T_2	2.80	0.65	0.64	0.45	0.27	0.08	0.10	0.44	0.38	0.06	0.06	0.06
T_3	27.97	0.84	0.84	0.72	0.42	0.13	0.14	0.66	0.73	0.09	0.09	0.10
T_4	22.90	1.09	1.03	0.95	0.61	0.26	0.25	0.85	0.97	0.13	0.16	0.15
T_5	30.06	1.35	1.24	1.13	0.84	0.46	0.34	1.04	1.14	0.18	0.21	0.19
T_6	24.46	1.56	1.47	1.36	1.14	0.64	0.46	1.17	1.27	0.27	0.34	0.29
T_7	33.60	1.74	1.75	1.53	1.28	0.84	0.65	1.37	1.56	0.46	0.57	0.42
T_8	27.36	2.05	1.97	1.84	1.74	1.05	0.95	1.65	1.92	0.65	0.86	0.92
T_9	2.78	0.26	0.22	0.13	0.11	0.023	ND	ND	ND	ND	ND	ND
T_{10}	1.45	0.36	0.38	0.23	0.16	0.043	ND	ND	ND	ND	ND	ND
CD (0.05)	2.068	0.175	0.152	0.119	0.144	0.113	0.104	0.141	0.144	0.086	0.094	0.065

ND-Not Detected

T_1-Degradable landfill materials 1 kg + 9 kg virgin soils with AMF inoculation

T_2-Degradable landfill materials 1 kg + 9 kg virgin soils without AMF inoculation

T_3-Degradable landfill materials 2 kg + 8 kg virgin soils with AMF inoculation

T_4-Degradable landfill materials 2 kg + 8 kg virgin soils without AMF inoculation

T_5-Degradable landfill materials 3 kg + 7 kg virgin soils with AMF inoculation

T_6-Degradable landfill materials 3 kg + 7 kg virgin soils without AMF inoculation

T_7-Degradable landfill materials 5 kg + 5 kg virgin soils with AMF inoculation

T_8-Degradable landfill materials 5 kg + 5 kg virgin soils without AMF inoculation

T_9-Control 1 – 10 kg virgin soil with AMF inoculation

T_{10}-Control 2 – 10 kg virgin soil without AMF inoculation

Table 33. Selective retention of different metal status in shoot portion of sunflower under the influence of different treatments, mg kg^{-1}

Treatments	Weight (g)	Al	Zn	Mn	Cu	Fe	Pb	Cd	Ni	Co	Cr	Hg
T_1	51.03	0.28	0.33	0.14	0.12	0.03	0.03	0.11	0.10	0.03	0.02	0.01
T_2	50.05	0.38	0.56	0.32	0.17	0.06	0.06	0.16	0.22	0.04	0.03	0.03
T_3	258.30	0.53	0.68	0.54	0.28	0.09	0.15	0.28	0.37	0.07	0.06	0.06
T_4	251.42	0.67	0.86	0.73	0.43	0.13	0.26	0.44	0.55	0.11	0.11	0.09
T_5	257.26	0.83	1.04	0.87	0.66	0.26	0.38	0.62	0.68	0.13	0.16	0.14
T_6	251.36	0.99	1.17	1.05	0.85	0.34	0.54	0.87	0.84	0.17	0.22	0.19
T_7	260.46	1.15	1.28	1.25	1.07	0.53	0.73	1.04	0.96	0.26	0.35	0.34
T_8	255.94	1.36	1.32	1.55	1.34	0.67	1.07	1.23	1.14	0.35	0.46	0.47
T_9	51.29	0.24	0.22	0.11	0.17	0.02	ND	ND	ND	ND	ND	ND
T_{10}	50.47	0.26	0.13	0.08	0.07	0.02	ND	ND	ND	ND	ND	ND
CD (0.05)	11.037	0.198	0.177	0.161	0.172	0.120	0.155	0.148	0.162	0.118	0.124	0.105

ND-Not Detected

T_1-Degradable landfill materials 1 kg + 9 kg virgin soils with AMF inoculation

T_2-Degradable landfill materials 1 kg + 9 kg virgin soils without AMF inoculation

T_3-Degradable landfill materials 2 kg + 8 kg virgin soils with AMF inoculation

T_4-Degradable landfill materials 2 kg + 8 kg virgin soils without AMF inoculation

T_5-Degradable landfill materials 3 kg + 7 kg virgin soils with AMF inoculation

T_6-Degradable landfill materials 3 kg + 7 kg virgin soils without AMF inoculation

T_7-Degradable landfill materials 5 kg + 5 kg virgin soils with AMF inoculation

T_8-Degradable landfill materials 5 kg + 5 kg virgin soils without AMF inoculation

T_9 .Control 1 – 10 kg virgin soil with AMF inoculation

T_{10} .Control 2 – 10 kg virgin soil without AMF inoculation

Table 34. Selective retention of different metal status in seed portion of sunflower under the influence of different treatments, mg kg^{-1}

Treatments	Al	Zn	Mn	Cu	Fe	Pb	Cd	Ni	Co	Cr	Hg
T_1	0.13	0.11	0.13	0.16	0.15	0.03	0.03	ND	0.01	ND	ND
T_2	0.16	0.13	0.16	0.17	0.18	0.05	0.05	ND	0.01	ND	ND
T_3	0.16	0.13	0.16	0.18	0.17	0.03	0.06	ND	0.01	0.01	0.01
T_4	0.15	0.17	0.18	0.23	0.19	0.06	0.07	0.01	0.02	0.01	0.01
T_5	0.18	0.19	0.18	0.23	0.22	0.07	0.08	0.06	0.04	0.02	0.01
T_6	0.17	0.25	0.17	0.25	0.24	0.03	0.09	0.05	0.05	0.02	0.01
T_7	0.23	0.26	0.24	0.27	0.25	0.10	0.12	0.09	0.07	0.04	0.02
T_8	0.29	0.24	0.26	0.26	0.25	0.11	0.13	0.09	0.07	0.05	0.02
T_9	0.15	0.10	0.09	0.14	0.08	ND	0.01	ND	ND	ND	ND
T_{10}	0.16	0.11	0.12	0.15	0.15	ND	0.01	ND	ND	ND	ND
CD (0.05)	NS	NS	NS	NS	NS	0.059	0.057	0.026	0.035	0.029	0.018

ND-Not Detected, NS-Non Significant

T_1-Degradable landfill materials 1 kg + 9 kg virgin soils with AMF inoculation

T_2-Degradable landfill materials 1 kg + 9 kg virgin soils without AMF inoculation

T_3-Degradable landfill materials 2 kg + 8 kg virgin soils with AMF inoculation

T_4-Degradable landfill materials 2 kg + 8 kg virgin soils without AMF inoculation

T_5-Degradable landfill materials 3 kg + 7 kg virgin soils with AMF inoculation

T_6-Degradable landfill materials 3 kg + 7 kg virgin soils without AMF inoculation

T_7-Degradable landfill materials 5 kg + 5 kg virgin soils with AMF inoculation

T_8-Degradable landfill materials 5 kg + 5 kg virgin soils without AMF inoculation

T_9.Control 1 – 10 kg virgin soil with AMF inoculation

T_{10}.Control 2 – 10 kg virgin soil without AMF inoculation

An overall comparison of Table 31 with Tables 32, 33 and 34 indicate that the absorption and retention of heavy metals by the root, shoot and seed portion of the sunflower were generally higher from those treatments without AMF inoculation. In other words, wherever AMF was inoculated in the potting mixture, the relative

availability of heavy metals in soil (post harvest soil samples) was higher and their corresponding uptake or retention in the plant parts was lower. All the observed content of heavy metals in the root, shoot and seed portions of sunflower were a true reflection of the levels of contamination in the growing media. The study further reveals that the heavy metal status in the seeds is far less than any of its other plant portions making seeds a hostile place for selective retention of heavy metals under normal levels of contamination.

4.4.3. Globe amaranth

4.4.3.1. Post harvest assessment of potting mixture

Table 35 depicts the various physico-chemical characteristics in the post harvest soil samples made available in each pot.

The influence of landfill materials in significantly altering the bulk density of the potting mixture was clearly evident at higher proportions of its usage. The application of AMF is seen to have marginally influenced the bulk density values in some sets of treatments. The range of bulk density values observed in the post harvest soil samples were between 1.21 and 1.50 g cc^{-1}.

Compared to control, there was significant difference in the enhancement of pH in all the treatments which received landfill materials in one proportion or other. The observed significant enhancement in pH was proportional to the increase in proportion of use landfill materials. The influence of AMF in altering the pH was not clear in the experiment. The observed range of pH in the potting mixture in the experiment ranged from 4.82-9.39.

The EC of potting mixtures in the post harvest samples though maintained significantly higher value at higher proportions of use of land fill materials. However, even at the highest quantity of land fill materials, EC values remained well within safe limits in all.

Table 35. Physico-chemical characteristics of potting mixture after globe amaranth

Treatments	BD ($g\ cc^{-1}$)	pH	EC ($dS\ m^{-1}$)	OC (%)	Av. N ($kg\ ha^{-1}$)	Av. P ($kg\ ha^{-1}$)	Av. K ($kg\ ha^{-1}$)	Al ($mg\ kg^{-1}$)
T_1	1.44	5.59	0.09	1.52	138.04	12.58	110.76	7.62
T_2	1.41	5.64	0.08	1.56	126.25	14.19	115.93	7.46
T_3	1.46	5.97	0.14	2.22	175.12	16.52	123.66	8.82
T_4	1.46	5.93	0.12	2.15	149.16	18.56	134.64	8.66
T_5	1.31	9.39	0.17	2.50	232.75	22.03	168.20	9.91
T_6	1.34	8.34	0.22	2.59	223.29	26.09	179.58	9.76
T_7	1.21	7.51	0.19	3.09	251.14	27.62	190.71	10.74
T_8	1.22	8.43	0.21	3.25	245.37	31.72	203.72	10.60
T_9	1.49	4.89	0.09	0.52	113.44	6.71	106.45	5.99
T_{10}	1.50	4.82	0.08	0.45	108.34	8.22	103.49	5.85
CD (0.05)	0.010	0.596	0.028	0.083	4.182	2.265	2.427	0.768

T_1-Degradable landfill materials 1 kg + 9 kg virgin soils with AMF inoculation

T_2-Degradable landfill materials 1 kg + 9 kg virgin soils without AMF inoculation

T_3-Degradable landfill materials 2 kg + 8 kg virgin soils with AMF inoculation

T_4-Degradable landfill materials 2 kg + 8 kg virgin soils without AMF inoculation

T_5-Degradable landfill materials 3 kg + 7 kg virgin soils with AMF inoculation

T_6-Degradable landfill materials 3 kg + 7 kg virgin soils without AMF inoculation

T_7-Degradable landfill materials 5 kg + 5 kg virgin soils with AMF inoculation

T_8-Degradable landfill materials 5 kg + 5 kg virgin soils without AMF inoculation

T_9-Control 1 – 10 kg virgin soil with AMF inoculation

T_{10}-Control 2 – 10 kg virgin soil without AMF inoculation

Significant enhancement in the organic carbon level in the post harvest samples of potting mixture were observed with enhancement in the levels of usage of landfill materials. The lowest level (0.45 per cent) of organic carbon was observed in T_{10} (control) while the highest level (3.25 per cent) of organic carbon associated with T_8 where the maximum quantity of landfill materials incorporated. Any specific trend

in altering the organic carbon content within a particular set of treatment could not be discerned due to the addition of AMF.

The available nitrogen status in the post harvest soil samples appeared to have scaled down from its corresponding pretreatment values. However the observed significant enhancement in available nitrogen status in post harvest soil samples with higher levels of usage of landfill materials was seen throughout the experiment particularly when compared with the set of controls with and without AMF.

On comparison of all treatments designed with and without AMF, it is seen that the values of available nitrogen had been pushed up significantly with the presence of AMF.

In general, the available phosphorus status in the post harvest soil samples appeared to have decreased from the respective pre-treatment values. With enhancement in the levels of addition of landfill materials in treatments, an inadvertent increase in available phosphorus proportional to the quantity added had been noticed. Incorporation of AMF was found to decrease the available phosphorus status at all points of its application and this observation can be confirmed with an enhanced phosphorus status in the pairing treatment without AMF. The range of available phosphorus observed in this experiment was between 6.71-31.72 kg ha^{-1}. Among the various treatments, control recorded the lowest level of available phosphorus status with no apparent and significant influence for AMF application.

The available potassium status in the post harvest soil samples maintained considerably lower levels when compared with the corresponding pretreatment values. Available potassium status ranged from 103.49- 203.72 kg ha^{-1}. There was an observed enhancement in available potassium status in pots with the successive enhancement in quantity of the landfill materials used in pots. There was significant depletion of available potassium status in soil wherever the use of AMF was ensured.

This can be confirmed within any pairing set of treatments with and without AMF application. Control values as usual recorded the lowest available potassium status.

The range of aluminium status in the post harvest soil samples where globe amaranth has been raised was between 5.85-10.74 mg kg^{-1} with the lowest value getting registered in control without AMF inoculation (T_{10}) and the highest content getting associated with (T_7) where landfill material had been used at maximum quantity with AMF inoculation. Compared to pretreatment samples, post harvest samples offered relatively lower values of aluminium. Incorporation of AMF had always rendered higher levels of aluminium in the soil particularly when compared with any pairing treatment which goes with and without AMF Compared to control, all the aluminium status in all other treatments remained significantly superior.

The post harvest heavy metal status after the harvest of globe amaranth, a well known hyper accumulator, grown for a period of three months is presented in Table 36.

The heavy metal status of post harvest soil samples where Globe amaranth had been raised indicate that there was a general enhancement of almost all metal status in the soil with corresponding enhancement in addition of landfill materials. Compared to the existence of different metal load in pre-treatment samples consequent to enrichment with different quantities of land fill materials, the post harvest soil status remained inferior with respect to many metals where AMF had not been used. The lowest levels of heavy metals have been detected in control (T_{10}) where application of AMF had been not made.

Table 36. Heavy metal status of potting mixture after globe amaranth, mg kg^{-1}

Treatments	Zn	Mn	Cu	Fe	Pb	Cd	Ni	Co	Cr	Hg
T_1	3.34	2.85	1.96	3.57	1.72	0.34	0.26	0.34	1.08	1.63
T_2	3.28	2.75	1.84	3.53	1.56	0.30	0.17	0.27	0.95	1.55
T_3	4.78	4.57	3.35	5.54	3.46	0.74	0.64	0.54	1.87	2.87
T_4	4.67	4.47	3.26	5.37	3.33	0.55	0.54	0.42	1.77	2.68
T_5	7.73	7.57	5.58	6.23	4.96	1.07	0.91	0.96	2.38	3.44
T_6	7.65	7.35	5.45	6.17	4.85	0.98	0.82	0.89	2.28	3.27
T_7	9.41	9.35	8.56	7.06	6.97	1.34	1.34	1.74	3.87	4.38
T_8	8.82	9.09	8.50	6.94	6.87	1.25	1.24	1.63	3.74	4.26
T_9	1.54	1.16	0.65	3.64	0.03	0.03	0.01	0.02	0.01	0.01
T_{10}	1.53	1.13	0.57	3.54	0.03	0.02	ND	0.01	0.00	0.01
CD (0.05)	0.164	0.893	0.586	0.612	0.153	0.146	0.200	0.139	0.151	0.177

ND-Not Detected

T_1-Degradable landfill materials 1 kg + 9 kg virgin soils with AMF inoculation

T_2-Degradable landfill materials 1 kg + 9 kg virgin soils without AMF inoculation

T_3-Degradable landfill materials 2 kg + 8 kg virgin soils with AMF inoculation

T_4-Degradable landfill materials 2 kg + 8 kg virgin soils without AMF inoculation

T_5-Degradable landfill materials 3 kg + 7 kg virgin soils with AMF inoculation

T_6-Degradable landfill materials 3 kg + 7 kg virgin soils without AMF inoculation

T_7-Degradable landfill materials 5 kg + 5 kg virgin soils with AMF inoculation

T_8-Degradable landfill materials 5 kg + 5 kg virgin soils without AMF inoculation

T_9-Control 1 – 10 kg virgin soil with AMF inoculation

T_{10}-Control 2 – 10 kg virgin soil without AMF inoculation

The highest zinc content (9.41 mg kg^{-1}) in post harvest soil samples had been associated with T_7 where the maximum quantities of landfill materials were used in conjunction with AMF. However, the lowest zinc content (1.53 mg kg^{-1}) was registered in T_{10} (control without AMF). The available range of manganese and

copper content in post harvest soils were between 1.13-9.35 mg kg^{-1} and 0.57-8.56 mg kg^{-1}, respectively for T_{10} and T_7. The iron content in the soil samples ranged between 3.54 and 7.06 mg kg^{-1}, respectively for T_{10} and T_7. The observed variations in lead and cadmium were between 0.026 - 6.97 mg kg^{-1} and 0.016-1.34 mg kg^{-1}, respectively. Similarly the observed variations in nickel, cobalt, chromium and mercury content were ranged in between 0.003-1.34, 0.006-1.74, 0.003-3.87 and 0.006-4.38 mg kg^{-1}, respectively.

4.4.3.2. Selective retention of metals

After raising globe amaranth for a period of three months in a series of designated treatment pots, the plant parts (root and shoot) have been separately analyzed for different metal contents like aluminium, zinc, manganese, copper, iron, lead, cadmium, nickel, cobalt, chromium and mercury and the details are provided in Table 37 and 38, respectively.

The biomass data on root and shoot weight revealed that the treatments had significantly and differentially influenced the growth of plants. Treatment T_7, in which 5 kg of landfill material and 5 kg virgin soil had mixed along with the application of AMF registered highest root (33.73 g) and shoot (300.27 g) weight.

While comparing the Tables 37 and 38, it can be discerned that the majority of heavy metal were confined in the root portions of globe amaranth rather than the shoot portions. However, in the case of lead this trend is reversed with maximum content of lead (0.97 mg kg^{-1}) accumulating in the shoot portions. In general, it is also seen that there was successive and significant enhancement in the absorption of various heavy metal status with enhancement in addition of the contaminated landfill materials in the growing medium. From the content of nickel absorbed by the root and shoot portions of globe amaranth, it is clearly visible that the quantum of absorption of nickel had significantly outranged the observed absorption of lead, cadmium, cobalt, chromium and mercury.

Table 37. Selective retention of different metals by root portion of globe amaranth, mg kg^{-1}

Treatments	Weight (g)	Al	Zn	Mn	Cu	Fe	Pb	Cd	Ni	Co	Cr	Hg
T_1	3.82	0.41	0.45	0.25	0.19	0.05	0.06	0.16	0.18	0.03	0.02	0.03
T_2	2.69	0.62	0.57	0.41	0.23	0.07	0.09	0.35	0.38	0.04	0.03	0.06
T_3	12.77	0.78	0.76	0.67	0.38	0.14	0.10	0.54	0.75	0.08	0.06	0.09
T_4	10.61	1.04	0.96	0.90	0.57	0.25	0.23	0.74	1.07	0.11	0.12	0.12
T_5	26.48	1.25	1.16	1.06	0.77	0.44	0.27	0.95	1.25	0.14	0.17	0.14
T_6	24.30	1.52	1.36	1.25	1.09	0.57	0.35	1.05	1.35	0.25	0.26	0.21
T_7	33.73	1.67	1.72	1.42	1.20	0.71	0.54	1.16	1.63	0.35	0.53	0.35
T_8	28.68	1.92	1.90	1.77	1.66	0.97	0.86	1.48	2.05	0.56	0.79	0.86
T_9	3.11	0.25	0.23	0.16	0.14	0.02	ND	ND	ND	ND	ND	ND
T_{10}	3.05	0.36	0.33	0.25	0.16	0.03	ND	ND	ND	ND	ND	ND
CD (0.05)	1.834	0.183	0.178	0.177	0.185	0.141	0.138	0.166	0.169	0.117	0.135	0.113

ND-Not Detected

T_1-Degradable landfill materials 1 kg + 9 kg virgin soils with AMF inoculation

T_2-Degradable landfill materials 1 kg + 9 kg virgin soils without AMF inoculation

T_3-Degradable landfill materials 2 kg + 8 kg virgin soils with AMF inoculation

T_4-Degradable landfill materials 2 kg + 8 kg virgin soils without AMF inoculation

T_5-Degradable landfill materials 3 kg + 7 kg virgin soils with AMF inoculation

T_6-Degradable landfill materials 3 kg + 7 kg virgin soils without AMF inoculation

T_7-Degradable landfill materials 5 kg + 5 kg virgin soils with AMF inoculation

T_8-Degradable landfill materials 5 kg + 5 kg virgin soils without AMF inoculation

T_9-Control 1 – 10 kg virgin soil with AMF inoculation

T_{10}-Control 2 – 10 kg virgin soil without AMF inoculation

Table 38. Selective retention of different metals by shoot portion of globe amaranth, mg kg^{-1}

Treatments	Weight (g)	Al	Zn	Mn	Cu	Fe	Pb	Cd	Ni	Co	Cr	Hg
T_1	50.98	0.26	0.26	0.15	0.09	0.03	0.03	0.09	0.14	0.04	0.02	0.01
T_2	49.38	0.28	0.53	0.26	0.12	0.07	0.06	0.14	0.25	0.06	0.02	0.02
T_3	154.02	0.45	0.62	0.45	0.24	0.10	0.15	0.23	0.37	0.07	0.04	0.06
T_4	124.05	0.53	0.82	0.65	0.34	0.15	0.22	0.35	0.56	0.09	0.09	0.07
T_5	235.03	0.74	0.97	0.76	0.57	0.22	0.33	0.54	0.73	0.10	0.11	0.13
T_6	218.56	0.87	1.06	0.96	0.75	0.27	0.47	0.76	0.86	0.13	0.18	0.14
T_7	300.27	1.06	1.17	1.16	0.95	0.43	0.64	0.95	1.04	0.21	0.27	0.25
T_8	258.11	1.23	1.27	1.42	1.15	0.55	0.97	1.17	1.18	0.28	0.37	0.33
T_9	51.09	0.26	0.12	0.15	0.16	0.02	ND	ND	ND	ND	ND	ND
T_{10}	49.36	0.27	0.21	0.08	0.07	0.02	ND	ND	ND	ND	ND	ND
CD (0.05)	9.371	0.214	0.188	0.193	0.171	0.140	0.144	0.158	0.168	0.082	0.079	0.10

ND-Not Detected

T_1-Degradable landfill materials 1 kg + 9 kg virgin soils with AMF inoculation

T_2-Degradable landfill materials 1 kg + 9 kg virgin soils without AMF inoculation

T_3-Degradable landfill materials 2 kg + 8 kg virgin soils with AMF inoculation

T_4-Degradable landfill materials 2 kg + 8 kg virgin soils without AMF inoculation

T_5-Degradable landfill materials 3 kg + 7 kg virgin soils with AMF inoculation

T_6-Degradable landfill materials 3 kg + 7 kg virgin soils without AMF inoculation

T_7-Degradable landfill materials 5 kg + 5 kg virgin soils with AMF inoculation

T_8-Degradable landfill materials 5 kg + 5 kg virgin soils without AMF inoculation

T_9-Control 1 – 10 kg virgin soil with AMF inoculation

T_{10}-Control 2 – 10 kg virgin soil without AMF inoculation

From the above Tables, it is further seen that the lowest level in use of land fill materials in the potting mixture, was not much significantly different from the control in registering any differential uptake of metals either into root or shoot

system from them. As seen in the case of sunflower, there was relative reduction in the heavy metals load in the shoot and root portions of globe amaranth wherever AMF was inoculated in the media and on the other hand, in the pairing treatment without AMF, the uptake of different metal were quite high in both root and shoot portions . The highest aluminium content was recorded in T_8 and the lowest in T_9 in case of both root and shoot portions and the respective values in root and shoot were 1.92 and 0.25 mg kg^{-1} in root and 1.23 and 0.26 mg kg^{-1} in shoot. Zinc and manganese dominated with their higher presence in the root and shoot portions. The maximum zinc concentration observed in root and shoot were 1.90 and 1.27 mg kg^{-1}, respectively and the maximum manganese recorded in root and shoot were 1.77 and 1.42 mg kg^{-1}, respectively both in T_8. The highest copper, iron, lead, cadmium, nickel, cobalt, chromium and mercury concentrations in roots were 1.66, 0.97, 0.86, 1.48, 2.05, 0.56, 0.79 and 0.86 mg kg^{-1}, respectively in T_8. The maximum content of copper, iron, lead, cadmium, nickel, cobalt, chromium and mercury in shoots were 1.15, 0.55, 0.97, 1.17, 1.18, 0.28, 0.37 and 0.33 mg kg^{-1}, respectively. In treatments T_9 and T_{10} the metals like lead, cadmium, nickel, cobalt, chromium and mercury were not detected both in root and shoot portions.

4.4.4. Marigold

4.4.4.1. Post harvest assessment of potting mixture

Table 39 depicts the various physico-chemical characteristics in the post harvest soil samples made available in each pot. The bulk density registered significant and lower values levels with every enhancement in the quantity of the usage of degradable landfill materials in the pots. Observation on highest bulk density value of 1.51 g cc^{-1} control (T_{10}) and the lowest value of 1.22 g cc^{-1} in T_8 which incidentally received maximum quantity of landfill materials in the potting mixture is a testimony to the above observation. After the harvest of marigold, the range in soil reaction (pH) was ranged from 4.48-8.88 indicating both acidic and alkaline nature.

The use of landfill materials in the mixture and their enhancement in the quantity in potting mixture brought both progressive and significant enhancement in pH. The influence of AMF in any visible alteration of pH in the experiment could not be discerned. Compared to control, other treatments maintained significantly higher levels of pH.

Table 39. Physico-chemical characteristics of potting mixture after marigold

Treatments	BD ($g\ cc^{-1}$)	pH	EC ($dS\ m^{-1}$)	OC (%)	Av. N ($kg\ ha^{-1}$)	Av. P ($kg\ ha^{-1}$)	Av. K ($kg\ ha^{-1}$)	Al ($mg\ kg^{-1}$)
T_1	1.43	5.48	0.12	1.54	137.85	13.81	116.64	7.71
T_2	1.43	6.25	0.11	1.55	125.62	15.38	119.59	7.64
T_3	1.45	6.66	0.18	2.26	165.42	18.46	126.69	8.93
T_4	1.44	6.77	0.12	2.16	155.65	19.31	129.53	8.80
T_5	1.38	6.72	0.29	2.59	238.28	22.42	165.42	6.95
T_6	1.36	7.15	0.38	2.65	226.41	27.67	188.73	9.87
T_7	1.22	8.88	0.34	3.32	263.79	31.59	209.61	10.70
T_8	1.20	8.83	0.27	3.39	250.92	34.72	226.69	10.54
T_9	1.48	4.93	0.12	0.62	114.44	6.60	85.85	6.06
T_{10}	1.51	4.48	0.12	0.53	112.74	8.02	91.49	5.95
CD (0.05)	0.004	0.514	0.057	0.038	2.846	1.887	2.755	2.769

T_1-Degradable landfill materials 1 kg + 9 kg virgin soils with AMF inoculation

T_2-Degradable landfill materials 1 kg + 9 kg virgin soils without AMF inoculation

T_3-Degradable landfill materials 2 kg + 8 kg virgin soils with AMF inoculation

T_4-Degradable landfill materials 2 kg + 8 kg virgin soils without AMF inoculation

T_5-Degradable landfill materials 3 kg + 7 kg virgin soils with AMF inoculation

T_6-Degradable landfill materials 3 kg + 7 kg virgin soils without AMF inoculation

T_7-Degradable landfill materials 5 kg + 5 kg virgin soils with AMF inoculation

T_8-Degradable landfill materials 5 kg + 5 kg virgin soils without AMF inoculation

T_9-Control 1 – 10 kg virgin soil with AMF inoculation

T_{10}-Control 2 – 10 kg virgin soil without AMF inoculation

The EC values observed in the post harvest experimental soils were in normal range when compared to lower levels of applications of landfill materials; the higher levels presented significantly higher values. But these values were high enough to create any threat. The EC values noted in the experiment ranged between 0.11 and 0.38 dS m^{-1}.

The organic carbon levels observed in various treatments brought significant differences between treatments and the extent of the use of degradable landfill materials in treatments was a real criterion for the observed significance. The organic carbon analyzed in the study ranged from 0.53-3.39 per cent. Control pots recorded the significantly lowest level of organic carbon.

The available nitrogen status made available from the study in the post harvest soils indicated that there was enhancement in their levels with enhancement in the usage of degradable landfill materials. The available nitrogen status ranged from 112.74-263.79 kg ha^{-1}. Compared to pretreatment samples there was considerable reduction in the level of available nitrogen in the post harvest soil samples in all corresponding treatments.

The available phosphorus status continued to remain lower in the post harvest samples compared to its corresponding values in the pretreatment samples. With enhancement in the usage of landfill material in the mixture there was significant enhancement in the available phosphorus status which remained significantly superior to any preceding levels in the treatments. Control values for available phosphorus were significantly lower than the rest of the treatments. Influence of AMF in altering the available phosphorus status within a paring treatment with and without the application of AMF is very clear and evident.

The available potassium status in the post harvest soil samples recorded from the Marigold experiment maintained a similar trend as seen in Sunflower or Globe amaranth. Compared to pretreatment values, the post harvest soil samples offered a

decline in the net availability of potassium. However from the entire experiment, it is seen that there was significant enhancement in the availability of potassium with every higher levels of usage of landfill materials in pots. Wherever the inoculation of AMF has been ensured in the media, there had been significant depletion of available potassium status particularly when compared with its pairing treatment without the use of AMF.

The heavy metal status in the postharvest soil samples in the field experiment after raising a hyper accumulator Marigold for three months with and without AMF inoculation is presented in Table 40.

Compared to pretreated soil samples, the post harvest status of heavy metals were comparatively lower. With enhancement in the quantity of degradable materials in the potting mixture/treatments there was corresponding enhancement in the concentration of almost all the metals status, but definitely much lower that its pretreatment values. In general, all the heavy metal status of pairing control pots with and without AMF maintained more or less similar status with that of T_1 and T_2 where the quantity of landfill materials have been restricted to minimum of 1 kg. Though there was enhancement in the availability of various metals in postharvest soils samples with enhancement in the quantity of use of land fill materials, the values were much lower than its pretreatment status. In this experiment, a comparison of effect of the inoculation and non inoculation of AMF revealed that inoculation of AMF restricted the entry of heavy metals into plant parts naturally creating higher levels of heavy metals in such treatments.

Table 40. Heavy metal status of potting mixture after marigold, mg kg^{-1}

Treatments	Zn	Mn	Cu	Fe	Pb	Cd	Ni	Co	Cr	Hg
T_1	3.42	2.92	2.07	3.62	1.83	0.37	0.34	0.44	0.86	1.74
T_2	3.29	2.82	1.96	3.56	1.72	0.33	0.29	0.32	0.66	1.61
T_3	4.85	4.62	3.53	5.61	3.55	0.82	0.73	0.63	1.54	2.96
T_4	4.73	4.53	3.30	5.51	3.45	0.75	0.65	0.51	1.32	2.85
T_5	7.83	7.65	5.66	6.35	5.04	1.06	1.04	1.02	2.06	3.54
T_6	7.71	7.51	5.53	6.22	4.95	0.95	0.94	0.94	1.92	3.42
T_7	9.62	9.51	8.67	7.03	7.05	1.44	1.50	1.88	3.42	4.44
T_8	9.44	9.36	8.55	6.94	6.93	1.33	1.37	1.72	3.26	4.36
T_9	0.46	1.03	0.72	3.76	0.08	0.06	0.04	0.04	ND	0.02
T_{10}	0.43	0.95	0.66	3.66	0.04	0.03	0.02	0.01	ND	0.02
CD (0.05)	0.072	0.064	0.062	0.073	0.078	0.072	0.066	0.060	0.075	0.056

ND-Not Detected

T_1-Degradable landfill materials 1 kg + 9 kg virgin soils with AMF inoculation

T_2-Degradable landfill materials 1 kg + 9 kg virgin soils without AMF inoculation

T_3-Degradable landfill materials 2 kg + 8 kg virgin soils with AMF inoculation

T_4-Degradable landfill materials 2 kg + 8 kg virgin soils without AMF inoculation

T_5-Degradable landfill materials 3 kg + 7 kg virgin soils with AMF inoculation

T_6-Degradable landfill materials 3 kg + 7 kg virgin soils without AMF inoculation

T_7-Degradable landfill materials 5 kg + 5 kg virgin soils with AMF inoculation

T_8-Degradable landfill materials 5 kg + 5 kg virgin soils without AMF inoculation

T_9-Control 1 – 10 kg virgin soil with AMF inoculation

T_{10}-Control 2 – 10 kg virgin soil without AMF inoculation

Treatment 7, which accommodated maximum quantity of degradable land fill materials with AMF inoculation in the potting mixture, provided the maximum metal load in the post harvest soil samples. When this metal status was compared with other treatments envisaging lesser quantum of use land fill material, the metal status

remained comparatively and significantly lesser. Treatment 7 recorded the highest levels of zinc (9.62 mg kg^{-1}), manganese (9.51 mg kg^{-1}), copper (8.67 mg kg^{-1}), iron (7.03 mg kg^{-1}), lead (7.05 mg kg^{-1}), cadmium (1.44 mg kg^{-1}), nickel (1.50 mg kg^{-1}), cobalt (1.88 mg kg^{-1}), chromium (3.42 mg kg^{-1}) and mercury (4.44 mg kg^{-1}). On the contrary, the lowest metal load in post harvest soil samples had been identified from treatment T_{10} (Control) where AMF inoculation was not made. Due to differential quantum in use of the degradable land fill materials in pots and differential uptake by plants, the metal availability also fluctuated accordingly, providing a range of availability in the post harvest soil samples. The zinc and manganese varied from 0.43-9.62 mg kg^{-1} and 0.95-9.51 mg kg^{-1}, respectively. The relative content of copper, iron and lead varied from 0.66-8.67, 3.62-7.03 and 0.04-7.05 mg kg^{-1}, respectively. The content of cadmium, nickel, cobalt and chromium were 0.03-1.44, 0.02-1.50, 0.01-1.88 and 0 - 3.42 mg kg^{-1}, respectively. Range of mercury in potting mixture after raising the marigold was between 0.016-4.44 mg kg^{-1}.

4.4.4.2. Selective retention of metals

The effectiveness of marigold as a hyper accumulator was assessed through a pot culture experiment where different proportions of contaminated landfill material were used with and without inoculation of AMF and the extent of various metal accumulations in the root and shoot portions are presented in Table 41 and 42.

As in the case of other two hyper accumulators, marigold in general, supported significantly higher content of heavy metals in the root portions of the plant compared to its shoot portions from any treatment. In T_8, which received maximum quantity of degradable land fill materials without an inoculation of AMF, supported the maximum metal load in both root and shoot portion of marigold.

Table 41. Selective retention of different metals by root portion of marigold, mg kg^{-1}

Treatments	Weight (g)	Al	Zn	Mn	Cu	Fe	Pb	Cd	Ni	Co	Cr	Hg
T_1	2.07	0.37	0.42	0.26	0.18	0.04	0.06	0.15	0.15	0.04	0.07	0.02
T_2	0.93	0.58	0.58	0.44	0.23	0.06	0.07	0.40	0.30	0.06	0.10	0.04
T_3	5.76	0.82	0.76	0.66	0.36	0.10	0.10	0.57	0.64	0.07	0.14	0.08
T_4	4.68	1.01	0.95	0.88	0.54	0.22	0.15	0.77	0.90	0.11	0.22	0.11
T_5	9.24	1.22	1.12	1.07	0.77	0.41	0.27	0.96	1.07	0.14	0.27	0.15
T_6	6.84	1.44	1.34	1.23	1.07	0.55	0.43	1.06	1.14	0.19	0.36	0.23
T_7	21.35	1.64	1.62	1.44	1.15	0.74	0.56	1.25	1.42	0.37	0.63	0.32
T_8	18.04	1.92	1.83	1.77	1.57	0.97	0.86	1.54	1.85	0.55	0.95	0.76
T_9	1.30	0.18	0.19	0.13	0.08	0.03	ND	ND	ND	ND	ND	ND
T_{10}	0.49	0.25	0.31	0.18	0.09	0.04	ND	ND	ND	ND	ND	ND
CD (0.05)	2.235	0.188	0.208	0.173	0.161	0.128	0.126	0.154	0.175	0.103	0.09	0.108

ND-Not Detected

T_1-Degradable landfill materials 1 kg + 9 kg virgin soils with AMF inoculation

T_2-Degradable landfill materials 1 kg + 9 kg virgin soils without AMF inoculation

T_3-Degradable landfill materials 2 kg + 8 kg virgin soils with AMF inoculation

T_4-Degradable landfill materials 2 kg + 8 kg virgin soils without AMF inoculation

T_5-Degradable landfill materials 3 kg + 7 kg virgin soils with AMF inoculation

T_6-Degradable landfill materials 3 kg + 7 kg virgin soils without AMF inoculation

T_7-Degradable landfill materials 5 kg + 5 kg virgin soils with AMF inoculation

T_8-Degradable landfill materials 5 kg + 5 kg virgin soils without AMF inoculation

T_9-Control 1 – 10 kg virgin soil with AMF inoculation

T_{10}-Control 2 – 10 kg virgin soil without AMF inoculation

Table 42.Selective retention of different metals by shoot portion of marigold, mg kg^{-1}

Treatments	Weight (g)	Al	Zn	Mn	Cu	Fe	Pb	Cd	Ni	Co	Cr	Hg
T_1	10.65	0.16	0.32	0.11	0.12	0.03	0.03	0.07	0.07	0.03	0.06	0.01
T_2	8.19	0.28	0.53	0.28	0.15	0.06	0.06	0.13	0.16	0.04	0.08	0.03
T_3	13.59	0.45	0.63	0.49	0.23	0.08	0.11	0.23	0.31	0.07	0.09	0.05
T_4	9.06	0.61	0.78	0.66	0.36	0.10	0.23	0.35	0.46	0.09	0.15	0.07
T_5	98.99	0.76	0.97	0.82	0.58	0.16	0.33	0.53	0.62	0.11	0.19	0.11
T_6	88.64	0.86	1.02	0.95	0.73	0.24	0.45	0.81	0.74	0.13	0.27	0.14
T_7	246.61	1.04	1.14	1.17	0.98	0.44	0.66	0.96	0.86	0.21	0.43	0.26
T_8	218.26	1.23	1.25	1.43	1.23	0.54	0.96	1.13	1.06	0.28	0.57	0.42
T_9	12.06	0.21	0.11	0.10	0.14	0.02	ND	ND	ND	ND	ND	ND
T_{10}	5.09	0.23	0.23	0.11	0.07	0.03	ND	ND	ND	ND	ND	ND
CD (0.05)	14.439	0.165	0.163	0.155	0.144	0.094	0.114	0.154	0.170	0.067	0.109	0.087

ND-Not Detected

T_1-Degradable landfill materials 1 kg + 9 kg virgin soils with AMF inoculation

T_2-Degradable landfill materials 1 kg + 9 kg virgin soils without AMF inoculation

T_3-Degradable landfill materials 2 kg + 8 kg virgin soils with AMF inoculation

T_4-Degradable landfill materials 2 kg + 8 kg virgin soils without AMF inoculation

T_5-Degradable landfill materials 3 kg + 7 kg virgin soils with AMF inoculation

T_6-Degradable landfill materials 3 kg + 7 kg virgin soils without AMF inoculation

T_7-Degradable landfill materials 5 kg + 5 kg virgin soils with AMF inoculation

T_8-Degradable landfill materials 5 kg + 5 kg virgin soils without AMF inoculation

T_9-Control 1 – 10 kg virgin soil with AMF inoculation

T_{10}-Control 2 – 10 kg virgin soil without AMF inoculation

The extent of different metal accumulation in roots from this treatment was Al (1.92 mg kg^{-1}), Zn (1.83 mg kg^{-1}), Mn (1.77 mg kg^{-1}), Cu (1.57 mg kg^{-1}), Fe (0.97 mg kg^{-1}), Pb (0.86 mg kg^{-1}), Cd (1.54 mg kg^{-1}), Ni (1.85 mg kg^{-1}), Co (0.55 mg kg^{-1}), Cr (0.95 mg kg^{-1}) and Hg (0.76 mg kg^{-1}). However, from the same treatment, the only

metal that was identified in shoot to exceed the accumulation levels in the root portions of marigold was lead. The extent of various metal retention in the shoot portions of T_8 were Al (1.23 mg kg^{-1}), Zn (1.25 mg kg^{-1}), Mn(1.43 mg kg^{-1}), Cu (1.23 mg kg^{-1}), Fe (0.54 mg kg^{-1}), Pb (0.96 mg kg^{-1}), Cd (1.13 mg kg^{-1}), Ni (1.06 mg kg^{-1}), Co (0.28 mg kg^{-1}), Cr (0.57 mg kg^{-1}) and Hg (0.42 mg kg^{-1}).

In case of T_9 and T_{10} metals like lead, cadmium, nickel, cobalt, chromium and mercury in both root and shoot were not detected in treatments. Though the lowest content of various other metals have been identified in the root and shoot portions from the control pot (T_9) with AMF inoculation, they were not much significantly different from those observed from T_{10} or T_1 or T_2. Here T_{10} was a pairing control pot with AMF inoculation while T_1 and T_2 received one of the lowest levels of contaminated landfill material addition (1kg each) in the 10 kg potting media with and without AMF inoculation.

Like other hyper accumulators undertaken in this study, all AMF inoculation in the growing media was found to restrict the absorption of heavy metal from it either into root or shoot portions. This fact can be verified from any pairing treatment without AMF inoculation where the metal absorption plant parts were relatively high. Between the higher and lower levels of usage of degradable land fill materials or between any two successive levels, the extent of absorption of metals in plant portions remained significant, more so when similar plant parts are concerned.

In the case of marigold, it is further seen that this particular plant had preferentially maintained higher levels of chromium in both root (0.95 mg kg^{-1}) and shoot (0.57 mg kg^{-1}) portions compared to the either sunflower or globe amaranth under similar situation. Thus this study elevates this plant to an excellent hyper accumulator for chromium.

Discussion

5. DISCUSSION

A study was undertaken to assess the impact of landfill on soil health and water quality in a waste disposal site at Vilappilsala, near Thiruvananthapuram. The study comprised of monitoring of waste materials from two adjacent landfill sites, leachates originating from them, soils along leachate zone at two depths, extent of contamination of different metals in the nearby ground water sources, identification of hyper accumulation capacity of popular weed species along the leachate zone, performance of certain selected hyper accumulators through a sand culture and pot culture experiment. The results obtained from the various segments of study are discussed below.

5.1. MONITORING OF LANDFILL AREA AND LEACHATE ZONE FOR ASSESSING THE CONTAMINATION LEVEL

5.1.1. Landfill material

The un-segregated solid waste materials of unknown etiology, generated in various parts of Thiruvanathapuram city had been taken to Vilappilsala for disposal. At the plant site, before dumping the collected waste, degradable organic part had been segregated and the remaining solid waste materials have been disposed off at two nearby sites in the designated garbage treatment plant area without attending to any of the scientific prerequisites insisted for a sanitary landfill. Hence for this reason, the disposal site does not qualify to be technically called as sanitary landfill and the issues arising from this can't be related or compared to any other sanitary landfill or landfill materials. At one dumpsite at Vilappilsala garbage treatment plant, there had been continuous dumping of waste, it's leveling and compaction and when once the area had been filled to designated capacity, surface was covered with welded UV-stabilized polythene sheet. Later over this, a thick soil capping was provided for giving normal look with necessary air vents provided at different places for allowing the landfill gases to escape. But in the second dumpsite, before this kind of covering

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and capping could be done, the plant had to be closed due to local agitations and severe protest, creating more environmental issues than the other. In short, both dumpsites within the plant area have not complied with either Municipal Solid Wastes (Management and Handling) Rules, 2000 (GOI, 2000) or Solid Waste Management Rules, 2016 (GOI, 2016) by Government of India.

5.1.1.1. Bulk density

The bulk density observed in the dumped materials (Table 9) is much lower than that observed for normal soils and this might be due to the presence of different slowly degrading materials which have come up for filling. Anikwe and Nwobodo (2002) also observed lower bulk density for the landfill material and is a perfect justification to the current observation. Since all the seasonal samples had been collected within one year of study from the geo-coded locations, the time factor was too short to bring any apparent variations in the observed bulk densities (Fig. 1).

5.1.1.2. pH

The acidic range of pH observed during the three sampling period which ranged from 5.37 to 6.41 (Table 9) might be due to the combined influence of the slowly degrading waste materials and the acidic nature of the soil which must have gone for capping the surface (Fig. 1). In this context, Aziz *et al.* (2010) opinioned that, the pH of any landfill material is likely to vary depending upon the age of landfill. According to them, for any relatively new landfill pH varies from 4.5 to 7.5 maintaining acidic nature due to the presence of volatile fatty acids. Further they indicated that as the age of landfill increases, there will be stabilization of pH due to stabilization of the humic and fulvic acids.

5.1.1.3. Electrical conductivity

In the case of EC the values, all observed values were normal and non-problematic at dump site sites and seasonal influences were insignificant (Table 9).

Since the current anlaysis was done three years after the execution of dump and in the absence of a then reference soil sample or reference EC value, it is not just possible to assess the swing in EC values. The absence of significant variation in EC at the samples in three seasons might be due to stabilization in the release of soluble ions from the dumped waste (Fig. 1).

5.1.1.4. Organic carbon

The reason for the non appreciable variations in the organic carbon levels (Table 9) in the study particularly between seasons might be due to stabilization of the available organic carbon at the sampling points. It is very much possible that stabilization of humic fractions might have taken place restricting the variations in organic carbon levels. This argument is in conformity with the observations of Aziz *et al.* (2010).

5.1.1.5. N, P, K, Ca, Mg and Al

Seasonal variations during the entire sampling period, was quite enough to bring in variations in the levels of N, P, K, Ca and Mg at the geo-referenced sampling points (Table 9). Marginal enhancement in their values in pre-monsoon season compared to other two seasons might be due the availability of sufficiently long hot spells prior to monsoon period for ionization processes. Observed lower values for various ions in the post-monsoon period might be due to the combined effect leaching of various ions from the landfill site by storm water during rainy seasons bringing lowest values during that season and the absence of sufficient time to recoup the various ions back to original status in post monsoon period (Fig. 1). The relatively higher content of potassium in the pre-monsoon period compared to the other two seasons must be a reflection of the higher content of potassium in the dumped waste material under the influence of a relatively long hot period after the monsoon season.

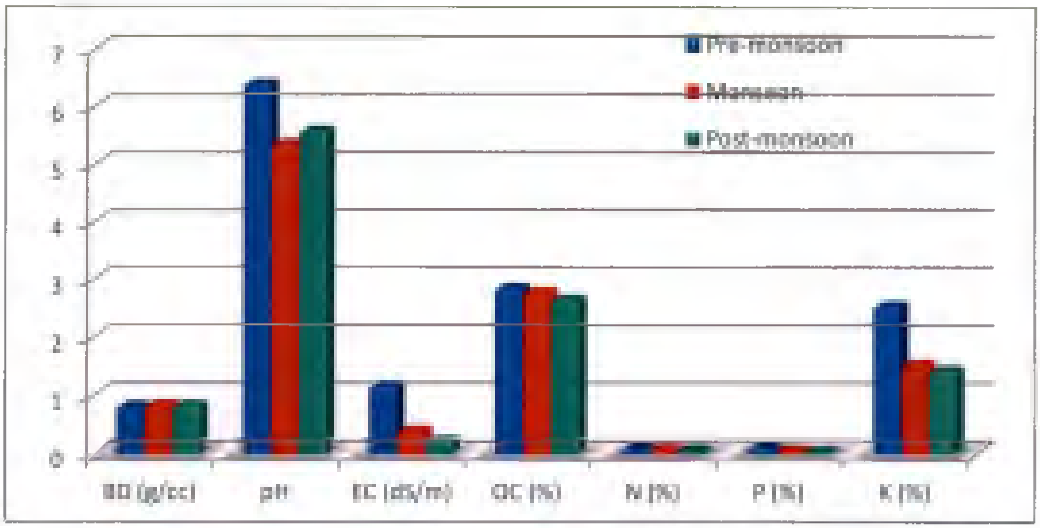

Figure 1. Seasonal variations in physico-chemical characteristics of landfill materials

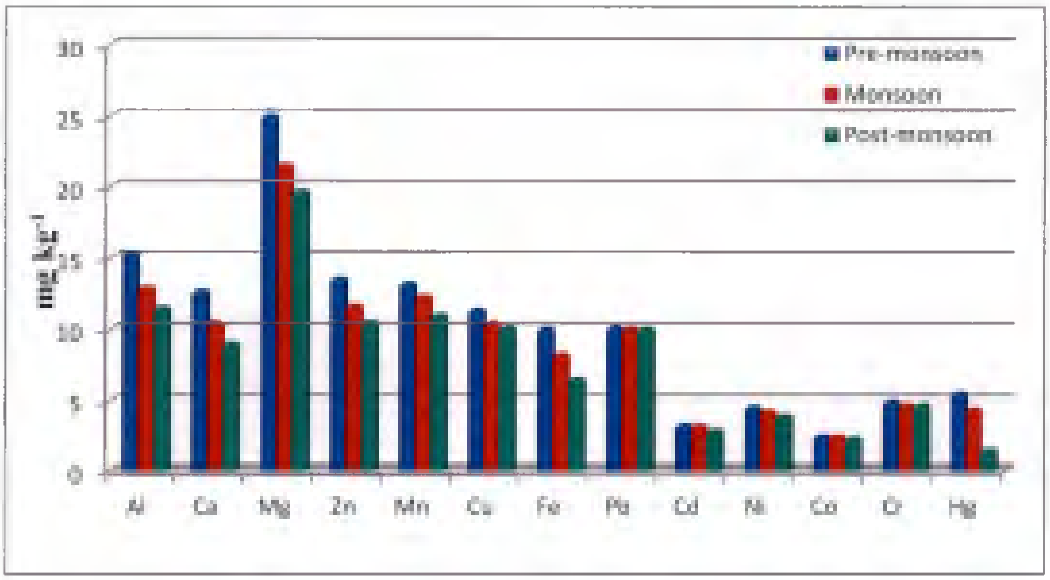

Figure 2. Seasonal variations in metal status of landfill materials

The same trend was seen for the observed aluminium content in the landfill materials and reasons substantiated above justify the observed values. Shivakumar and Srikantaswamy (2012) also endorsed a similar view about a general higher availability of nutrients in the pre-monsoon period.

5.1.1.6. Heavy metals

Evaluations on the availability of heavy metals like Zn, Mn, Cu, Fe, Pb, Cd, Ni, Co, Cr and Hg in the geo-referenced sampling points in waste dump across the three successive seasons of study indicated marginal differences between seasons (Table 9 and Fig. 2). The main reason for the observed variation in the concentration of a particular metal between seasons must obviously due to the seasonal effect particularly of the rainfall in either diluting the concentration and subsequent plant removal from that point. D'souza and Somashekar (2013) indicated that there is good possibility for getting variations in the heavy metal status within landfill materials and particularly between seasons specifically on account of the dilution effect and leaching effect introduced by rainfall.

5.1.2. Soil samples

5.1.2.1. Bulk density

From the Tables 10, 11 and 12 which depicts the physico-chemical properties of soil samples along the leachate zone at two depths when monitored up to a distance of 350 m from the landfill site in three distinct seasons of study revealed that the observed increase in bulk density at the second depth of sampling (30-60 cm) compared to first depth (0-30 cm) might be due to the natural compaction and low organic matter content of the soils (Fig. 3). The relatively higher content of organic matter in the upper layer might also have contributed in promoting better aggregation and aggregate stability in the surface soil justifying a lower bulk density in the upper

layers compared to its second depth. Hamza and Anderson (2005) endorsed a similar view in their studies reasoning the variations in bulk density at two depths in a soil.

5.1.2.2. pH

Irrespective of the depth of sampling, the soils maintained an acidic reaction all through the sampling seasons (Fig. 4). A general enhancement in pH noted during the monsoon period compared to other seasons might be due to the alkaline nature of the effluents which oozed out from the dumped waste in greater proportions during the monsoon seasons. The excessive dissolution of salts (soluble ions) and release of exchangeable cations during mineralization of waste material particularly at lower depths might have influenced the leachate in attaining a higher pH during the monsoon period. According to Ali *et al.* (2014), such a possibility has been worked out as a main reason for escalation of pH in the leachate sample during monsoon period.

Though the leachate emanating from landfill remained alkaline in rainy season, the failure of the soil to pick up an alkaline reaction might be due to the attended dilution brought in by the rainfall in the leachate zone and nullifying its potential to enhance the pH of the surface soils. According to Shivakumar and Srikantaswamy (2012), the buffering effect of organic carbon available in the surface soil might have prevented the soil from attaining an alkaline reaction.

5.1.2.3. Electrical conductivity

The marginal enhancement of EC in monsoon period (Table 11) noted in many of the soil samples particularly up to a distance of 150 m from landfill area might again be due to the direct influence of some ions (more soluble cations) in the emanating leachate from the waste zone (Fig. 5). The subsequently lower EC in soil samples beyond 150 m might be due to the direct impact of the rainfall or because of the dilution effect initiated by the running water through this area and also due to the

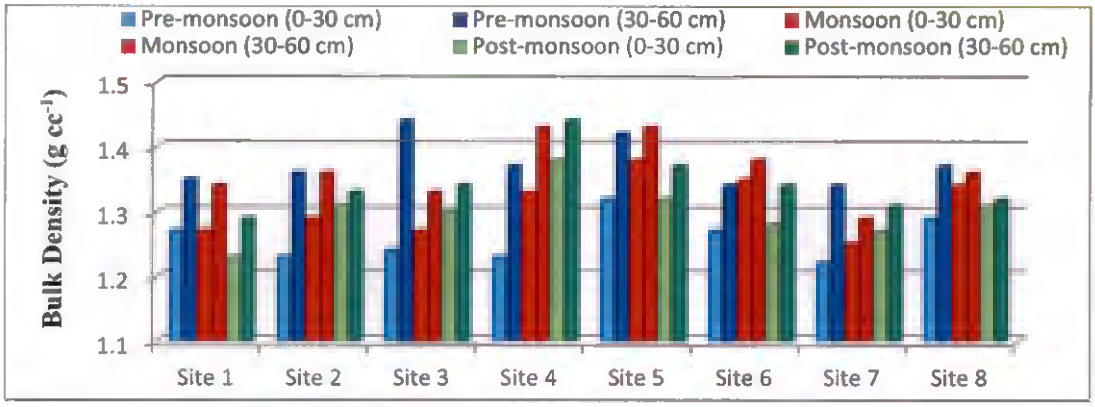

Figure 3. Seasonal variations in bulk density of soils at two depths along the leachate zone

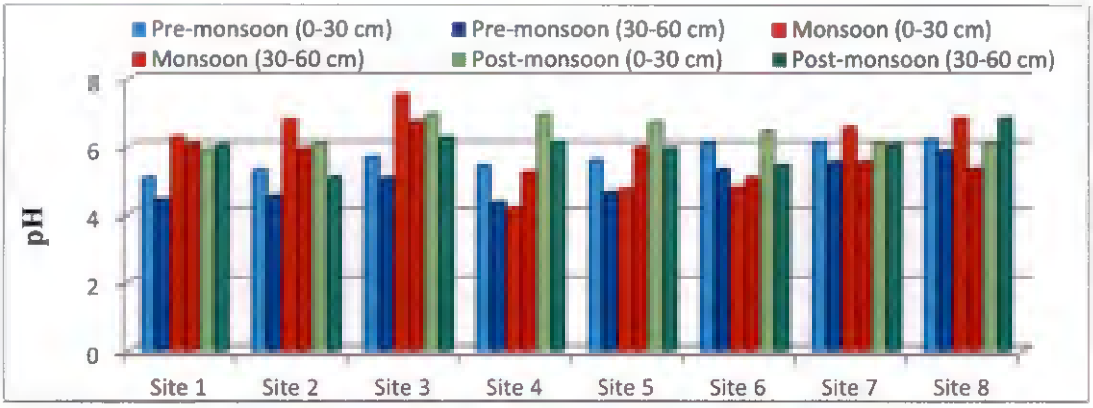

Figure 4. Seasonal variations in pH at two soil depths along the leachate zone

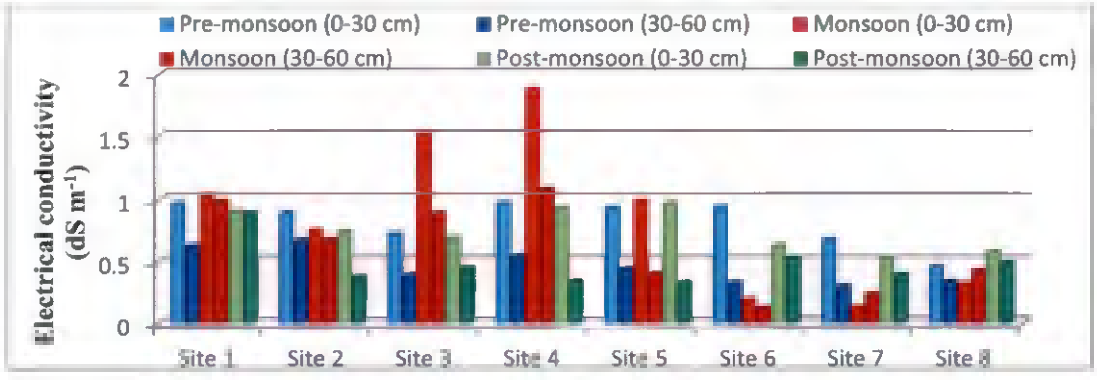

Figure 5. Seasonal variations in electrical conductivity at two soil depths along the leachate zone

absorption of soils. According to Anikwe and Nwobodo (2002), it is suggested that dilution effect is possible not only in the horizontal direction but also in vertical direction in dump sites.

5.1.2.4. Organic carbon

Organic carbon levels also appeared to be normal in soils in the three seasons of study. Comparatively lower organic carbon observed in the leachate zone particularly in monsoon and post-monsoon period must be due to an inadequate opportunity for the soils to build organic carbon during the monsoon and post-monsoon period (Fig. 6).

5.1.2.5. Available nutrients

The reasons for the observed decrease in available nitrogen, phosphorus and potassium status at lower depths might be due to the general compaction of soils at lower depth. General decrease in nutrient status at sampling points with the advancement of distance from the dump site might be due to its ready uptake by the innumerous weed plants growing in the leachate zone leaving only lesser load at farther end (Fig. 7, 8 and 9). Anikwe and Nwobodo (2002) in their study also reported lower content of nutrients in leachate with advancement in distance. Sinha *et al.* (2013) also reasoned that natural compaction in soils at lower depth was a hindrance for recording higher nutrient status at that depth.

5.1.2.6. Heavy metals

The availability of different metals and heavy metal status at two depths along the leachate flow zone within the treatment plant area across three specific seasons of the study is presented in Table 13, 14 and 15 and graphically represented in Fig. 10 to 22. Certain definite changes in the pattern of availability of metals with change in seasons are discussed. None of the samples reflected the actual metal load of the landfill site in any of the seasons studied. Infiltration of rain water within the tightly

packed landfill towards the base of the landfill must have picked up explosive levels of various toxic metal ions and must have let off these contents at its exit point forcing higher levels of detection of various metals at sampling site 1. The tendency to record comparatively lower levels of different metals with enhancement in distance from dump site in all the seasons might possibly be due to greater adsorption of different metals in soil which maintained closer proximity to the contamination source. The observations of Miller (1997) indicated that the distribution of heavy metals in soils along a leachate zone is affected by various processes such as dilution, dispersion, sedimentation, adsorption and desorption can be validated in this situation also.

The observed lower content of different metals at second depth of 30-60 cm again must be due to the greater adsorption of these metals at the surface layers permitting fewer ions for adsorption at lower layers. Further in a flowing leachate zone the natural compaction available at the surface also must not have permitted the leaching of metals to lower region. According to Orhue and Frank (2011), the presence of organic matter in surface layers and functional groups available in these organic fractions might have held heavy metals closely to them particularly in the surface layers not making these metals available at lower layers. De-Abreu *et al.* (1998) also reported that heavy metals do accumulate in surface layers and its concentration decreases with soil depth.

An overview of the metal load at the same geo-referenced sampling points in the monsoon season provided a dismal picture for almost all the metals and the same trend getting repeated as in the pre-monsoon period. This must obviously be due to the impact of rainfall, associated dilution or removal of potential organic colloids from the surface forcing lower adsorption levels in soil (Shivakumar and Srikantaswamy, 2012).

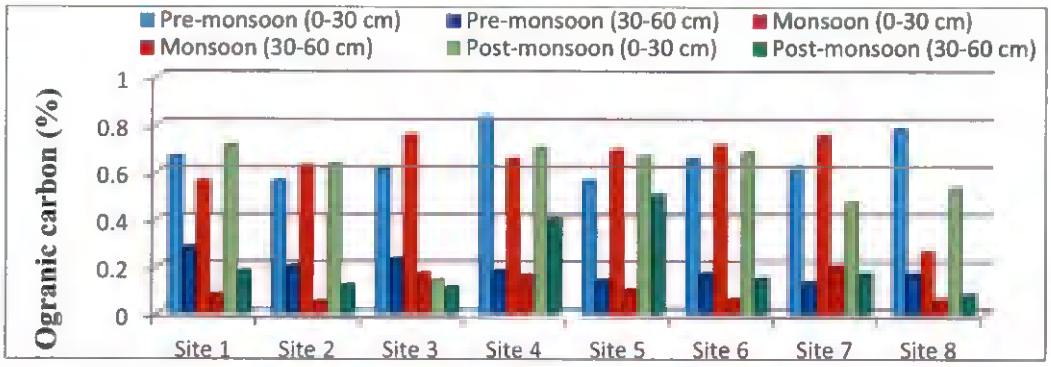

Figure 6. Seasonal variations in soil organic carbon status at two soil depths

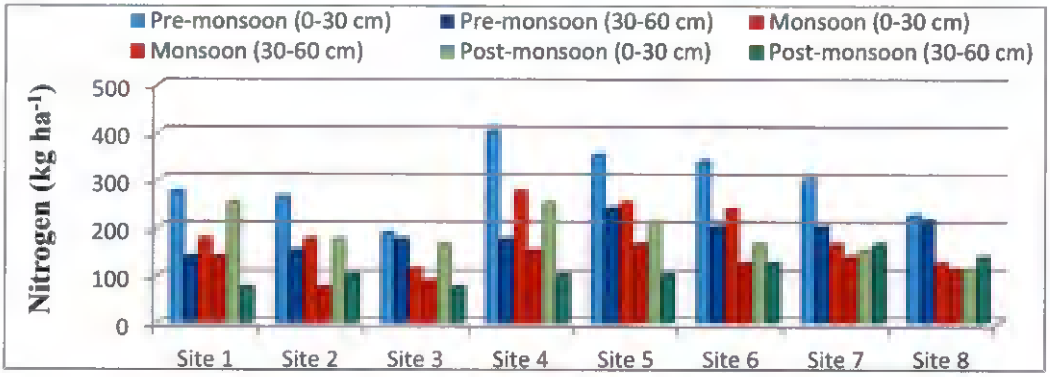

Figure 7. Seasonal variations in available nitrogen status at two soil depths

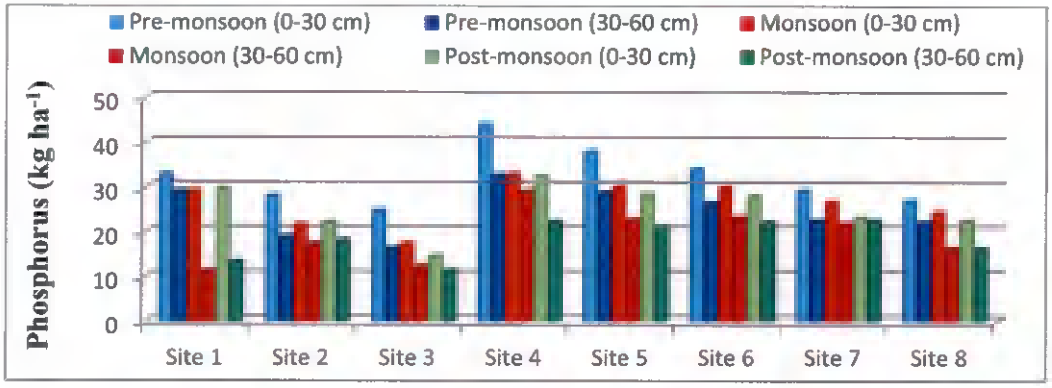

Figure 8. Seasonal variations in available phosphorus status at two soil depths

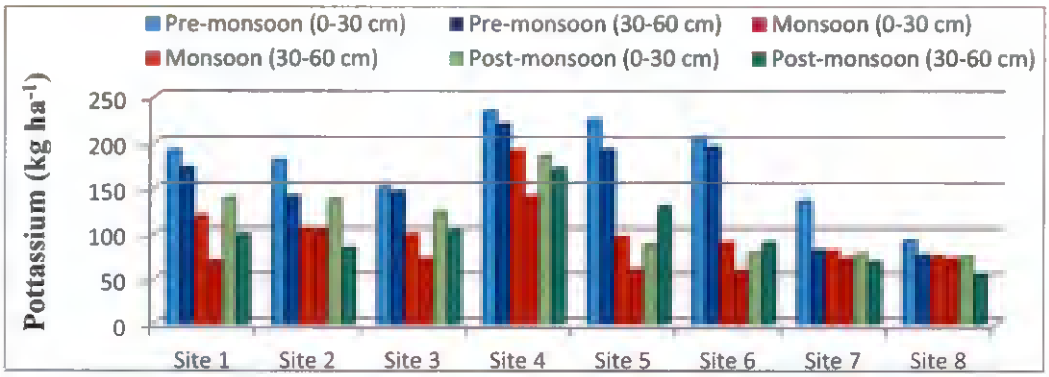

Figure 9. Seasonal variations in available potassium status at two soil depths

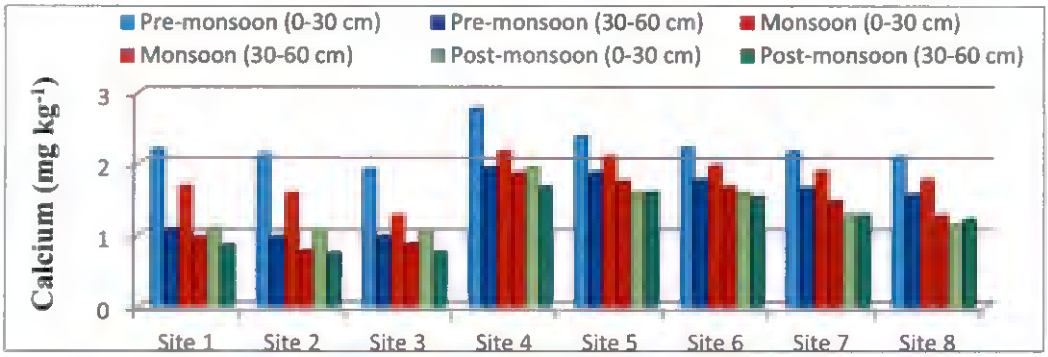

Figure 10. Seasonal variations in exchangeable calcium at two soil depths

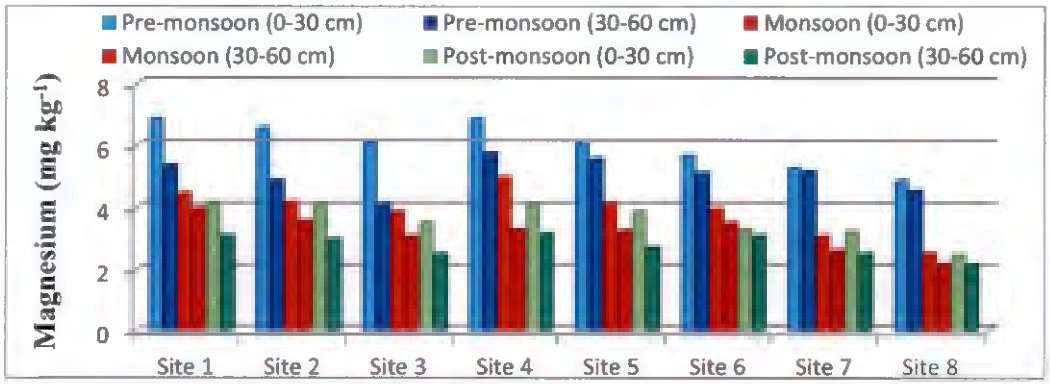

Figure 11. Seasonal variations in exchangeable magnesium at two soil depths

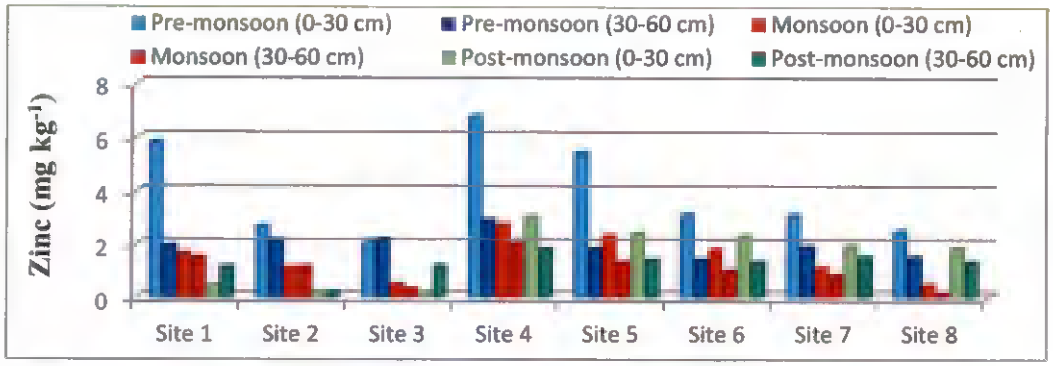

Figure 12. Seasonal variations in zinc content at two soil depths

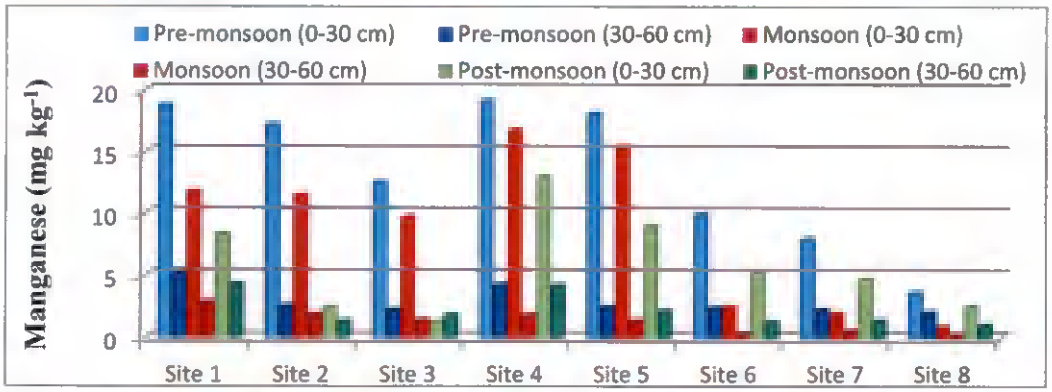

Figure 13. Seasonal variations in manganese content at two soil depths

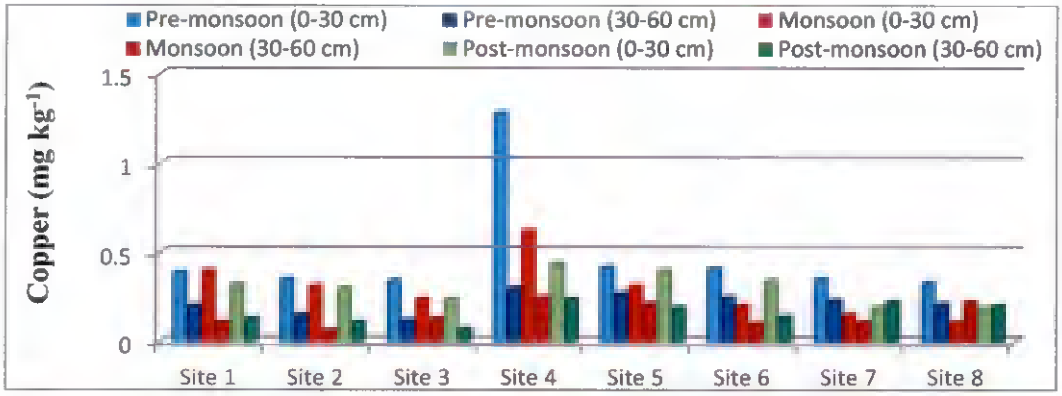

Figure 14. Seasonal variations in copper content at two soil depths

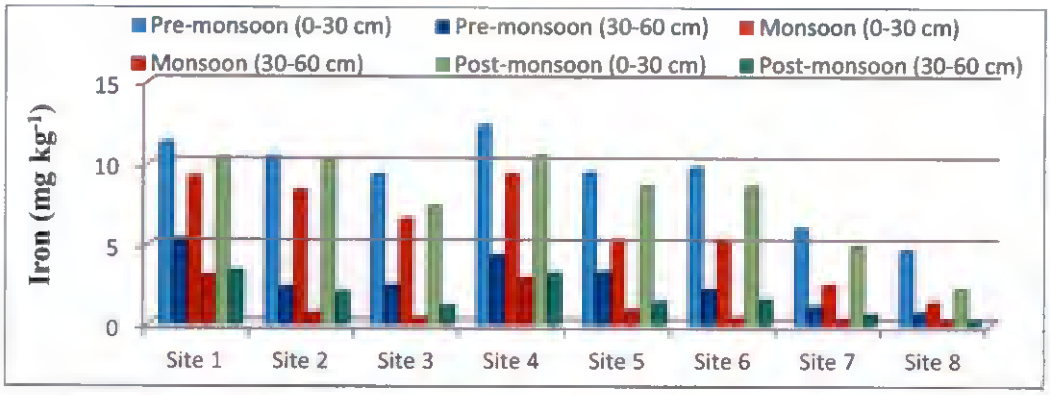

Figure 15. Seasonal variations in iron content at two soil depths

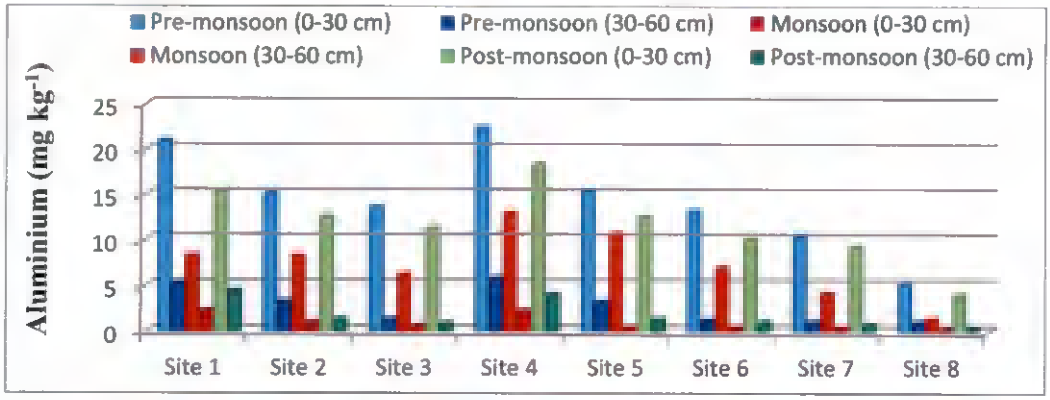

Figure 16. Seasonal variations in aluminum content at two soil depths

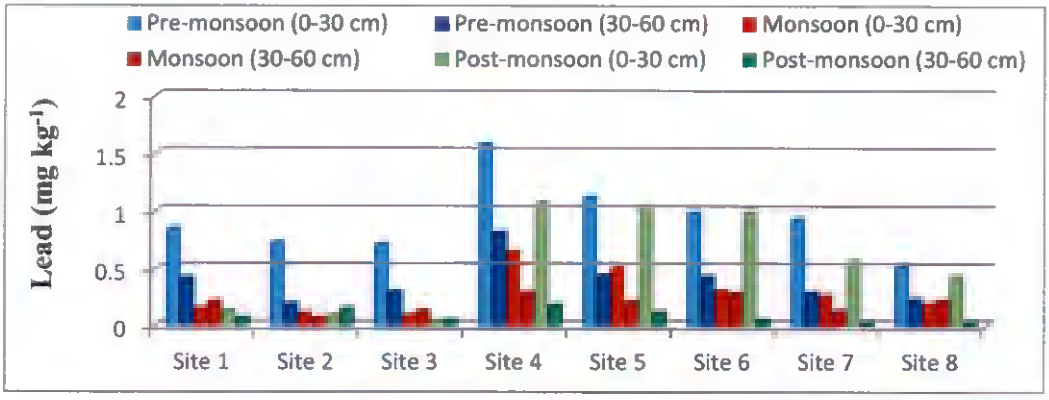

Figure 17. Seasonal variations in lead content at two soil depths

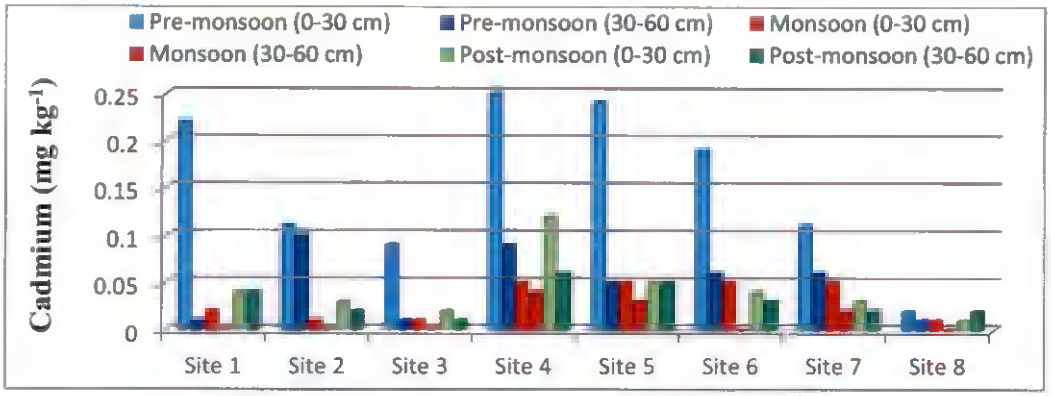

Figure 18. Seasonal variations in cadmium content at two soil depths

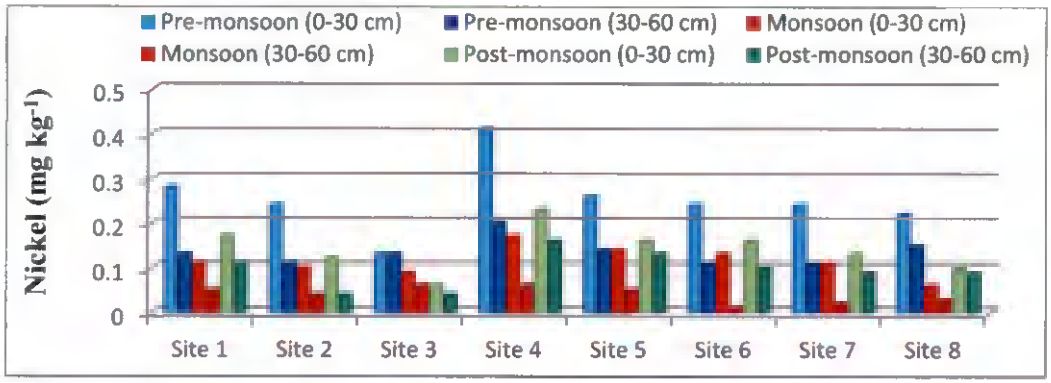

Figure 19. Seasonal variations in nickel content at two soil depths

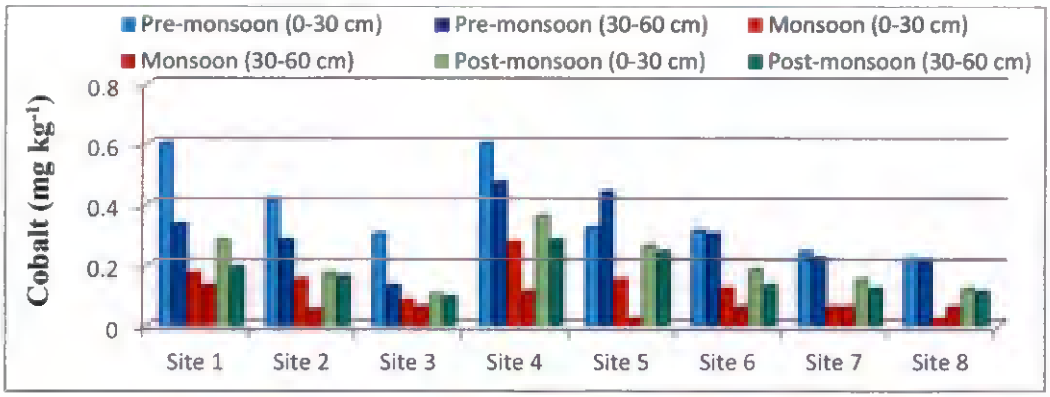

Figure 20. Seasonal variations in cobalt content at two soil depths

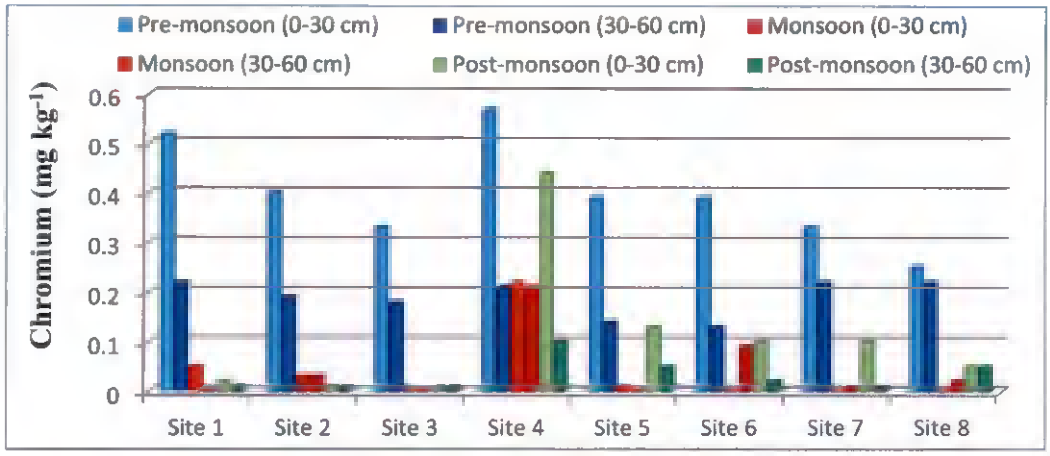

Figure 21. Seasonal variations in chromium content at two soil depths

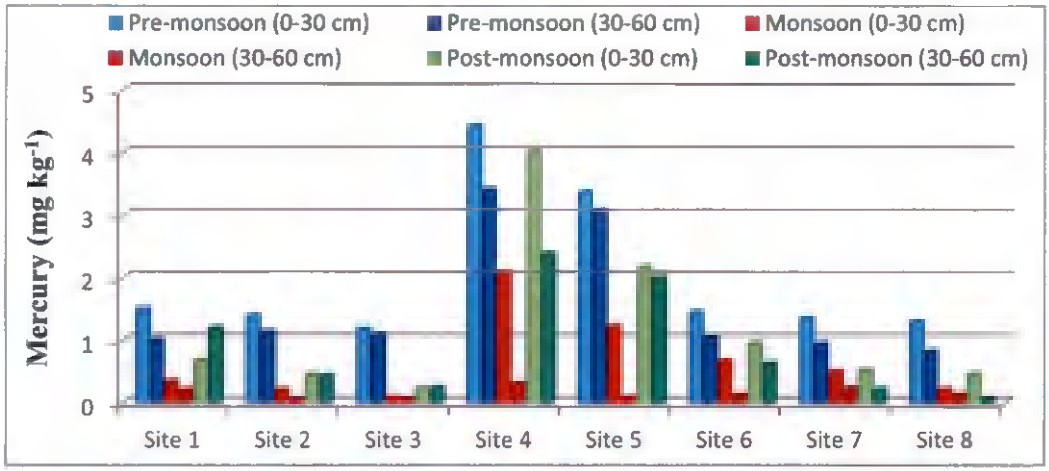

Figure 22. Seasonal variations in mercury content at two soil depths

However on the contrary, the various metal status recorded during post-monsoon period managed to maintain marginally higher values over the monsoon period. Reasons for this observation might be due to the natural concentration of leachate originating from the landfill site and attendant reflection of the same in the leachate zone. Similar observations have been reported by D'souza and Somashekar (2013) while monitoring the seasonal influence of leachate in soils.

5.1.3. Leachate samples

5.1.3.1. pH

Table 16, which provided the chemical properties of leachate from 11 geo-referenced sampling sites in the leachate zone at a regular interval of 50 m from the landfill site indicated alkaline pH all through the pre-monsoon and monsoon seasons (Fig. 23). Dissolution of basic cations from the landfill materials into the leachate must be the reason for the observed higher pH in the effluent leachate. This observation has been justified with the findings of Abu-Daabes *et al.* (2013) and Ali *et al.* (2014).

Observation of acidic to near neutral pH in samples during the post-monsoon seasons might be due to the reduction in the quantum of effluents and associated reduction in the load of basic cations.

5.1.3.2. Electrical conductivity

Comparatively higher EC levels were observed during the pre-monsoon period which might be due to the concentration of leachate (Table 16). The hydraulic connection between the waste and the surrounding environment might have been established only at a later stage due to slow infiltration and compaction within the landfill materials in the previous monsoon period. On the other hand, observed reduction in EC during the monsoon season might be due to the dilution effect (Fig. 24). Ali *et al.* (2014) reported that rainy season introduced dilution effect and

accompanying reduction in dissolved salts. The gradual scaling up in EC noted during post-monsoon season in many of the samples must again be due to concentration of dissolved materials in the leachate initiated by seasonal effect. The observed isolated higher EC at sampling site 4 might be due to the impact of convergence of leachate from an adjoining dump site within the plant area.

5.1.3.3. Total dissolved solids

The generally low TDS value observed during the monsoon period might be due to the dilution effect initiated by rainfall in the leachate zone (Table 16). On the other hand noted enhancement of TDS values during post-monsoon and pre-monsoon might certainly be due to concentration in the leachate content on account of seasonal effects (Fig. 25). Hossain *et al.* (2014) also reported similar observation. It is quite natural to have relatively higher TDS values at initial sampling points (in close proximity to landfill site) than the tail end samples in the leachate zone. The possible reasons for fluctuation in TDS along leachate zone could be due to higher adsorption of dissolved ions by soil colloids near the dump site or might be due to the absorption many ions by weed plants growing along the leachate flow zone . Orhue and Frank (2011) reported that higher adsorption of ions could result whenever organic fractions are available in greater quantities. However, in the present study all the TDS values noted during the three seasons fall within the ambit of safe limit of TDS (2.10 g l^{-1}). Hence these values are not going to be an environmental concern in the present study. The isolated enhancement in TDS with site 4 at a distance of 150 m from main landfill site is definitely due to an additive effect of dissolved salts from another adjoining landfill converging at this point.

5.1.3.4. Biological oxygen demand

The biological characteristics of the leachate when monitored at a definite distance of 50 m from the landfill area up to a distance of 500 m till it made an exit from the plant area is presented in Table 17. As far as BOD is concerned both pre-

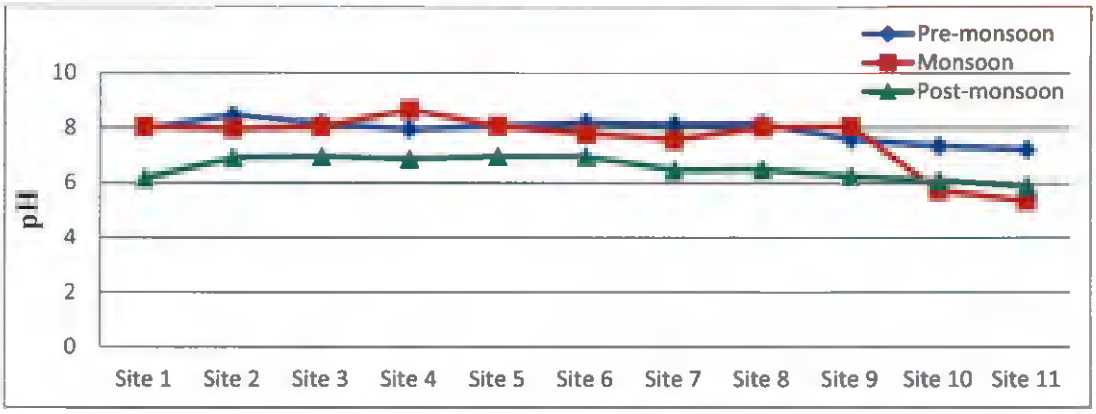

Figure 23. Seasonal variations in pH of leachate samples along the flow zone

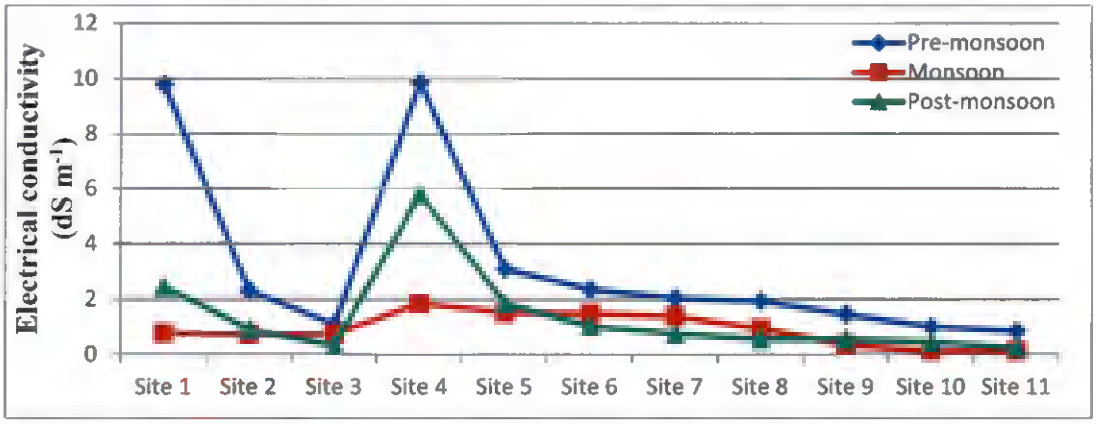

Figure 24. Seasonal variations in EC of leachate samples along the flow zone

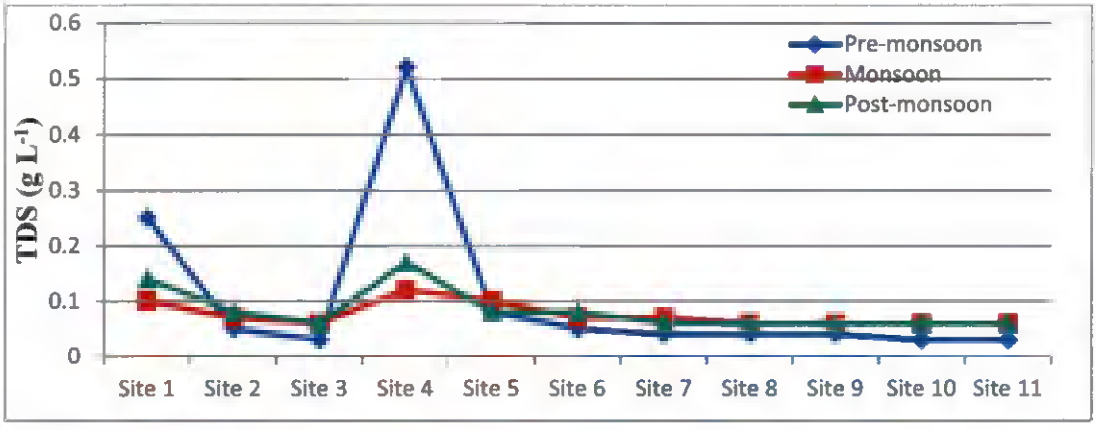

Figure 25. Seasonal variations in TDS of leachate samples along the flow zone

monsoon and post-monsoon samples registered comparatively higher values over the monsoon period (Fig. 26). According to Hossain *et al.* (2014), the dilution effect brought automatic reduction in BOD levels in rainy season. The influence of rainfall and consequent dilutions occurring on leachate might have been a valid reason for the observed lower values during monsoon period. On the other hand in pre-monsoon and post-monsoon, the absence of rainfall, reduction in the out flow of leachate from the landfill area and attended concentration of leachate will be enough for justifying the observed higher values. The isolated higher BOD value noted at a distance of 150 m from landfill site is due to the complementary effect of the convergence of another leachate path originating from an adjoining landfill. Decrease in BOD values with advancement in distance from the landfill site can only be due to the natural aeration occurring in the leachate flow zone. Further it is also possible that there could be reduction in the carbon load in the leachate with the advancement of distance from its origin. As the BOD levels of the leachates exceeded the minimum standard of 30 mg L^{-1} as per the Solid Waste Management rules 2016 at all points of sampling and at all points of time, the leachate in the present study will never stamp a clearance for safe disposal.

5.1.3.5. Chemical oxygen demand

An evaluation of the COD along the leachate zone across the three seasons of study revealed a quite different trend with monsoon period registering higher values as compared to pre-monsoon and post-monsoon seasons (Table 17 and Fig. 27). However, results of the studies of Hossain *et al.* (2014) were quite contrary to the present observation where they had witnessed a reduction on COD values with dilution. Slow infiltration of water into the waste dump site through soil capping and the time taken for its exit through the lower strata of the waste dump site must have pushed higher carbon load in the leachate necessarily demanding a higher oxygen level for oxidation. The comparatively lower COD in other two seasons must be a reflection of the lesser load of carbon particles in the leachate. Isolated enhancement

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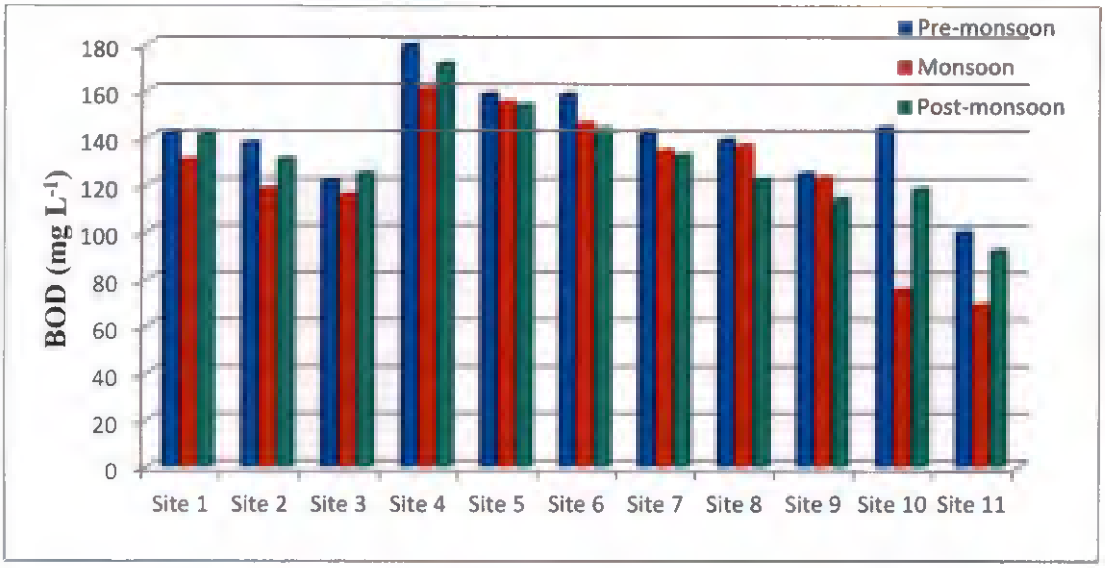

Figure 26. Seasonal variations in BOD of leachate samples along the flow zone

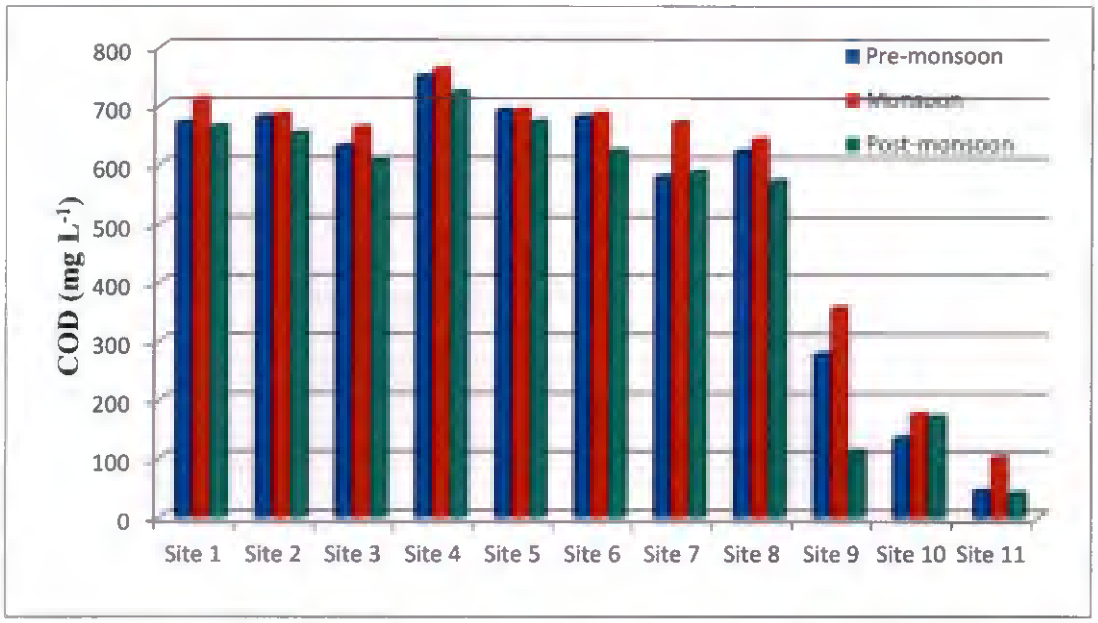

Figure 27. Seasonal variations in COD of leachate samples along the flow zone

in COD values at site 4 is justified with the same reason for the observed enhancement in BOD at this point. Reduction in COD values with advancement in distance must again be a reflection of lesser loads of carbonaceous material reaching the tail end of the stream. As long as the minimum standard of COD insisted by Solid Waste Management rules 2016 remain at 250 mg L^{-1}, even a lenient view of many of the leachate samples particularly at the originating site will not get clearance of safety.

5.1.3.6. Coliforms

The coliform bacterial count observed along the geo-referenced site in three consecutive seasons, indicated its presence much above the minimum standard of 0.5 MPN index ml^{-1} in some samples which drawn from near the landfill sites (Table 17). Unusual pop up in counts noted at different points of sampling might be due to the availability of congenial atmosphere for the bacteria to multiply and exist. The relatively lower count of coliforms noted during monsoon period might be due to the dilution effect or flushing effect by running water from rainfall (Baghel *et al*., 2005).

5.1.3.7. Calcium, magnesium, zinc and manganese

Table 18 presents a comparison of the metal status of calcium, magnesium, zinc and manganese content in the leachate samples all through the three seasons of the study period (Fig. 28, 29, 30 and 31). The observed decrease in the metal content towards the tail end of the sampling site compared to the vicinity of the dumpsite might be due to its higher successful adsorption on the inorganic or organic colloids available in such soils. According to Orhue and Frank (2011), the potential availability of organic colloids with active functional group will always permit higher adsorption of metallic ions. Hence their observation also justifies the observed lower levels of various metallic ions at the tail end of the leachate zone.

Results of the sample collection during the monsoon period revealed much lower values of these various ions compared to its counter parts in pre and post-monsoon periods. This can only be due to the dilution effect introduced by the rainfall. Isolated occurrence of observed higher values of different ions at site 4 must be because of the fact that the exterior boundaries of adjacent landfill is in close contact with the hydrological connection permitting higher levels of metals and dissolved salts at that point. The relatively higher values of the metal in pre-monsoon and post-monsoon period over the monsoon period can only be due to a natural concentration of the leachate in the absence of rainfall.

All the calcium levels irrespective of the season or sampling sites remained well within the minimum standard of 75 mg L^{-1}. Similarly for magnesium majority of the values recorded from sites were well within the ambit level of 30 mg L^{-1}. However, at site 4 and 5, the safe limit for magnesium has been exceeded on account of the contribution of metal by a nearby landfill site. The same reasons and validations uphold and justify the higher zinc and manganese content at site 4 and 5 during the various seasons of study.

5.1.3.8. Aluminium, copper, iron and lead

Table 19 reveals the concentration of aluminium, copper, iron and lead in the leachate samples at 11 different sampling sites identified along the leachate flow zone. The fluctuations of these metals have also been recorded at various sites during pre-monsoon, monsoon and post-monsoon seasons. Although the metal loads in leachate may be quite different from one another in numerical terms, they were seen to scale down with enhancement in distance with respect to every immediately preceding site (Fig. 32, 33, 34 and 35). Possibilities for successful adsorption at the initial sites must have automatically provided lesser metal load at every succeeding sample site necessarily lowering the various metal loads towards the tail end of the leachate zone. Similar contention has been upheld by Orhue and Frank (2011) where

reasons for lesser load of metals at the farther end of sampling site have been justified by higher adsorption at the initial sampling points.

The observed reduction in the metal load in leachate during rainy season must be a direct effect of dilution or through the removal of surface colloidal complexes of soil through running water. Similarly in the absence of rainfall, concentration of leachate might have been taken place and this might be a reason for the observed higher values of metal ions like aluminium, iron and lead in the pre-monsoon and post-monsoon period. However in the case of copper, may be because of the lower metal load, only few and isolated samples could show off higher content of metal more so at some sites after the 4^{th} confluence point. When metal concentration are assessed in the light of Solid Waste Management rules 2016 standards many samples immediately after the convergence sample at site 4 supported higher levels of this metal above their minimum standard for safe disposal into a surface water source. Under no circumstances, the concentration of metal ions like aluminium and iron never provided a safety level at any point of sampling along the leachate zone against their respective standards. The tagged minimum standard for aluminium and iron were 0.30 mg L^{-1} in both cases.

5.1.3.9. Other heavy metals

The level of toxic heavy metals *viz*; cadmium, nickel, cobalt, chromium, mercury and arsenic in leachate samples identified at definite geo-referenced sampling site across three consecutive seasons (Table 20 and 21) indicated quite lower levels dipping down to even non-detectable limits (Fig. 36, 37, 38, 39 and 40). General decrease in concentration during the monsoon period had been recorded for cadmium, nickel, cobalt, chromium and mercury might be due to either dilution effect or due to their lower mineralized content in the dumped waste materials. Sparks (1995) also endorsed a similar reasoning for the observed lower levels of metals in leachate during rainy season. The reason for cadmium and arsenic to get to lower

levels beyond detectable limit in monsoon season can again be defended in view of the above observation.

Reasons for comparatively higher enhancement in concentrations of metals like cadmium, nickel and cobalt during pre-monsoon and post-monsoon period might be due to the absence of dilution factor or due to concentration of leachate under the influence of season. Sequel to this, the specific enhancement of chromium and arsenic at the initial sampling site during pre-monsoon and monsoon seasons could only be due to the proximity to the waste dump site from where the leachate is emanating. The reduction in the metal levels at 2^{nd} and 3^{rd} sampling sites for this metal might either be due to adsorption of this metal on colloidal surfaces or absorption by one or more of the profusely growing weed species in that area. The resurgence of this metal at sampling site 4 has to be reckoned as the contribution of these metals from the adjoining dump site whose leachate path merge at this sampling point. The presence of this metal at subsequent sampling point towards the tail end can only be seen as a contribution or reflection of this metal from the adjoining dumpsite. The total failure to detect arsenic in the leachate along the entire sampling points during the post-monsoon season might be a reflection of the relative lower arsenic metal load in the dumped material or its absorption by weed plants in the area leaving nothing to get detected in leachate.

However, in the case of mercury quite contrary to the normal expectation of having lower levels of mercury under the influence of dilution in rainy season, the all sampling sites registered much higher levels of this metal (>0.01 mg L^{-1}) which is more than the minimum standard of safe disposal prescribed by Solid Waste Management rules 2016. This observation is an indirect reflection of a very high level of mercury accumulation within the dumping site coming either from broken CFL lamps or tube lights or from other sources. As long as we don't have any data on this metal load in the yester years or at the time of set up of this landfill it is difficult to predict or assess the extent of availability in the ensuing years. Reflection of a high

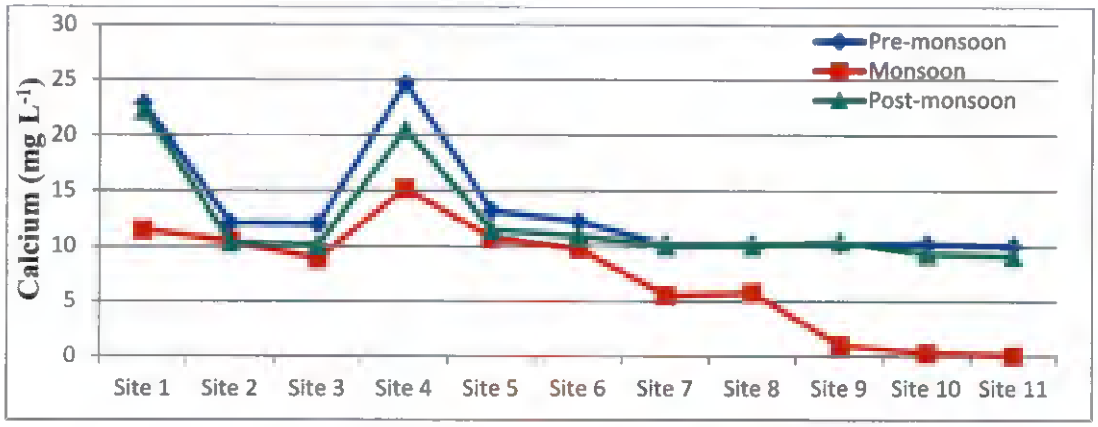

Figure 28. Seasonal variations in calcium content of leachate samples

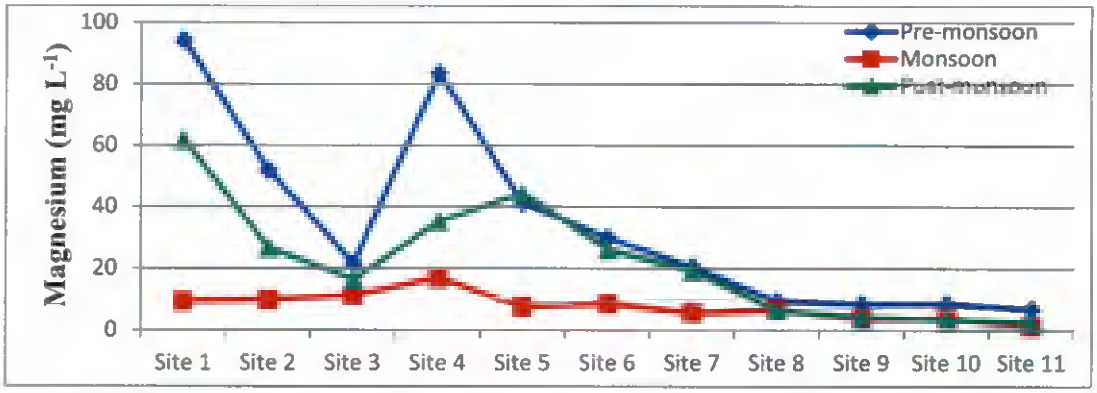

Figure 29. Seasonal variations in magnesium content of leachate samples

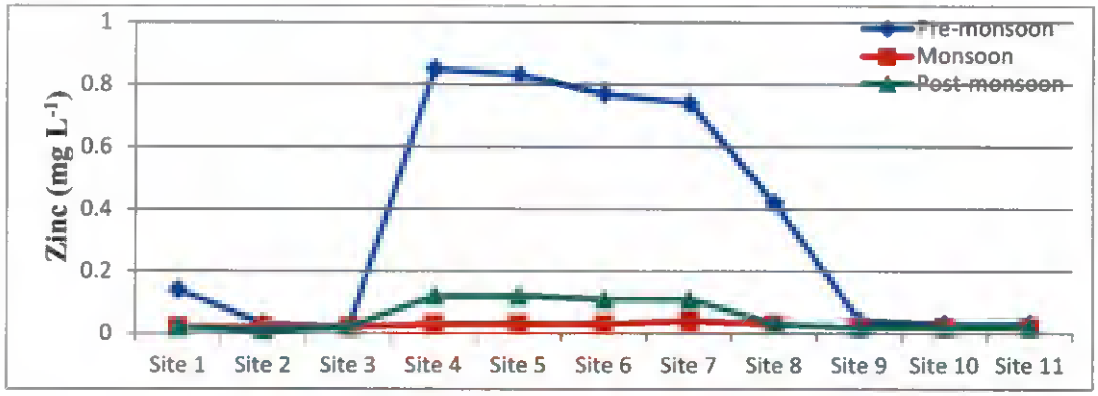

Figure 30. Seasonal variations in zinc content of leachate samples

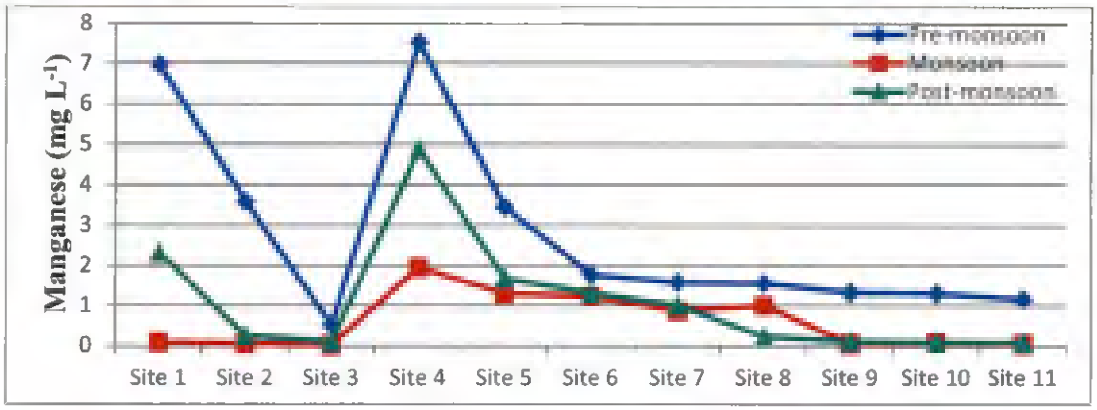

Figure 31. Seasonal variations in manganese content of leachate samples

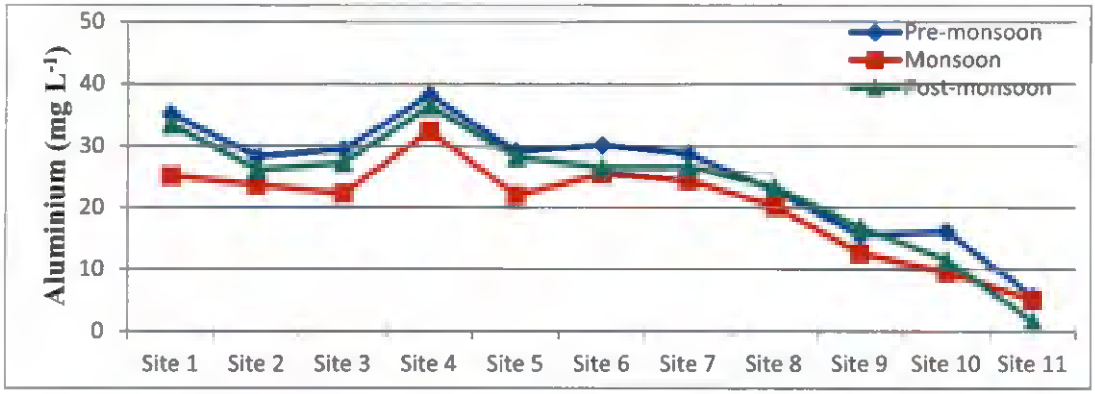

Figure 32. Seasonal variations in aluminium content of leachate samples

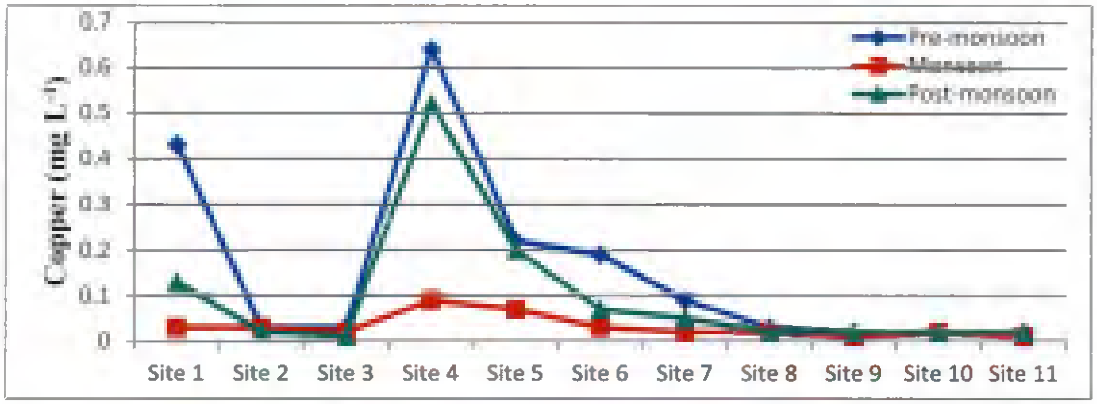

Figure 33. Seasonal variations in copper content of leachate samples

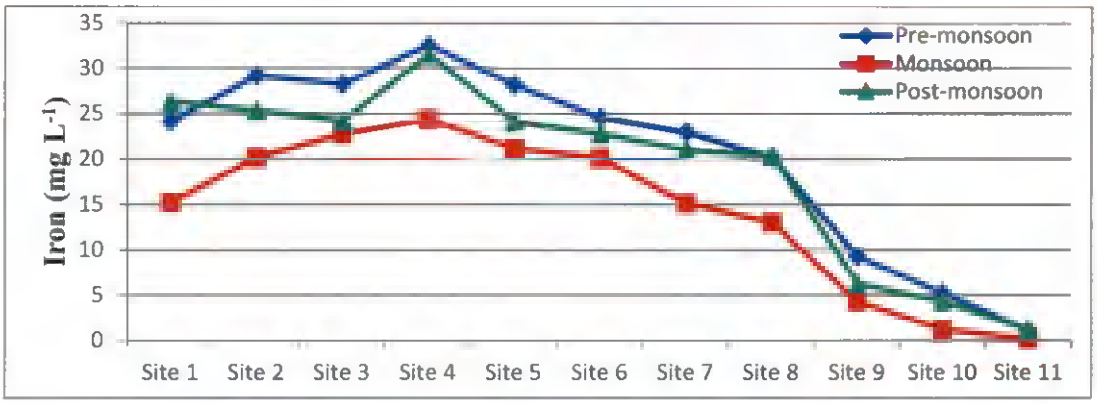

Figure 34. Seasonal variations in iron content of leachate samples along the flow zone

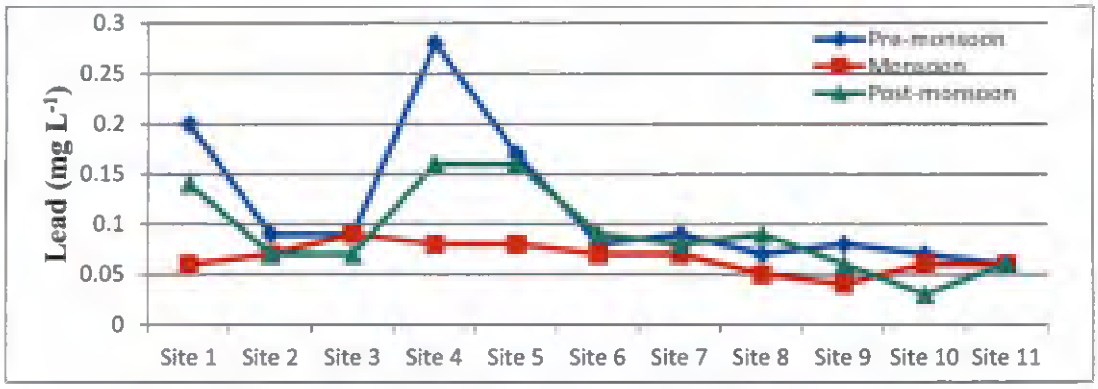

Figure 35. Seasonal variations in lead content of leachate samples

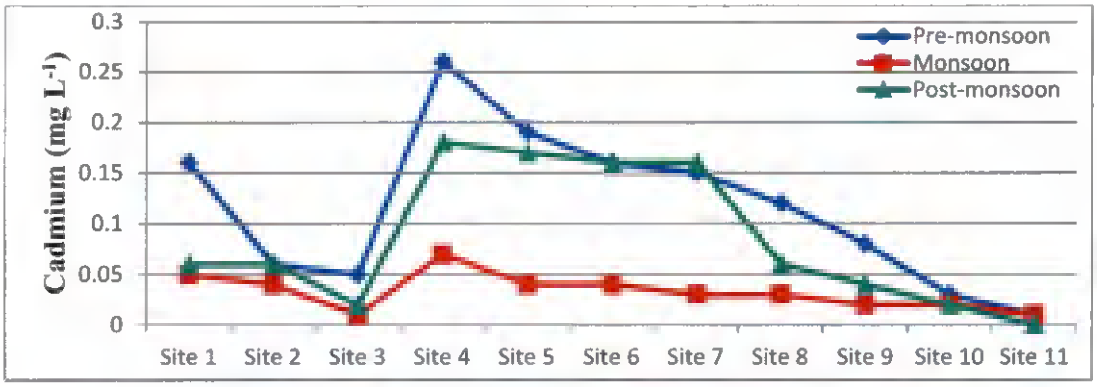

Figure 36. Seasonal variations in cadmium content of leachate samples

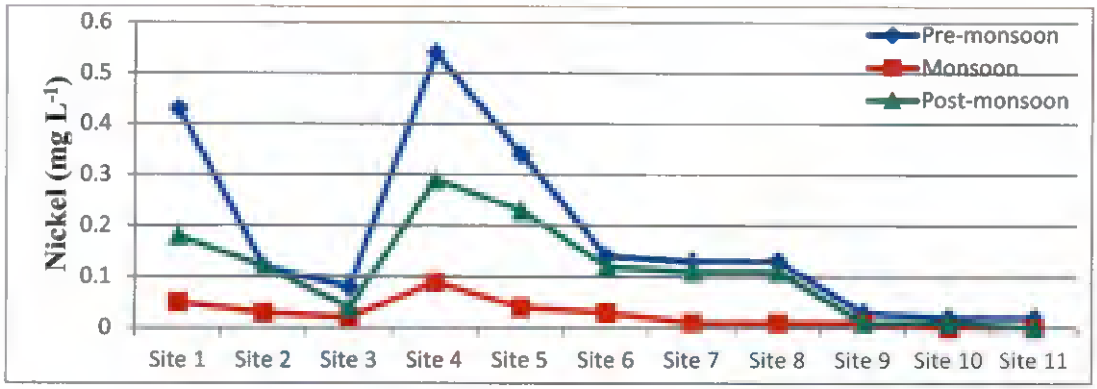

Figure 37. Seasonal variation in nickel content of leachate samples

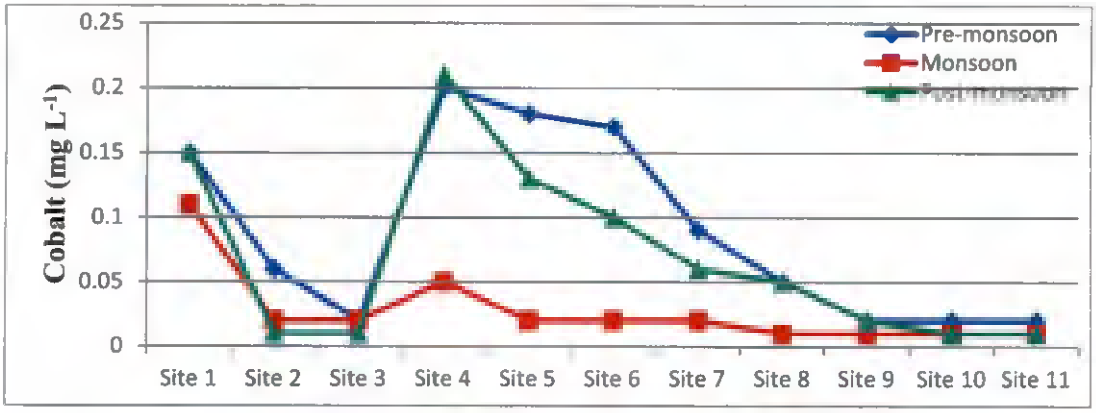

Figure 38. Seasonal variations in cobalt content of leachate samples

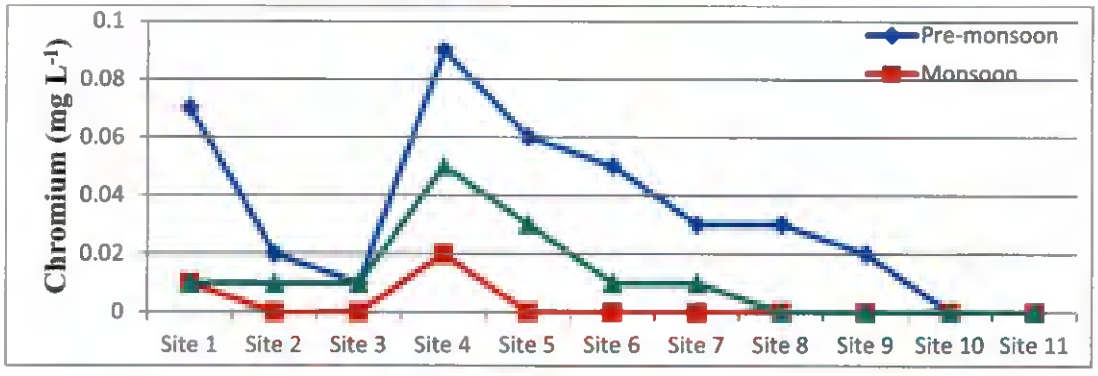

Figure 39. Seasonal variations in chromium content of leachate samples

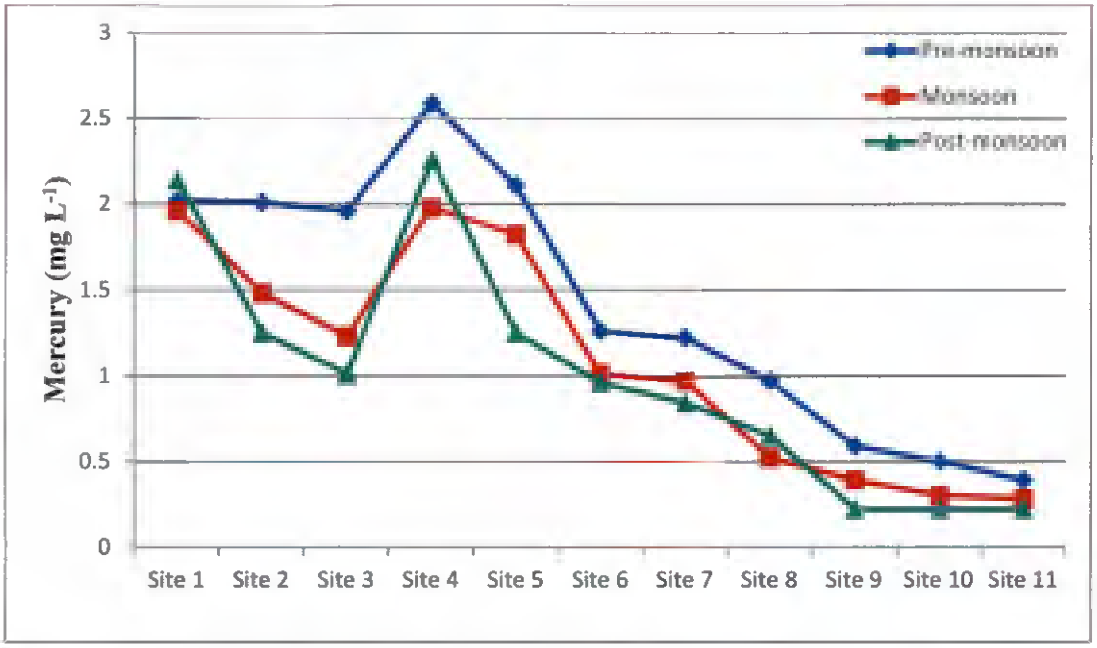

Figure 40. Seasonal variations in mercuric content of leachate samples

mercury load in the leachate collected during the monsoon period raises great concern particularly when its biological pathways in the leachate associated environment are obscure. This also calls for the need to have a leachate treatment plant to contain various problems associated with leachate at this point.

5.1.4. Ground water samples

Variations in chemical and biological characteristics of the ground water sources outside the plant area and particularly those remaining in close proximity to the main channel carrying all the effluents from the landfill site was also monitored. The three ground water sources (wells) available in the vicinity of the main canal have been monitored in this connection and details provided in Table 22 and 23.

5.1.4.1. pH

Not much of seasonal variations in pH could be seen in ground water as most sources maintained more or less acidic range. However, it is seen in well 1 and 2 which remained relatively closer to the landfill site but outside the treatment plant maintained higher pH than the farthest one where the pH value of 5.85 in the pre-monsoon season. The relatively higher pH observed in well water 1 and 2 compared to well water 3 might be due to the possible lateral seepage or infiltration of alkaline leachate into these wells. With advancement in distance and under the influence of generally acidic soils of these areas the effectiveness of the leachate in altering the pH must have been nullified preventing it from turning into alkaline nature.

During the monsoon season, the observed stabilization in pH of all well water sources in spite of the heavy release of alkaline leachate from the landfill site might be due to the dilution effect occurring within wells due to direct impact of rain water or inability of alkaline leachates to undertake a lateral seepage under the influence of the gushing nature of water in the canals during monsoon period. The maintenance of slightly acidic nature of well water in post-monsoon season must be due to the

reduced presence or total absence of basic nature of salts in leachate along the canals. It is also equally possible that the aftermath of rainfall and associated efflux of water in the channels must not have permitted the buildup the alkaline leachate in the canal preventing alkaline reactions in the nearby well and helping water sources to restore slightly acidic reactions. On rating the pH of the ground water sources based on safety standards, the values appeared to be quite safe against the BIS standards insisted for pH (6.5-8.5).

5.1.4.2. Electrical conductivity and total dissolved solids

Similarly the EC values monitored in all the wells across the three seasons were well within the range of safe limits of 0.75 dS m^{-1} and thus necessitating no further discussion on this. The scenario of the TDS in the three wells taken for the study was also well within the safe limits across the three seasons and hence does not warrant further discussion.

5.1.4.3. Biological and chemical oxygen demand

The BOD values monitored in the well water across three seasons of study also came within the acceptable limit of 30 mg L^{-1} with marginal variations observed between the seasons. The reasons for the existing range of BOD values(15.84 to 26.26 mg L^{-1}) in well water to be close to the upper limits of standards insisted by BIS might be due to the presence of persistent organic carbon sources in water sources. Further, these BOD values close to upper limits of acceptable standards might be forerunner to an impending unhealthy build up of BOD levels in the near future. COD values assessed across the three well water samples were also within the safe limits, where the acceptable limit has been put at 250 mg L^{-1}. The negative impact of the leachate appears to be absent across the ground water samples. According to Hossain *et al.* (2014), the contaminants in the leachate can slowly move down the soil and eventually reach the aquifiers of water and it is being decided by

several important factors including seasonal effect and soil factors besides contaminant characteristics.

5.1.4.4. Coliforms

Coliform counts from the well water indicate that pre-monsoon samples were relatively safe and well within the safe limit of 0.1MPN index ml^{-1}. However, isolated enhancement of coliform count in the first and third well water during monsoon period must be due to the migration of contaminated leachate carrying coliform into these wells or it must be a reflection of the existing local contamination. The values of coliform count in post-monsoon samples from the first well water had crossed the safe limit and this might be due to the multiplication of the coliform bacteria which was detected in the monsoon period under some favourable conditions.

5.1.4.5. Calcium, magnesium and aluminium

The calcium, magnesium and aluminium levels identified in all the well water sources across the three seasons does not pose any problem as far as their limits are concerned or when these values were compared with the acceptable level of drinking water quality. Hence these metallic concentration identified within the wells does not merit any special discussion particularly in view of the absence of any possible health hazards.

5.1.4.6. Heavy metals

The data on the presence of different metal ions like zinc, manganese, copper, iron, lead, cadmium, nickel, cobalt, chromium and mercury in the three wells under study were monitored for three consecutive seasons during the study year. The zinc, manganese and copper content in the wells under all periods of observation were found to be below the acceptable level and hence a further discussion in this regard is not merited. However, iron content in both pre-monsoon and post-monsoon seasons in all the wells is much above the critical limit of 0.30 mg L^{-1} making it partially unfit

for human consumption. This must be due to the reduction of iron sources in soil permitting its concentration in water. During the monsoon period, the observed reduction in the iron content in well water must in all probability be due to dilution effect. The occurrence of a relatively higher metal load of 0.97 mg L^{-1} iron in the second well under study might be a reflection of the local concentration abetted by natural concentration occurring in water under the influence of hot climate during pre-monsoon season. It is to be realized that once the iron goes beyond the permissible limit for any reason, either the taste or appearance of water or both are affected and will put automatic restriction on domestic uses. Further there could be chances for higher levels of iron bacteria in such cases (Ridgway *et al.*, 1981).

As far as the heavy metals are concerned, the presence of toxic metals lead and cadmium has been found to exceed their acceptable limit of 0.01 and 0.003 mg L^{-1}, respectively in all the three seasons. Though this is the case, the levels of lead and cadmium in all the well waters have increased during monsoon season compared to pre-monsoon level or post-monsoon levels, in spite of an expected dilution effect. This throws up real health concerns and should be prevented for human consumption. Existence of such a situation during monsoon period must obviously be due to the migration of these metals from the leachate into the ground water sources in the process of charging the ground water system. This is quite alarming since the presence of these toxic levels of metal in water can't be detected by either by visual observation or by any distaste or odour. Prolonged consumption of this by any human being could invite severe health problems. In view of this concern, the study strongly recommends that this water be consumed only after removing the metal ions through some suitable processes available in the market.

Levels of nickel and chromium identified in the well water across all the seasons of study were below the acceptable level. The inability of chromium to get detected in the well during monsoon and post-monsoon periods should be a testimony of the poor metal load of chromium in the dumped waste and its distribution in the

leachates emanating from that source. Since the acceptable limit of cobalt has not been determined it is difficult to identify whether these well waters are safe or unsafe for human consumption. However, if any effort is taken to remove the metals from water before consumption this metal and its concerns on human health will also be eliminated. The presence of cobalt though at a lower level cannot be ruled out as safe since these well waters are continuously being consumed by a regular set of people residing in that area. Since no data of these metals in the wells in the past are available for reference, it is difficult in this study to conclude whether the metal levels are on the increase or decrease over the years in the wake of closure of the treatment plant.

The mercury levels in well waters have been identified to be above the acceptable limit in case of pre-monsoon and post-monsoon periods. But during the monsoon period the levels of mercury were below detectable limit possibly on account of the dilutions that might have taken place in the well. Simultaneously, it is to be realized that not much of the mercuric ions have migrated into the ground water sources although the leachate emanating from landfill area was heavily contaminated with mercury. According to Inacio *et al.* (1998), it is very much possible that these metals get adsorbed to organic fractions which are readily available in surface soils. In the Vilappilsala context the presence of sufficient quantities of organic matter available in surface soils along the leachate zone might have facilitated greater adsorption of this metal thus preventing the metal from entering the ground water sources. Further the ability of many of the weeds flourishing in the leachate zone might have also mined this metal into them to justify the situation.

5.2. ASSESSMENT OF WEED FLORA IN THE LEACHATE ZONE FOR THEIR HYPER ACCUMULATION CAPACITY

Table 24 and 25 provide the details of the content of different metals in the shoot and root portions of the already identified profusely growing 15 weed species

in the leachate zone with the assumption that each plant will be absorbing differential levels of these metals from the contaminated growing environment. Chowdhury and Tandon (2009) had reported that weed species are more capable than many crop plants in increasingly absorbing heavy metals from their environment and the extent of absorption in such weeds will go up to 500 times more than the normal crop plants. According to Wei *et al.* (2008), the higher absorption of metals in weed plants are facilitated through their highly ramified roots having special adaptation to contain them without exhibiting any tolerant symptoms.

The selective retention of metals can be assessed by calculating the bioconcentration factor (BCF). BCF can be calculated by using the formula as below (Chaney *et al.*, 1997).

BCF = concentration of metal in shoot/ concentration of metal in root

While calculating the BCF ratio (Table 43) of all the selected weeds from the project area, a general trend observed is that majority of the metals are being selectively retained in the root portions of this weed with a lesser load of these metals in the shoot portion. This type of selective retention in weeds according to Raskin *et al.* (1997) might be possible because of a variety of reasons. The possibilities include insolubility of the metals within the plant or precipitation as carbonates or sulphates or phosphates and their storage in the apoplastic membrane as insoluble materials.

However, isolated occurrence of weeds like *Sphagneticola trilobata* (Pb and Ni), *Commelina diffusa* (Pb), *Mikania micrantha* (Cr) and *Ricinus communis* (Ni) retaining more toxic metal loads in the shoot portion than the root portions might be due to an inability to their root system in either precipitating them as various salts or maintaining them as insoluble form.

Table 43. Bioconcentration factor of selected weed species from the leachate flow zone

Plants	BCF ratio									
	Ca	Mg	Zn	Mn	Cu	Pb	Cd	Ni	Co	Cr
Alternanthera tenella	0.95	1.17	0.66	1.4	0.83	0.68	0.23	0.37	0.18	0.53
Sphagneticola trilobata	1.09	2.58	1.79	0.82	1.55	1.14	0.98	1.99	0.90	0.77
Commelina diffusa	1.18	1.75	0.62	0.96	0.81	1.06	0.42	0.50	0.41	0.71
Colocasia esculenta	1.29	1.68	0.67	0.91	0.67	0.61	0.62	0.31	0.25	0.46
Mikania micrantha	1.22	1.19	0.60	0.50	0.10	0.66	0.79	0.52	0.44	1.89
Ricinus communis	1.41	1.15	1.13	2.43	0.84	0.99	0.96	1.36	1.01	1.00
Eupatorium odoratum	0.92	0.81	0.77	0.66	0.78	0.63	0.33	0.76	0.81	0.42
Brachiaria distachya	1.01	0.37	1.39	0.92	0.40	0.68	0.44	0.37	0.35	0.81
Centrosema pubescens	0.78	1.53	0.17	0.93	0.79	0.76	0.46	0.82	0.17	0.82
Boerhavia diffusa	0.68	0.77	1.51	0.92	0.50	0.65	0.24	0.80	0.10	0.66
Celosia argentea	0.76	0.43	0.79	1.21	0.54	0.81	0.33	0.47	0.24	0.43
Cynodon dactylon	0.82	1.16	0.39	0.57	0.38	0.55	0.08	0.69	0.05	0.56
Mitracarpus verticillatus	1.05	0.97	1.08	0.84	0.70	0.56	0.26	0.94	0.38	0.19
Sida rhombifolia	0.84	0.82	0.86	0.88	0.46	0.68	0.67	0.90	0.28	0.20
Dactyloctenium aegyptium	1.07	0.73	0.57	0.93	0.91	0.95	0.26	0.93	0.37	0.32

In the present assessment of weed *Alternanthera tenella* had been identified as the best hyper accumulator based on the total concentration of most of the heavy metals, both in shoot and root portions at higher levels than any other weed species. This weed plant might have achieved this higher level of metal accumulation through several physiological steps. According to Lombi *et al.* (2002), transport of metal across plasma membrane of root cells might have taken place at initial stage and subsequently these metals must have been loaded in xylem vessels which then might have been transported to a different plant part where it gets sequestered with detoxification of the metal. In the case of *Alternanthera tenella* these mechanisms might have successfully operated to provide the status of hyper accumulator.

5.3. SAND CULTURE EXPERIMENT

The actual performance and survival mechanisms of 4 well known hyper accumulators namely Indian mustard, sunflower, globe amaranth and marigold were compared with *Alternanthera tenella*, a weed which has been identified and selected as one of the best hyper accumulator from the project area based on the total metal content were tested in sand culture under the influence of three toxic heavy metals supplied at three levels. Details of the retention of these metals in these hyper accumulators are available in Table 26 and 27 and graphically represented in Fig. 41 to 49.

It is seen that among the hyper accumulators, marigold was identified as the topper in retaining the maximum metal load within the plant particularly in shoot portions under the influence of the highest load (2.5 ppm) of these three metals. As suggested by Lombi *et al.* (2002), these metals might have been absorbed by this plant through the root system later loaded in xylem vessels and later it must have been transported to aerial parts where it might have sequestered and detoxified irrespective of the levels of absorption. However, in the case of root portion of marigold the maximum absorption of lead was noted from the highest and

immediately next lower levels. The possible mechanisms that might have operated to facilitate the present observation of high retention of lead in the root portion of marigold might have been due to the precipitation of this metal as carbonate, sulphate or phosphate. This kind of reasoning has been proposed by Raskin *et al.* (1997) for selective and higher retention of lead in root portions.

Even though *Alternanthera tenella* was handpicked from among the weeds based on its unique capacity to accumulate heavy metals among the different weed species this particular plant was relegated to a much lower level in the experiment considering the quantum of retention of heavy metals by the other four competitors employed in the study.

From the present study it can also be concluded that globe amaranth is a successful hyper accumulator of lead at lower concentration and not at higher concentration in both root and shoot portions. In a similar way, sunflower has proved to be yet another effective hyper accumulator of nickel particularly at lower levels of contamination. Inability to maintain the same status of nickel at higher levels of contamination might be due to the peculiarity of the roots to exclude this metal at higher concentration. According to Baker (1981), some roots are capable of excluding certain metal ions from an externally high concentration and permitting only a lower uptake and transport into the root or shoot portions. At the same time sunflower maintained higher levels of retention of cadmium in the root portion under the influence of highest levels in the media.

In the experiment it was also concluded that Indian mustard was ineffective as a hyper accumulator at both lower and higher levels of cadmium. This observation is quite contrary to the findings of Wani *et al.* (2012). The absence of organic matter content and soil in the growing media in the rhizosphere of Indian mustard must have certainly deprived the media of any chances for cation exchange which otherwise would have provided a gradual and steady release of the metals to the rhizosphere. In

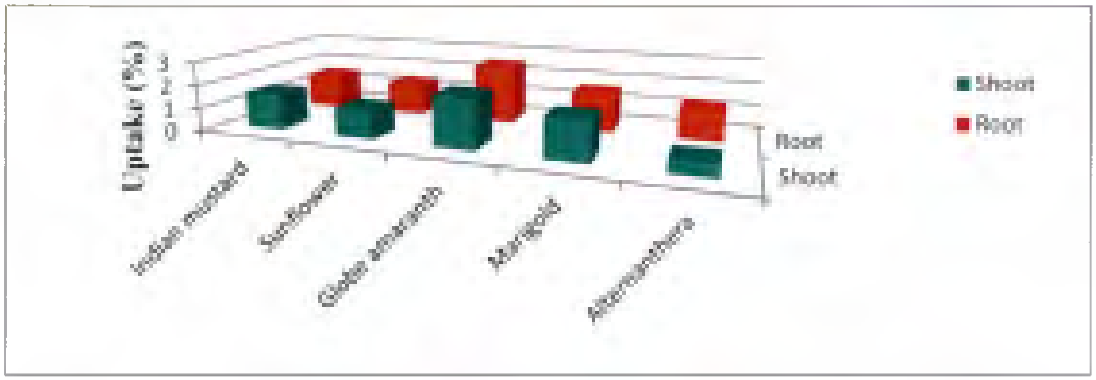

Figure 41. Uptake of lead in shoot and root of different hyper accumulators when grown in media containing 0.5 mg kg^{-1} lead

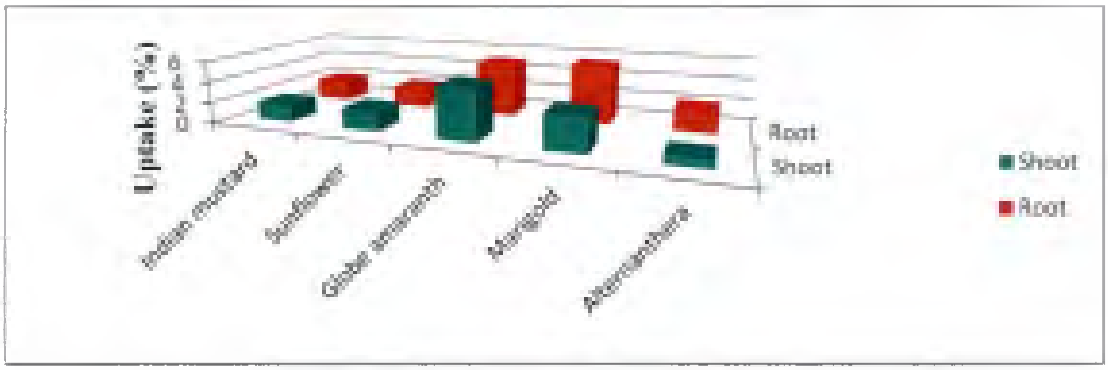

Figure 42. Uptake of lead in shoot and root of different hyper accumulators when grown in media containing 1.5 mg kg^{-1} lead

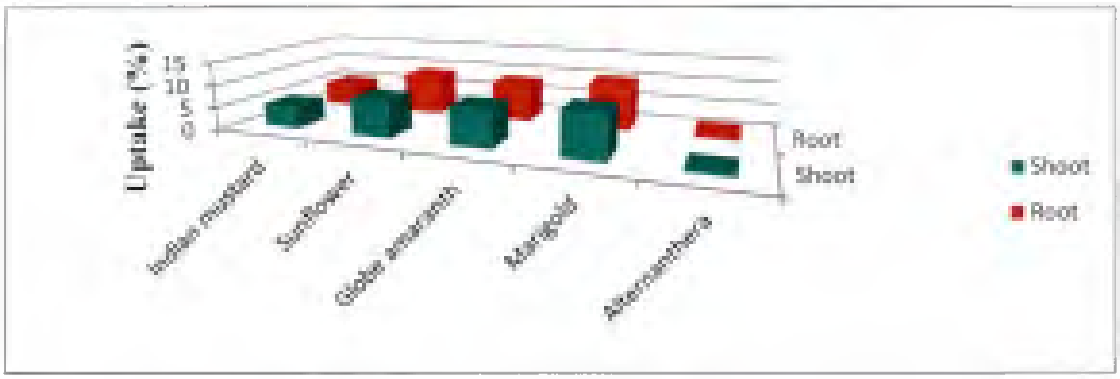

Figure 43. Uptake of lead in shoot and root of different hyper accumulators when grown in media containing 2.5 mg kg^{-1} lead

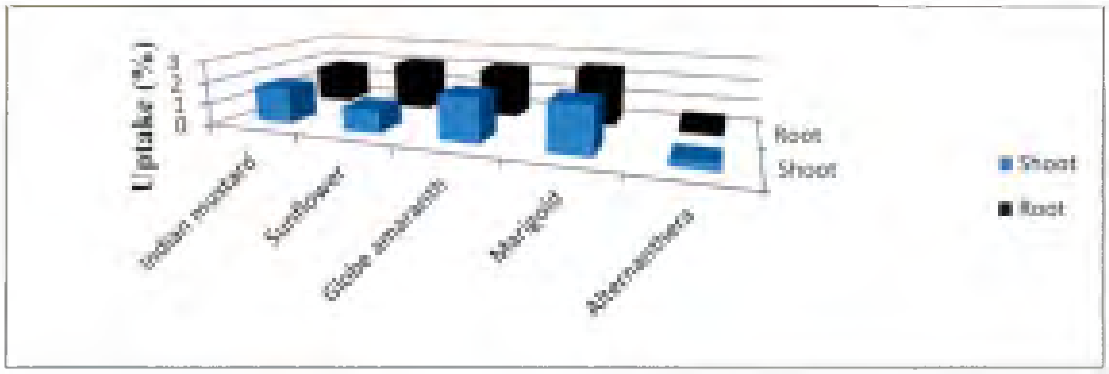

Figure 44. Uptake of cadmium in shoot and root of different hyper accumulators when grown in media containing 0.5 mg kg^{-1} cadmium

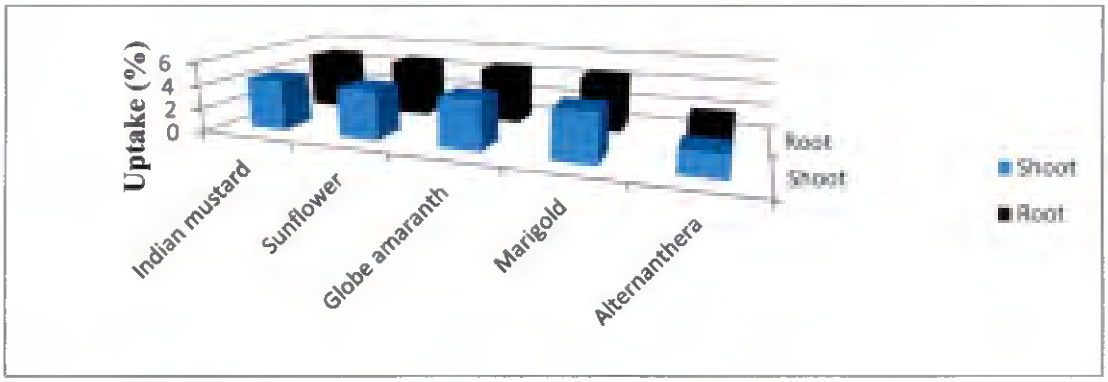

Figure 45. Uptake of cadmium in shoot and root of different hyper accumulators when grown in media containing 1.5 mg kg^{-1} cadmium

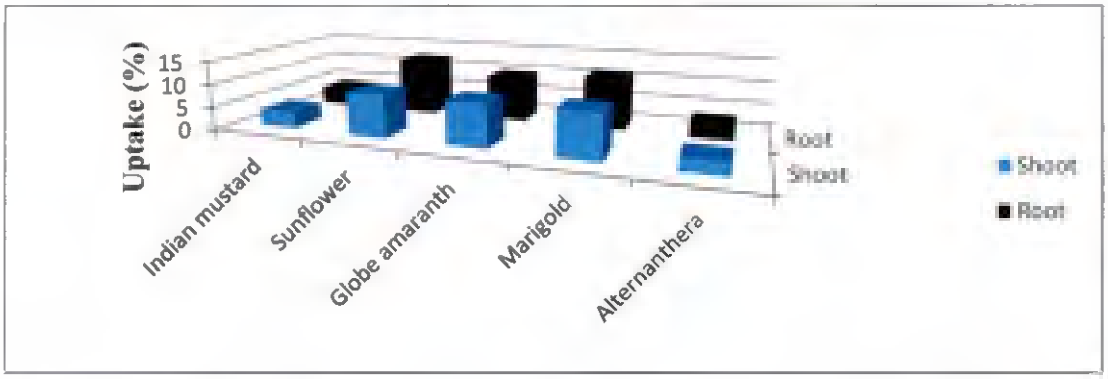

Figure 46. Uptake of cadmium in shoot and root of different hyper accumulators when grown in a media containing 2.5 mg kg^{-1} cadmium

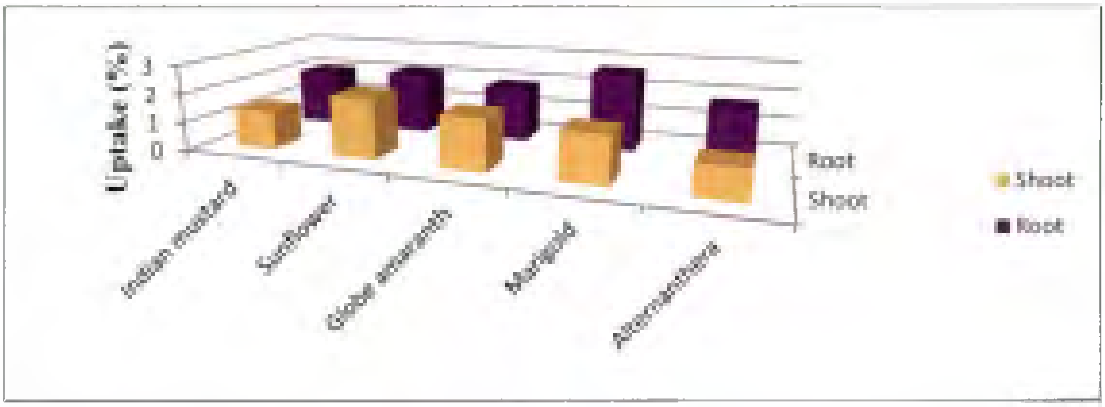

Figure 47. Uptake of nickel in shoot and root of different hyper accumulators when grown in a media containing 0.5 mg kg^{-1} nickel

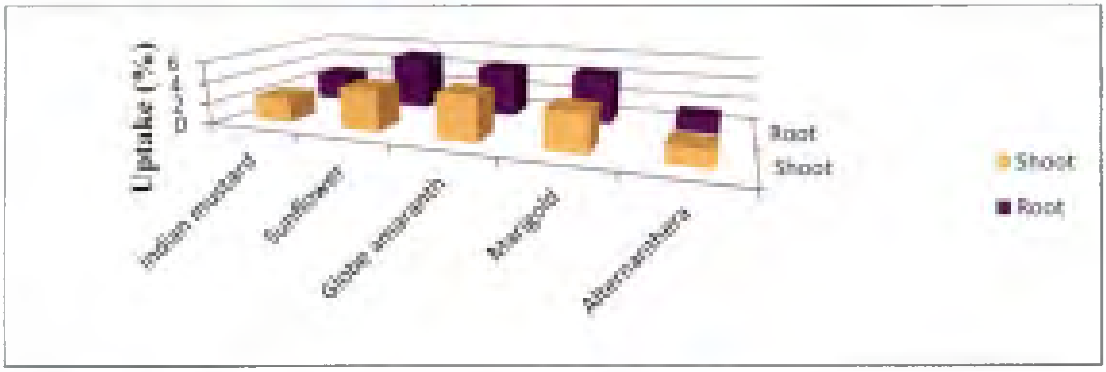

Figure 48. Uptake of nickel in shoot and root of different hyper accumulators when grown in media containing 1.5 mg kg^{-1} nickel

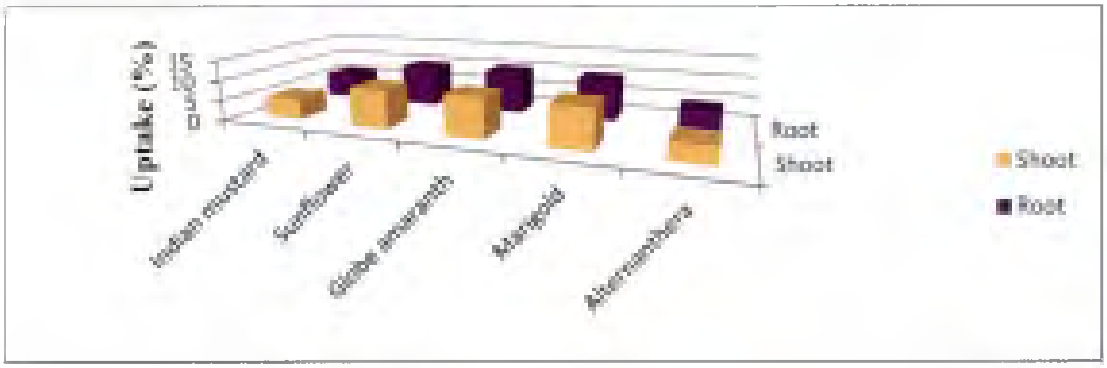

Figure 49. Uptake of nickel in shoot and root of different hyper accumulators when grown in media containing 2.5 mg kg^{-1} nickel

the present study, the ready availability of a higher concentration of cadmium outside the root system must have upset the physiological processes operating within the roots preventing its uptake. Yashona *et al.* (2016) reported that cadmium absorption will be more effective only if soils have high CEC and organic matter content.

However, the present sand culture study generally endorses the fact that higher concentration of metals in the rhizosphere permit higher absorption from metalliferous media through some physiological mechanisms which enable them to proportionately absorb and tolerate the metal toxicity through internal detoxification. Baker (1981) substantiated a similar observation that the hyper accumulators maintained higher concentration of metals in plants grown in sand culture and it was more related to the degree of metal saturation in the media. Exactly similar observations have been reported by Miller (1997).

5.4. POT CULTURE EXPERIMENT

In order to revalidate the existing information on the hyper accumulators from the sand culture experiment and to see its performance in the backdrop of contaminated waste dump, a pot culture experiment was conducted. For this a 10 kg potting mixture was constituted with different proportions of virgin soil and waste materials from the dump site with and without the usage of AMF. The introduction of AMF in the mixture was done purposefully to see the effectiveness of AMF in mitigating the pollution effect. Garg and Bhandari (2012) has reported that the usage of AMF were very much effective in heavy metal contaminated soils particularly for mitigating the metal load in plants.

In order to present an effective discussion on this study employing different hyper accumulators (sunflower, globe amaranth and marigold), Table 28 which provide the basic data on the different physico-chemical properties of the pre-treatment potting mixture is compared with that from the post harvest soils (Table 30, 35 and 39) under three test crops.

The post harvest heavy metal status in the potting mixture for sunflower, globe amaranth and marigold is provided in Tables 31, 36 and 40, respectively. The selective retention of heavy metal status in the root, shoot and seed portions of sun flower is provided in tables 32, 33 and 34, respectively. The selective retention status of metals in the root and shoot portions of globe amaranth is provided in Tables 37 and 38 while that of marigold is presented in Table 41 and 42. The selective retention statuses of different metals in all the three tested plants were graphically represented in Fig. 50 to 60.

In general it is seen in post harvest soil that there had been marginal enhancement in soil reaction compared to the initial soil. This marginal increase can be attributed to the dissolution of the various soluble salts which might have come along with the landfill materials during the course of three months growing period making alterations in soil reaction. This observation has been substantiated by the finding of Ali *et al.* (2014). Further, it is also possible that metals like iron and aluminium which were exceedingly present in the landfill materials were also capable of introducing potential acidity in the media could have been removed by the growing hyper accumulators and thus eliminating the chances for bringing in substantial changes in soil reaction, particularly when Bessho and Bell (1992) reported that presence of ions of aluminium and iron in the growing media created prospective chances for acidifying the soil. The incorporation of AMF could not bring in any specific change in pH.

The marginal decrease in the EC observed between pre and post harvest samples could have been obviously due to the utilization of the ions from the growing media which otherwise should have enhanced the EC. The influence of AMF in either decreasing or enhancing the EC was totally absent in the study. In all possibility this could be due to the quick and preferential adsorption by plants rather than by the mycorrhizal fungi, particularly when AMF application failed to mark any difference in altering the EC.

The general enhancement of bulk density observed in the entire post harvest sample compared to its basic data after stabilization of potting mixture might be due to the natural compaction that might have occurred within the pot during the growth period (Hamza and Anderson, 2005). AMF introduction brought in comparatively lesser bulk density than its pairing treatment without it. The triggering of root growth under the influence of AMF and associated enhancement in root growth within the pot might have resulted in the marginal decrease in bulk density (Willis *et al.*, 2013).

The general decrease in the organic carbon content in post harvest soils and particularly in the absence of AMF might have been due to the biological oxidation of carbon source by various microorganisms. Comparative enhancement of organic carbon in AMF treated pots can be attributed to the better growth of roots and associated contribution of biomass from both microorganism and root exudates. Further, sloughing of roots during growth where cells from root cap are shed to the soil can also contribute to the organic carbon status. A similar observation was endorsed by Singh *et al.* (2007).

In the case of nitrogen status there was a general scaling down in the post harvest soil samples. There could have been fair utilization of this element from the media by the growing plant to support the plant biomass of the different hyper accumulator plants. Obviously this could be a valid reason for the observed decrease in the nitrogen status in post treatment soil. However, the higher nitrogen status generally observed in all the AMF treated pots could be an indirect reflection of the extra soil biomass introduced at the expense of flourishing root system or microbial association in the rhizosphere.

The available phosphorus status in the post harvest soils generally remained lower than the constituted potting mixture. The decrease in the phosphorus level could only be due to the utilization of this element by growing plants over a period of three months time. Still lower phosphorus observed in AMF treated pots might in all

possibility be due to the higher and effective absorption of this element by plants by virtue of the known capacity of the mycorrhizal fungi. According to Tanwar *et al.* (2015), plants utilized higher P content to overcome the heavy metal stressed condition and the inoculation of AMF, always complimented this situation. Further, according to them, such plants facilitated absorption of many useful nutrients resulting in high chlorophyll content and growth.

Like phosphorus, the observed decrease in available potassium in post harvest soil sample might be due to the general utilization of this element by growing plant from the limited media. Further, the ability of this root colonizing fungi might have supported better absorption of potassium from the soil to the host plant through its ramified mycelia existing either as endo or ecto- mycorrhiza. Gohre and Paszkwoski (2006) also supported such a contention where in they reported that the mycelia ramification available with the fungus on successful establishment with host root system provided better nutritional status.

The concentration of aluminium in the postharvest samples also registered decline in trend compared to pre-treatment levels. The hyper accumulators which were raised in this reconstituted potting mixture might have removed aluminium ions along with other ions and thus forcing a decline in concentration in the growing media all through a period of three months growth of hyper accumulators. The relatively high content of aluminium noted in AMF treated media in post harvest soil samples compared to any pairing treatment without AMF, might be due to the ability of mycelia fungi to hold back the metal from being absorbed by the plant. A similar exclusion strategy of metal ions in plants colonized by AMF has described by Marques *et al.* (2009).

The availability of different heavy metals in the growing media was assessed after a period of three months after raising different hyper accumulators is being discussed. In general zinc, manganese, copper, iron, lead, cadmium, nickel, cobalt,

chromium and mercury registered a decline over its original status at the time of constitution of the potting mixture. This decline can only be substantiated by the removal of various metals by the individual hyper accumulator plants raised in the medium. The extent of removal of metals by different hyper accumulators was more or less proportional to the various heavy metal loads made available in the potting mixture at various proportions of mixing necessitated in the study. This observation of higher absorption by plants under higher metallic load in medium is in total congruity with the findings of Baker (1981). The availability of sufficient CEC and organic matter status in medium must have also facilitated steady release of various metals for absorption. Similar view has been endorsed by Yashona *et al.* (2016).

The negative influence of AMF inoculation in the contaminated media was evident in the hyper accumulators with lesser absorption and retention of these metals in the plant biomass. The possible mechanisms that might have operated in this context could be due to the extra radical mycelium of AMF with innate higher sorbing capacity for heavy metals than the root cells might have been instrumental in facilitating higher absorption and consequently their lesser entry into the plant system. Further, this phenomenon of screening of heavy metals by AMF colonized on roots was explained by Meier *et al.* (2012). According to them, their illustration was that many of the functional groups like amino, hydroxyl, carboxyl and other groups available in the cell wall components of AMF bound these potentially toxic heavy metals and thus temporarily rendering unavailable for the plants for absorption.

On comparison of three hyper accumulators namely sunflower, globe amaranth and marigold, it is seen that sunflower can be adjudged as one among the best in removing heavy metals from the contaminated media more so in the absence of AMF inoculation. The observations of Meier *et al.* (2012), can be explained to justify the screening processes of heavy metals by the fungal hyphae of AMF in withholding metals from the contaminated media from being absorbed leading to lesser load of metals in plants. The lower levels of heavy metal content in the seed

portions and sufficient accumulation of other metals in the other plant parts of this oil yielding plant opens up another opportunity for utilizing contaminated soils for raising them either as an economic crop for oil extraction or for other aesthetic sense with the rider that there should not be any recycling of this plant part to the same location.

Though the unopened buttons of globe amaranth is in high demand as a flower in the local market and the present availability of this flower in the capital is met from the neighboring states from Tamil Nadu and Karnataka. In the present study it has been concluded that this plant is a super accumulator of nickel which is abundantly available in the waste dump. Since these flowers are not consumed in the food chain for any purpose, the potential of growing this plant extensively over the landfill materials will open up chances for not only reducing the import of this flower from neighboring states, but also pave way for mitigating different metal load in the media besides enhancing the aesthetic beauty of the hitherto unutilized land area. The removal of biomass after de-capping the buttons from that area will also help in gradual mining of the nickel load from the surface layers of the landfill site making it fit and safe for alternate crops at a later stage.

The concluded experiment throws up another potential opportunity for raising marigold as another phytoremediator for mining the area of the heavy metal load. This flower has high demand in the local market and currently being imported from two neighboring states. If the contaminated soils of Vilappilsala plant area can be utilized for raising this, the soils can be relieved of many metal load in the course of time. Though this plant is identified to retain preferential doses of chromium in tissues, care should be taken not be recycle the plant parts after harvest of flowers. In this way, the chromium load of surface soil can be gradually siphoned off over a period of time.

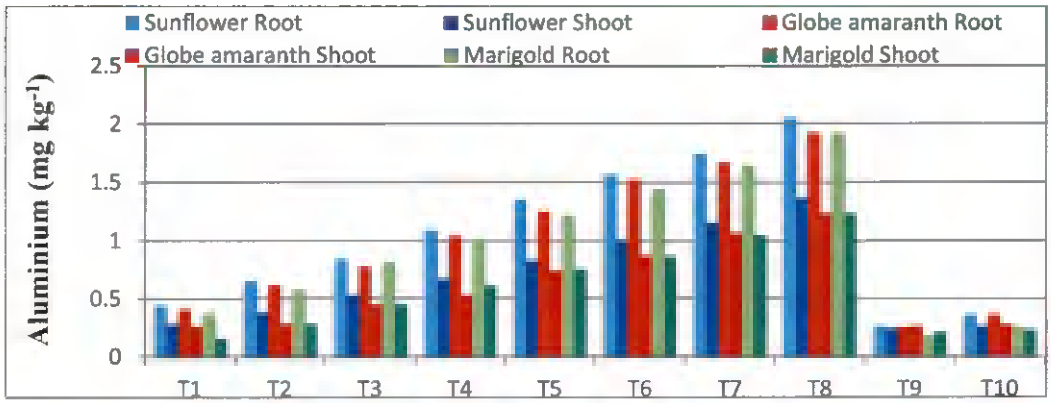

Figure 50. Extent of selective retention (root and shoot) of aluminium in hyper accumulators raised under the graded doses of contaminated landfill materials

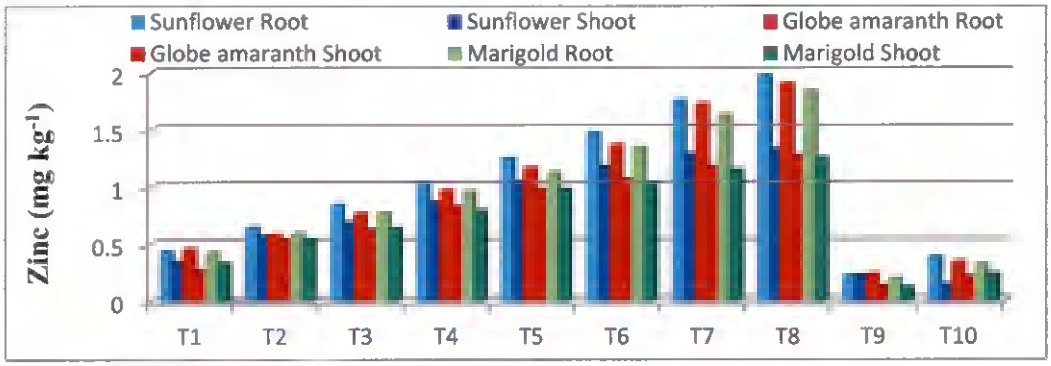

Figure 51. Extent of selective retention (root and shoot) of zinc in hyper accumulators raised under the graded doses of contaminated landfill materials

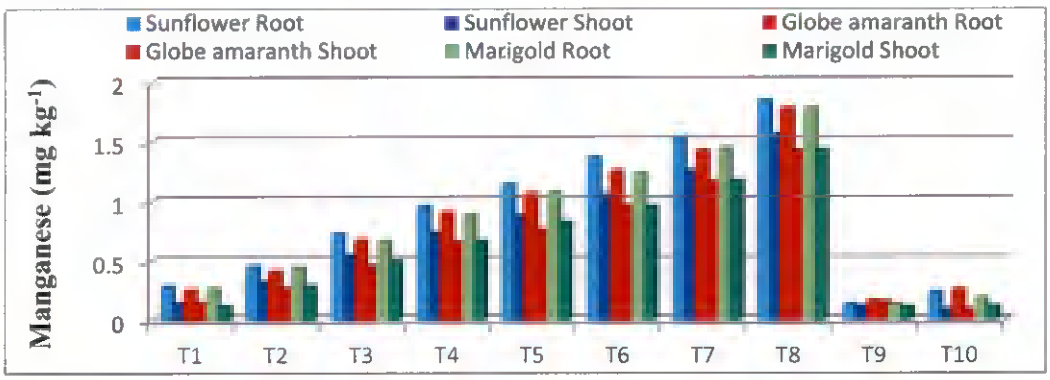

Figure 52. Extent of selective retention (root and shoot) of manganese in hyper accumulators raised under the graded doses of contaminated landfill materials

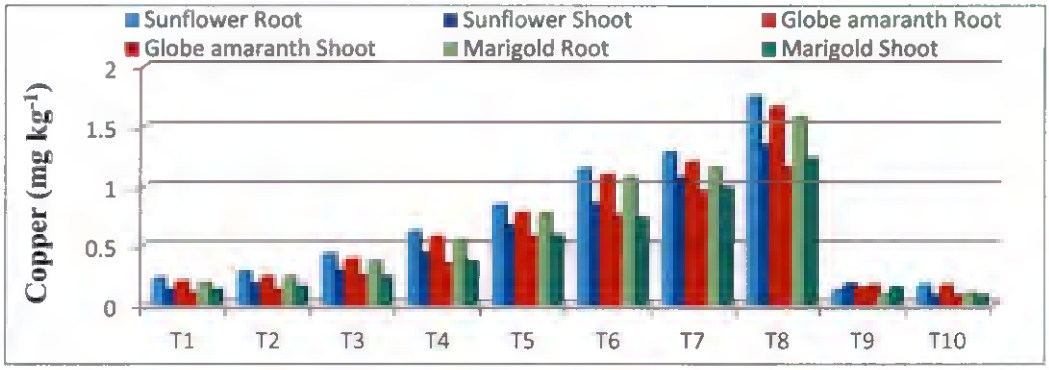

Figure 53. Extent of selective retention (root and shoot) of copper in hyper accumulators raised under the graded doses of contaminated landfill materials

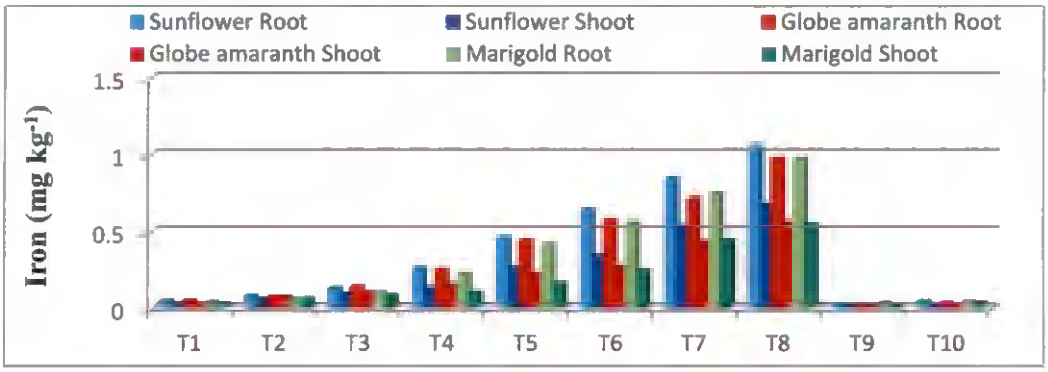

Figure 54. Extent of selective retention (root and shoot) of iron in hyper accumulators raised under the graded doses of contaminated landfill materials

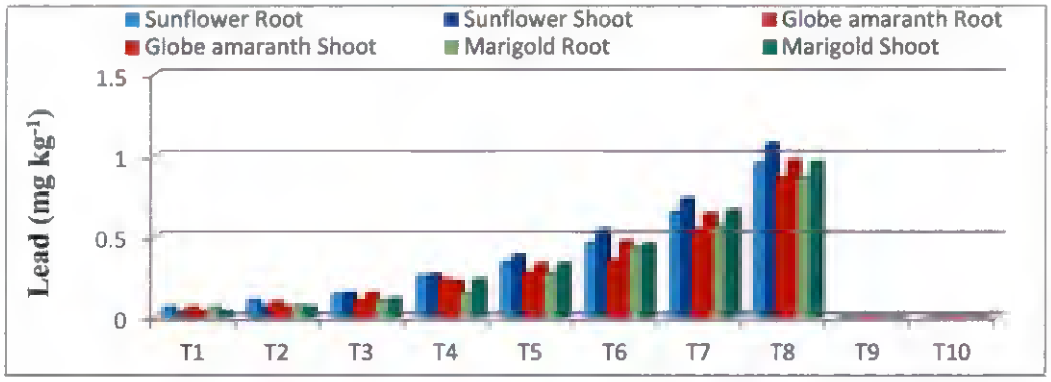

Figure 55. Extent of selective retention (root and shoot) of lead in hyper accumulators raised under the graded doses of contaminated landfill materials

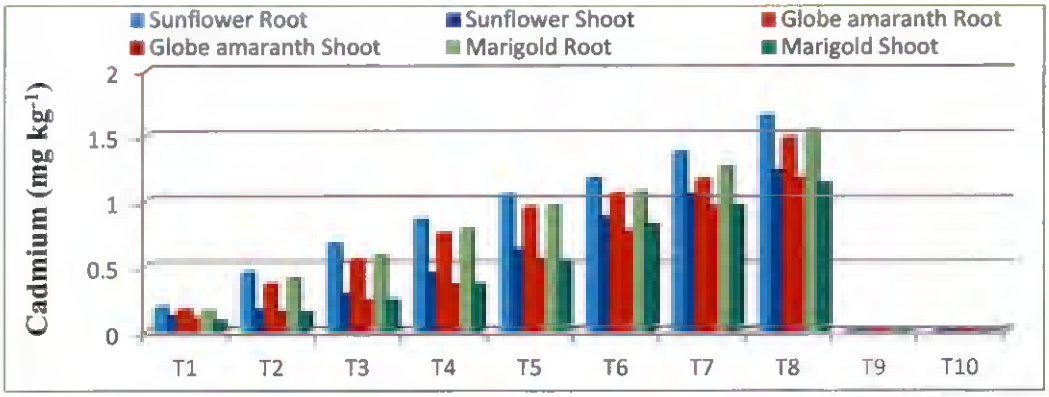

Figure 56. Extent of selective retention (root and shoot) of cadmium in hyper accumulators raised under the graded doses of contaminated landfill materials

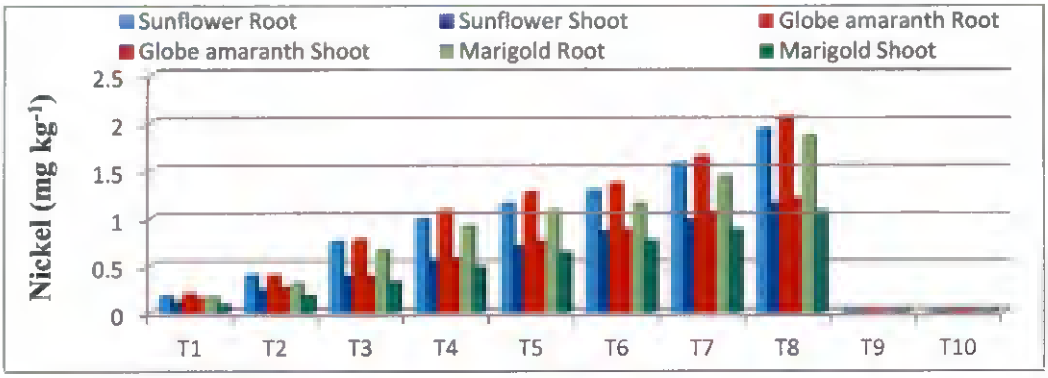

Figure 57. Extent of selective retention (root and shoot) of nickel in hyper accumulators raised under the graded doses of contaminated landfill materials

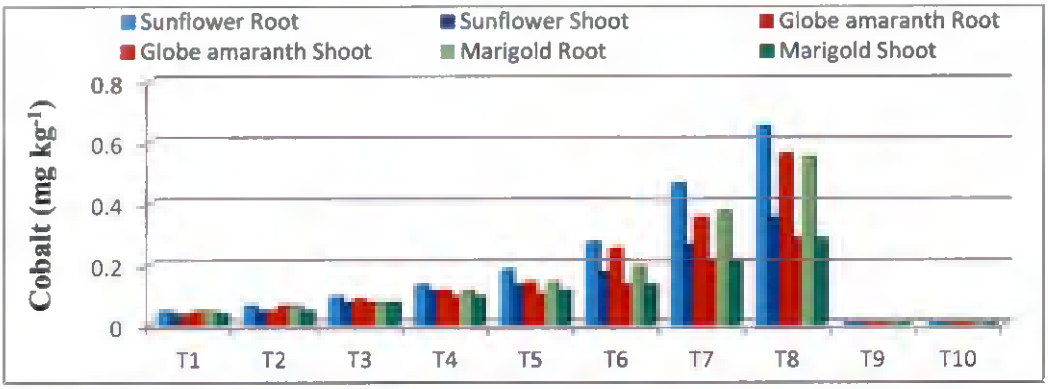

Figure 58. Extent of selective retention (root and shoot) of cobalt in hyper accumulators raised under the graded doses of contaminated landfill materials

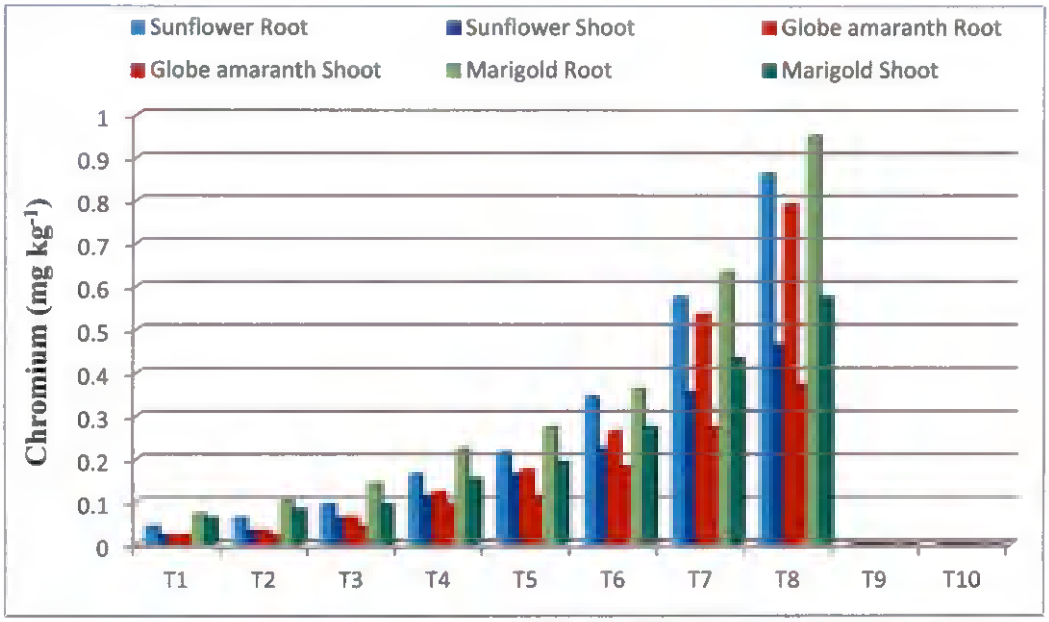

Figure 59. Extent of selective retention (root and shoot) of chromium in hyper accumulators raised under the graded doses of contaminated landfill materials

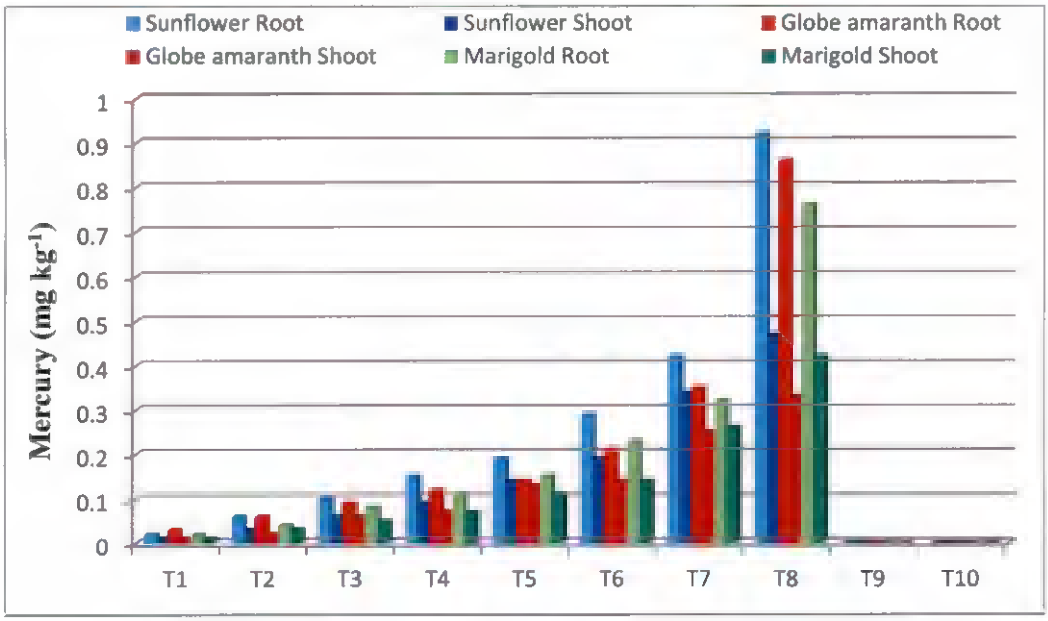

Figure 60. Extent of selective retention (root and shoot) of mercury in hyper accumulators raised under the graded doses of contaminated landfill materials

Since the three test crops have their own peculiarities of selective removal of heavy metals, it is suggested that there should be either rotation of these flowering crops in the area or there should be a mixture of these crops in that area with locations getting rotated. Such an action will help to generate revenue for the corporation if this kind of cultivation practices is adopted. Further, this area can be developed into a bio-park leaving it opened to public in a bid to make the city greener.

In the Vilappilsala treatment plant area where dumping of non degradable part of the waste materials had been practiced, the net result is that two landfill sites available in the locality it is an epicenter of various metal ions. The extent of metal contamination cannot be predicted or assessed correctly in view of the uncertainties in the origin and the depth of dump. The absence of a leachate treatment plant in the design has been identified as a major lacuna in the entire setup and this has been identified as a major reason for letting out the contaminants whose chemical characteristics fluctuates with seasonal changes. Since the major study had been confined mainly within the plant area and to some extent, few underground water sources outside the area contaminations have been identified, it is to be realized that potential risk of biological and chemical pollution still lie within the landfill site. Many contaminants from the landfill, outside the scope of this study will also be passed on to down streams of the *Meenampally thodu* and the exact fate of that will always be obscure. It is further clear that the closure of the plant does not insulate immediate surroundings of the problems associated with the dumped waste as long as the leachate plant is absent. The study strongly recommends the necessity for erection of a leachate plant even in the absence of fresh receipt of waste in the area.

The study also suggest that these areas can be converted into a bio-park where phytoremediators and flowering plants sunflower, globe amaranth and marigold can be grown on a large scale and marketed locally to meet the flower demand. As long as these items are not consumed the question of biomagnifications does not arise and

gradually over a period of time the level of contaminated metal ions can be reduced. However, a word of caution is to be exercised in raising edible fruits or agricultural crops in this area in view of the existing levels of metal ions. In the absence of proper benchmark details of the metal status at any point prior to this study has incapacitated any comparison. However, the present study which has provided different metal status within the plant can be taken as a bench mark for comparing the shift in the metal status at any later period for the purpose of assessing the possibility of mitigation in the contamination levels. The authorities are requested to put stricture on the free use of ground water in the vicinity of the treatment plant and it is recommended that the potable water in the vicinity from ground water sources must be subjected to filtration of metal ions before it is consumed.

Summary

6. SUMMARY

The study entitled "Impact assessment of landfill on soil health and water quality in a waste disposal site" was undertaken with an objective to assess the impact of dumping Municipal Solid Waste (MSW) on soil and water quality, spatial variability in the level of biological and chemical contamination along the leachate flow zone and identification of a few bioremediators and their possible effectiveness of decontamination. As a part of this study, geo-referenced sampling points have been identified initially and later from these points, dumped waste materials (from existing two dumpsites), soil samples (from two depths) and leachate sample along the leachate zone at a regular interval of 50 meters, were collected in three distinct seasons. Groundwater samples were collected from outside the Vilappilsala garbage treatment plant area and analyzed for various physico-chemical and biological parameters. The extents of possible heavy metal contamination in the collected samples were also assessed. The various parameters which were focused in the study were bulk density, pH, electrical conductivity, nitrogen, phosphorus, potassium, calcium, magnesium, aluminium and heavy metals like zinc, manganese, copper, iron, lead, cadmium, nickel, cobalt, chromium and mercury. The leachate samples and well water samples collected were also specially examined for the seasonal variations in pH, electrical conductivity, total dissolved solids, biological oxygen demand, chemical oxygen demand, coliform count, calcium, magnesium, aluminium, zinc, manganese, copper, iron, lead, cadmium, nickel, cobalt, chromium and mercury.

Some of the profusely growing weed species along the leachate flowing zone were also collected initially assuming that they might be holding a reflection of the heavy metals which might have come out from the dumped waste materials through leachate. Hence their selective retention capacities for various heavy metals were assessed separately in roots and shoot portions, besides their uptake of calcium and magnesium. The purpose of this attempt is to identify, select and earmark some weed as best hyper accumulator and later to compare and evaluate its efficiency with that of

the already established hyper accumulator plants namely; Indian mustard, sunflower, globe amaranth and marigold. This part of study was attempted through a sand culture experiment (maintained for a month) where the performance established hyper accumulators along with one weed plant (*Alternanthera tenella*) were assessed for their selective retention capacity under four graded doses of lead, cadmium and nickel.

From this study, the best three plant species showing one of the highest hyper accumulation capacities for various heavy metals was carried forward to assess their actual performance in the landfill materials collected from Vilappilsala. For this, the landfill materials were mixed in different proportions with virgin soil collected from the College of Agriculture and used in grow bags as pot culture experiment. Since there were reports that use of AMF in soil could mitigate the heavy metal uptake by plants, this aspect was also included in the pot culture study for authentication of the claim. Both pre-treatment and post harvest soil samples of potting mixture in different treatments were analyzed for bulk density, pH, electrical conductivity, available N, P, K, Ca, Mg, Al, Zn, Mn, Cu, Fe, Pb, Cd, Ni, Co, Cr and Hg. The plants were allowed to grow for a period of three months and later harvested carefully for separate assessment different metal load in their root and shoot portions. However, in case of sunflower, the seeds were also analyzed separately for possible heavy metal contamination in view of its economic importance as an oilseed.

The salient outcome of this study are summarized and listed below.

- The dumped waste materials generally had low bulk density than the normal soils and the impact of seasonal effect in the study was too short a period to impart changes in the bulk density of the waste materials
- The pH of the waste material indicated acidic reaction and the electrical conductivity was normal and within safe limits

- Absence of variation in organic carbon content across the seasons of study in the waste materials might be due to its stabilization within the dump.
- Seasonal effect was well pronounced within the waste material with respect to the content of N, P, K, Ca, Mg and Al. Invariably during the pre-monsoon season, the samples registered relatively much higher value and post-monsoon samples provided the lowest values.
- Comparatively very high level of potassium was identified in waste material across all the seasons of study, particularly when compared to the levels of nitrogen and phosphorus.
- Marginal variations were observed with respect to heavy metals like Zn, Mn, Cu, Fe, Pb, Cd, Ni, Co, Cr and Hg within the waste materials under the influence of different seasons and highest value noticed during pre-monsoon season.
- In the leachate zone, at lower depths (30-60 cm) all soil samples maintained higher bulk density than surface soils (0-30 cm) and there was no seasonal effect or impact in altering this values.
- Irrespective of the depth variations, all soil samples maintained acidic reactions. Marginal enhancement in pH was observed in monsoon season.
- Electrical conductivity of the soil samples in leachate zone were quite normal and well within safe limits in all the seasons. However, there was marginal enhancement observed EC during monsoon period at all the sampling points.
- Organic carbon content in soil did not register much variation in samples across the seasons except for some observed higher value during pre-monsoon season. Sampling depths also could not bring in much variation in organic carbon content.
- There was an observed reduction in NPK in the subsurface samples compared to its upper layer samples at 0-30 cm depth. In general, there was a gradual reduction in NPK content with enhancement in distance from the dumpsite.

- The actual metal load observed in the waste materials were not reflected in soil samples collected along the leachate zone. Generally, higher heavy metal load was noticed in the pre-monsoon season and monsoon seasons always presented lesser metal load. Marginal enhancement in metal load in soils was noticed during the post-monsoon season. Compared to upper layers, the lower layers maintained decreased content of heavy metals.
- Leachate collected from all designated sampling points maintained alkaline reaction associated with high electrical conductivity. This is particularly true during the pre-monsoon season, which then decreased during monsoon season and later picked up during the post-monsoon season
- Monsoon period samples recorded lower values for total dissolved solids (TDS) than the other two seasons. Enhancement in TDS observed in fourth sampling site is specifically due to the impact of convergence of leachate from an adjoining dumpsite within the plant area
- The BOD of leachates from all the sampling sites crossed the minimum standard for safe disposal to an inland surface water source prescribed by Solid Waste Management rules in 2016 in all the seasons and comparatively low value recorded in monsoon season than the pre-monsoon and post-monsoon seasons
- The leachates collected from near the dump sites also crossed the limit of COD for safe disposal into a surface water source and monsoon seasons invariably lifted the COD values compared to other two seasons of study.
- Coliforms were found in all the leachate samples and some of them above the minimum standard in all three seasons. However, there was lowering of its values during monsoon period was recorded
- Ca, Mg, Zn and Mn recorded a low value during monsoon season and as the distance from dumpsite increased the concentration decreased. Except some

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of the sampling sites of Mg and Mn all other sampling sites these metal concentrations were well within the minimum standard of safe disposal

- In case of Al, Cu, Fe and Pb, the same trend as seen in the case of Ca, Mg, Zn and Mn with respect to distance and seasons were noticed. The concentrations of Al and Fe never provided a safe range at any sampling point all along the leachate zone.
- The heavy metal concentration with respect to Cd, Ni, Co, Cr, Hg and As in soil samples decreased during monsoon season even to non-detectable limits particularly in case of Cd and As.
- Arsenic was totally absent during post-monsoon season in all the sampling sites along the leachate flowing zone though its presence was identified in other two seasons
- Mercuric content in the leachate samples were very high and much above the safe limit of disposal and this were true in all the seasons of study.
- All the well water samples collected and analyzed were in acidic in reaction and there was an enhancement in pH in well water which remained in close proximity to the dumpsite. However, all well waters maintained safe limits of pH when compared with BIS standards
- EC, BOD and COD values of all the well waters were well within the safe limits during all the three seasons of study.
- Coliforms were present in all the well waters in all the seasons making it unfit for human consumption without proper corrections in monsoon season and post monsoon seasons. However, during pre-monsoon the levels of coliforms appeared to be safe since there was considerable reduction in their count
- Ca, Mg, Al, Zn, Mn, Fe and Cu levels in well water maintained a safe limits in all the seasons except the concentration of Fe in pre-monsoon and post-monsoon seasons and the concentration of Al in all three seasons

- The concentration of Pb, Cd and Hg in the well water exceeded the acceptable limits insisted by BIS for human consumption during all the three seasons of study. However, Ni and Cr values were lower and were well below the permissible limits in all seasons. Excessive levels of Hg were noticed in well water in pre and post-monsoon seasons.
- Almost all the metals like Ca, Mg, Zn, Mn, Cu, Pb, Cd, Ni, Co and Cr were found to be selectively retained in root portions than the shoot portions in majority of weeds selected for study.
- Weeds like *Sphagneticola trilobata*, *Commelina diffusa*, *Mikania micrantha* and *Ricinus communis* were found to retain more toxic metal load in the shoot portion than the root portions
- Among the 15 weed species collected from the leachate zone of the Vilappilsala treatment plant area, *Alternanthera tenella* was identified as the best hyper accumulator with respect to its gross uptake of the heavy metals and hence this plant was honoured as one of the best hyper accumulator weed plant for trial in sand culture study
- There was proportionate accumulation of metals in plant parts with enhancement in the treatment load of metals in growing media (acid washed sand) in well known hyper accumulators and selected weed plant
- The results of sand culture experiment reveled that all the experimental plants (Indian mustard, sunflower, globe amaranth, marigold and *Alternanthera tenella*) maintained high retention of various metals in root portion rather than the shoot portion
- From the sand culture experiment, marigold was adjudged as the topper in retaining the maximum metal load (Pb, Cd and Ni) particularly under the highest dose of metal application (2.5 mg kg^{-1}) and its selective retention site had been specifically identified in root portion

- The root portions of marigold were able to maintain the maximum metal load of lead from the highest treatment dose (2.5 mg kg^{-1}) and proportionately with the next lower level (1.5 mg kg^{-1}).
- In the comparison, *Alternanthera tenella* was relegated to a much lower level considering the quantum of retention of heavy metals by the other four competitors employed in the sand culture study
- Globe amaranth was identified to be a successful hyper accumulator of lead at lower concentration and not at higher concentration in both root and shoot portions
- Sunflower has proved to be yet another effective hyper accumulator particularly for nickel at lower levels of contamination.
- It is seen that sunflower maintained higher levels of retention of cadmium in the root portion even under the influence of highest levels in the sand media
- Indian mustard was identified in the sand culture study as an ineffective hyper accumulator of cadmium at both at lower and higher levels of application of treatment.
- Based on the performance of sunflower, globe amaranth and marigold in the sand culture experiment with respect to the uptake of heavy metals from the media, they were taken forward as best and final hyper accumulators in the study for revalidation of its performance the pot culture experiment using landfill materials
- In pot culture experiment a marginal enhancement in soil reaction was noticed when compared to the initial soil pH and the incorporation of AMF could not bring in any specific change in modifying the pH
- There was general enhancement in the observed bulk density in the entire post harvest soil samples compared to its corresponding pre-treatment values and the introduction of AMF brought in comparatively lesser bulk density than its pairing treatment without AMF.

- There was a general decrease in the organic carbon content in post harvest soil samples and this more so with the absence of AMF.
- In case of nitrogen status, there was a general scaling down in status in the post harvest soil samples. Higher nitrogen status was generally identified in all the AMF treated pots.
- The available phosphorus status in the post harvest soils generally remained lower than the constituted potting mixture before growing plants. All AMF treated pots registered lower phosphorus status compared to non-AMF pots
- The available potassium also maintained similar trend as seen for phosphorus and the impact of AMF in pots also remained similar.
- The post harvest status of aluminium in soil registered a decline in trend compared to pretreatment levels and relatively high content of aluminium was retained by post harvest soils where AMF was included
- Zinc, manganese, copper, iron, lead, cadmium, nickel, cobalt, chromium and mercury registered a decline over its original status (pre-treatment values) when assessed in the post harvest soil samples.
- In case of the absorption by hyper accumulators from pot culture experiment, it was seen that there had only been lower levels of metals uptake from soil at all points where AMF had been included in the treatment. The contrast in metal absorption values were very clear with non-AMF treated pots
- Among the hyper accumulator experimented in pots using landfill materials, it is seen that sunflower is the best plant identified to remove maximum load of heavy metals from the constituted growing media.
- Even though sunflower accumulated most of the heavy metals from the growing media, majority of the metal absorption was restricted roots, then lesser quantity to shoots and finally a very low quantity to the seeds, making the economic product safer.

- Globe amaranth has been specifically identified as a super accumulator of nickel when compared to sunflower and marigold and presence of AMF in the growing media retarded the absorption rate as seen in other cases.
- Marigold is identified to retain heavy doses of chromium in both root and shoot portions when compared with sunflower and globe amaranth

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* Originals not seen

Appendices

APPENDIX - I

Fertility classes of soil reaction and nutrients

Parameters	Fertility class	Critical range
pH	Extremely acid	3.5-4.5
	Very strongly acid	4.5 – 5.0
	Strongly acid	5.0-5.5
	Moderately acid	5.5-6.0
	Slightly acid	6.0-6.5
EC (dS/m)	Low	<0.25
	Medium	0.25-0.75
	High	0.75-2.25
	Very high	>2.25
Org. C (%)	Low	< 0.3
	Medium	0.3-0.9 sand (0.5-1.5 clay)
	High	> 0.9
Available N (kg ha^{-1})	Low	<280
	Medium	280-560
	High	>560
Available P (kg ha^{-1})	Low	< 10
	Medium	10 – 24
	High	> 24
Available K (kg ha^{-1})	Low	< 115
	Medium	115 - 275
	High	>275
Available Ca (mg kg^{-1})	Sufficient	>300
	Deficient	<300

Fertility classes of soil reaction and nutrients

Parameters	Fertility class	Critical range
Available Mg (mg kg^{-1})	Sufficient	>120
	Deficient	<120
Available S (mg kg^{-1})	Sufficient	5 - 10
	Deficient	<5
Available Fe (mg kg^{-1})	Sufficient	>5
	Deficient	<5
Available Cu (mg kg^{-1})	Sufficient	>1
	Deficient	<1
Available Zn (mg kg^{-1})	Sufficient	>1
	Deficient	<1
Available Mn (mg kg^{-1})	Sufficient	>1
	Deficient	<1
Available B (mg kg^{-1})	Sufficient	>0.5
	Deficient	<0.5

APPENDIX- II

Standards for disposing treated leachates (as per Solid Waste Management rules, 2016)

Sl. No.	Parameter	Standards (Mode of disposal)		
		Inland surface water	Public sewers	Land disposal
1	Suspended solids, mg/l, max	100	600	200
2	Dissolved solids (inorganic) mg/l, max.	2100	2100	2100
3	pH value	5.5 to 9.0	5.5 to 9.0	5.5 to 9.0
4	Ammonical nitrogen (as N), mg/l, max.	50	50	-
5	Total Kjeldahl nitrogen (as N), mg/l, max.	100	-	-
6	Biochemical oxygen demand (3 days at 270 C) max.(mg/l)	30	350	100
7	Chemical oxygen demand, mg/l, max.	250	-	-
8	Arsenic (as As), mg/l, max	0.2	0.2	0.2
9	Mercury (as Hg), mg/l, max	0.01	0.01	-
10	Lead (as Pb), mg/l, max	0.1	1.0	-
11	Cadmium (as Cd), mg/l, max	2.0	1.0	-
12	Total Chromium (as Cr), mg/l, max.	2.0	2.0	-
13	Copper (as Cu), mg/l, max.	3.0	3.0	-
14	Zinc (as Zn), mg/l, max.	5.0	15.0	-
15	Nickel (as Ni), mg/l, max	3.0	3.0	-
16	Cyanide (as CN), mg/l, max.	0.2	2.0	0.2
17	Chloride (as Cl), mg/l, max.	1000	1000	600
18	Fluoride (as F), mg/l, max	2.0	1.5	-
19	Phenolic compounds (as C6H5OH) mg/l, max.	1.0	5.0	-

APPENDIX III

IS 10500 : 2012 Drinking water – specification

Sl.No.	Characteristics	Acceptable limit	Permissible limit in the absence of alternate source
1	Colour, Hazen units, *Max*	5	15
2	Odour	Agreeable	Agreeable
3	*p*H value	6.5 -8.5	No relaxation
4	Total dissolved solids, mg/l, max	500	2000
5	Aluminium (as Al), mg/l, *Max*	0.03	0.2
6	Ammonia (as total ammonia-N), mg/l max.	0.5	No relaxation
7	Calcium (as Ca), mg/l, *Max*	75	200
8	Copper (as Cu), mg/l, *Max*	0.05	1.5
9	Iron (as Fe), mg/l, *Max*	0.3	No relaxation
10	Magnesium (as Mg), mg/l, *Max*	30	100
11	Manganese (as Mn), mg/l, *Max*	0.1	0.3
12	Zinc (as Zn), mg/l, *Max*	5	15
13	Cadmium (as Cd), mg/l, *Max*	0.003	No relaxation
14	Lead (as Pb), mg/l, *Max*	0.01	No relaxation
15	Mercury (as Hg), mg/l, *Max*	0.001	No relaxation
16	Molybdenum (as Mo), mg/l, *Max*	0.07	No relaxation
17	Nickel (as Ni), mg/l, *Max*	0.02	No relaxation
18	Total arsenic (as As), mg/l, *Max*	0.01	0.05
19	Total chromium (as Cr), mg/l, *Max*	0.05	No relaxation

IMPACT ASSESSMENT OF LANDFILL ON SOIL HEALTH AND WATER QUALITY IN A WASTE DISPOSAL SITE

by

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ABSTRACT OF THE THESIS

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ABSTRACT

The study entitled "Impact assessment of landfill on soil health and water quality in a waste disposal site" was undertaken with an objective to assess the impact of dumping Municipal Solid Waste (MSW) on soil and water quality, spatial variability in the level of biological and chemical contamination along the leachate zone and identification of a few bioremediators and their possible effectiveness in decontaminating the landfill materials. As a part of this study, geo-referenced sampling points have been identified initially for dumped waste materials (from the existing two landfill sites), soil (from two depths) and leachate samples along the leachate flow zone at a regular interval of 50 m within the plant area and ground water samples outside the area were collected. All the samples were monitored from these geo-referenced sampling points in three successive seasons, *viz*., pre-monsoon, monsoon and post-monsoon. The values for all the physico-chemical parameters in landfill materials were high during pre-monsoon period and only a marginal variation observed in heavy metal content in three seasons of study. Soil samples were acidic in reaction and a reduction in N, P, K and heavy metals were observed as the depth of sampling increased. Comparatively high values were observed in all parameters during pre-monsoon period than the other two seasons both in soil and leachate samples. Fe, Al and Hg content in leachates were very high and the concentrations of Fe, Al, Pb, Cd and Hg in ground water exceeded the acceptable level insisted by BIS. The leachate samples also recorded a high value for biological oxygen demand, chemical oxygen demand and coliform count than the ground water samples.

Fifteen profusely growing weed species were identified and collected along the leachate flowing zone and the shoot and root portions were analyzed separately for various heavy metals to assess their selective retention capacities. Most of the weed species except *Sphagneticola trilobata*, *Commelina diffusa*, *Ricinus communis*, and *Mikania micrantha* were found to retain more toxic metal load in the root portion than the shoot portions. Among them, *Alternanthera tenella* was identified as the

best hyper accumulator with respect to its gross uptake of the metals like Mg, Mn, Pb, Cd, Ni, Co and Cr. Hence, this plant was selected for the sand culture study along with other established hyper accumulator plants namely; Indian mustard, sunflower, globe amaranth and marigold analyzed for selective retention capacity under four graded doses of lead, cadmium and nickel.

This study identified three best plants species (sunflower, globe amaranth and marigold) showing highest hyper accumulation capacities and hence they were carried forward to another pot culture study employing contaminated and degradable landfill materials for the final revalidation of claims. The experiment consisted of ten treatments and the treatments where the growing medium was re-constituted with different proportions of degradable landfill materials and virgin soil with and without the AMF inoculation. The plants which were grown for three months were analyzed separately for root and shoot portions for the exact quantum of selective retention status of metals like Al, Zn, Cu, Fe, Pb, Cd, Ni, Co, Cr and Hg. Lower levels of metal accumulation was recorded in all the plant parts where AMF had been inoculated in the media than its pairing treatment without inoculation, indicating the specific effect of AMF in preventing the uptake of heavy metals by plants and at the same time permitting the absorption of other ions needed for growth. Sunflower had been adjudged as the best plant that removed maximum load of studied heavy metals from the contaminated growing media except nickel and chromium. Similarly globe amaranth had been specifically identified as an excellent accumulator of nickel. Marigold was identified to be efficient accumulator of chromium.

From the investigation it can be concluded that the soil and water bodies near the dumpsite sufficiently contaminated with the heavy metals like Zn, Mn, Cu, Fe, Pb, Cd, Ni, Co, Cr and Hg. As the distance from the dumpsite increased the extent of various chemical and biological contaminations showed a decreasing trend. Sunflower, globe amaranth and marigold were found to be effective hyper accumulators for the area in decontaminating the soils.