Performance Evaluation of Phytocapping As Covering For Sanitary Landfill Sites

Bhavya D. Shah[1], Dr. Mehali J. Mehta[2], Abhishek Khapre[3]

[1]Deputy General Manager (Process Design),
GREEN Design & Engineering Services Pvt. Ltd., Surat, India,
bhavyashah.2708@gmail.com

[2]Post Graduation In-charge, Masters of Engineering (Environmental Engineering), Assistant Professor. Civil Engineering Department
Sarvajanik College of Engineering & Technology, Surat, India,
mehali.mehta@scet.ac.in

[3]Senior Research Fellow
CSIR-National Environmental Engineering Research Institute Nagpur, Maharashtra, India,
abhishek.khapre@yahoo.in

Abstract*: Commonly adopted method for discarding of Municipal Solid Waste (MSW) is disposal on landfill sites. The practice involves treatment of MSW before disposal, which is infrequent in most of the places in India. With the disposal of untreated waste, the biodegradation of MSW triggers the formation of Landfill Gases (LFG). Moreover, the closer of aged landfill must be practiced with application of soil over the layer of last dumped waste, which is also infrequent, in turn the landfills are used until management thinks they can. This unplanned and haphazard use of landfill creates countless environmental hazard. To overcome this approach, the present paper focuses on a novel idea of closure of landfill by the application of vegetation (phytocaps) on its top. In the experiment three planters were used each depicting solid waste disposal site. Two planter P1 and P2 depicts MSW landfill sites with application of phytocaps and planter P3 portrays conventional MSW landfill sites. Five Indian species of plants, commonly named as Basil, Lemon grass, Indian Mustard, Sunflower and Lily with locally available soil were taken in experiment for evaluation of phytocaps for covering of landfill sites. The implementation of plants decreases the amount of nutrients and heavy metals in leachate, thereby decrease in threat of groundwater pollution. They also enhance the methane oxidation in soil. Roots of plants absorbs the essential nutrients from the soil leading to the bio-availability of oxygen for the methanotrops to oxidize the CH_4. The leachate characteristics, plant height, root depth, heavy metal uptake by roots, chlorophyll analysis and methane emission analysis from each planter were studied. The experiment resulted in 60-63% of reduction in methane emission in planter 1 and 2 while the emission in planter 3 increased with the course of time. Similarly, leachate samples from planter 1 and 2 showed reduction of 99% COD, 95-99% heavy metals, 75-82% nutrients and pH was found to be alkaline.

***Keywords*: Phytocap, Methane, MSW, Landfill gases.**

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I. Introduction

Due to rapid industrialization, urbanization, population, and economic growth, the generation rate of municipal solid waste is increased significantly. According to a survey conducted by the Central Pollution Control Board (CPCB) in 59 cities (35 metro cities and 24 state capitals) through the National Environmental Engineering Research Institute (NEERI), 59 cities generated 39,031 ton / day (TPD) of municipal solid Waste [26,31] . According to the available data from the State Pollution Control Board / Pollution Control committee (2009 to 2012) 1,27,486 tones TPD municipal solid waste was generated during the 2012-13 period. MSW management (MSWM) is one of the major environmental problems of Indian cities. The disposal of waste without any processing causes an unfavorable effect on all the factors of the environment and human health.

Among all available options for MSWM, landfill disposal is the most commonly employed waste management option in India, although waste disposal is the least preferred option in the waste management hierarchy theoretically. The survey conducted by the Federation of Indian Chambers of Commerce and Industry (FICCI) reveals MSW disposal at dumpsite varies from 16 to 100%, like in Kozhikode (Kerala) it is 16%. Ludhiana (Punjab) and Greater Mumbai (Maharashtra) have 100% waste disposal and in Delhi and Surat (Gujarat) around 95% of MSW reached to landfill sites, and in the rest of the cities/town less than 90% waste disposed to dumpsites (CPCB, 2013; FICCI, 2009). Annually, India produces around 70 million tons of municipal solid waste, of which only 5% of waste is processed scientifically. The FICCI survey reveals MSW discharge at landfill sites varies from 16 to 100%, like in Kozhikode district of Kerala, it is 16% and in Greater Mumbai it is 100%. 100% waste disposal was found in Greater Mumbai (Maharashtra) and Ludhiana (Punjab), MSW of about 95% reached respective landfill sites in Delhi and Surat (Gujarat), and less than 90% waste reached dumpsites in the rest of the regions (CPCB, 2013; FICCI, 2009). Adverse Effects of Landfilling consist of groundwater contamination and surface water contamination due to infiltration and runoff, bad odour, fly nuisance, fires due to methane gas burning, soil stability and soil erosion, acidity in soil in nearby areas of landfill and majorly Green-house gases emission such as Methane (CH_4), Nitrous oxide (N_2O), Carbon dioxide (CO_2).

In landfill, MSW is degraded by the microbial activity in anaerobic conditions. Landfill gases (LFG), generated during anaerobic decomposition of organic matter in buried municipal waste consists of 55-60 % methane (CH_4) and 40-45% carbon-dioxide (CO_2). CH_4 is one of the most important greenhouse gases. As a result of human activities, the concentration of CH_4 in the atmosphere increased from 715 ppb in the pre-industrial period to 1,732 ppb in the early 1990s and 1774 ppb in 2005 (IPCC, 2007). Although the concentration of CH_4 in the atmosphere is much lower than that of carbon dioxide, its global warming potential is 21 times higher than that of carbon dioxide (IPCC, 2007).

The formation of this gases leads to fire in the waste dumped and odour issue. Gas extraction systems that extract methane and other gases are used at some places but are found to be expensive. CH_4 gas migration from landfill to surrounding environment negatively affects both environment and humankind. India ranks fifth in the world's total greenhouse gas emissions (MoEF, 2010) [30]. Mitigating CH_4 emissions from landfills can significantly reduce the GHG emissions from waste sectors and attenuate the global CH_4 budget.

As a result of rising solid waste, composition changes, mismanagement and poor public attitudes, people face health risks directly. Landfills generally cause health problems, particularly cancer, reproductive outcomes and inadequate mortality. Due to leukocyte and platelet activation and airway inflammation, landfill workers are more susceptible to tissue damage and cardiovascular disease [12].

The alternative designs of landfill covers involve planting shrubs and/or tress directly into the top landfill cover soil, have been termed “PhytoremediationCaps/Phytocaps”. Plant root penetration may also affect the integrity of the clay barrier. Phytocapping provides a natural soil-plant alternative to the traditional compacted clay barrier cover design. Rather than providing a "raincoat" barrier that relies on the ability of a porous substrate (usually locally available soil) to store water along with the natural processes of surface evaporation and plant transpiration to remove stored water as a control Landfill. Thus, they are commonly referred to as Evaporative Transpiration (ET) covers, soil plant coverings, storage and release caps or monolithic covers, as they depend on the ability of the soil layer to "absorb" water and remove "pump" as a biological plant community Water storage. The phytocaps is mainly used due to its inclusion of phyto, the Latin prefix of plants, which emphasizes the importance of plant based systems. Since conventional barrier covers typically include drainage layers designed to reduce the effect of hydraulic heads on barriers to minimize percolation, their designs are inherently more complex and expensive. It is reported that the construction cost of phytocaps is low, usually only 35% to 72% of the conventional cover. Phytocaps are primarily concerned with the use of plants that are resistant to leachate and are closely related to established remediation techniques known as phytoremediation. The use of phyocaps to oxidize CH_4 and reduce greenhouse gas emissions has another major advantage over traditional impermeable covers. It has been demonstrated that porous biotic cover systems can reduce LFG emissions by creating a favorable aerobic environment to promote microbial CH_4 oxidation in soil coverings. The CH_4 oxidation potential of a phytocaps can be thought of as a biological covering in which the microbial activity is enhanced by plant roots. Recent laboratory scale and field experiments have shown that plant cover can significantly improve soil CH_4 oxidation. Phytocap’s function depends on the intrinsic characteristics and communication between the local climate, the substrate (soil) and the established plant community.

This paper focuses on the novel idea of landfill closure by application of phytocaps as a top layer to evaluate its performance in reduction of methane gas emission and to improvise the nature of leachate produced.

II. EXPERIMENT

The methodology adopted for the present work includes laboratory scale phytocap setup, selection of plant species, soil characterization. Specific plants, MSW and locally available soil were used.

A. *Lab scale setup*

Laboratory-scale setup on phytocapping using Indian native plants with in 3 planters of dimension 50cm x 30cm x 38cm each were used. The planters consisted of the bottom layer of locally available soil, above it the layer of 7kg of MSW was applied with the top layer of the same soil. The plantation was applied in the top layers of soil in Planters 1 and 2. The layering was done as shown in Fig. 1. The plate was kept in the base of each planter for the collection of leachate and gas was collected in the bag with the perforated aluminum rod inserted in the MSW in each planter. The Fig. 2 shows the planter containing MSW, Fig. 3 and Fig. 4 shows the growth of plants since November month to March month i.e. five months, respectively. (Note: The planters in Figures are in order from left as P1, P2 and P3).

B. *Selection of plant species*

The native species of trees, shrubs and grass were chosen which are tolerant to toxic leachate, can achieve higher root depths resulting in higher accumulation of heavy metals and are closely related to the established remediation technology referred as phytoremediation. The Tulsi planted had roots of 6.5 cm initially. The total seeds weigh 50 gm. And it was equally planted in two planters i.e. 25 gm in each planter. Table I shows the plants selected in the research work.

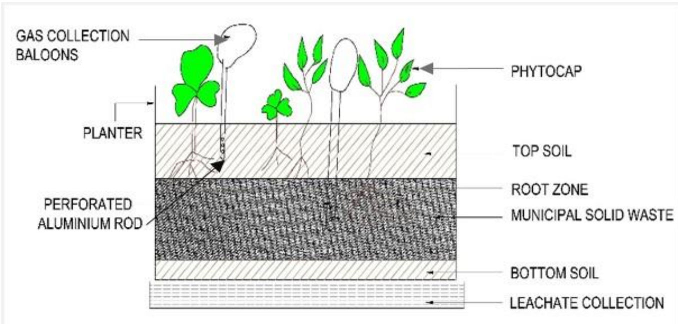

Fig. 1. Schematic diagram of lab scale set up

TABLE I. PLANTS SELECTED AS PHYTOCAPS

Sr. No.	Scientific name	Common name
1	Ocimum Basilicum	Basil/Tulsi
2	Cymbopogon Citrates	Lemon grass
3	Brassica Juncea	Indian Mustard
4	Helianthus Annus	Sunflower
5	Hyacinth	Lily

Fig. 2. Planter containing MSW

Fig. 3. Lab scale set up of phytocapping (5th month - March)

Fig. 4. Lab scale set up of phytocapping (1st month -November)

Fig. 5. Perforated aluminum pipe for gas collection

C. Soil Property

The locally available deep black soil was used for phytocap construction at each trial set. The soils are dark brown to very dark greyish brown in colour as shown in Fig. 6. The deep black soils, in general, are clay-like in texture and they contain 40 to 70% clay minerals. The soil used had 15% moisture content.

D. Feed Stock

The waste required in the study was collected from Solid Waste Transfer Station. The waste used was Municipal Solid waste. Table II shows the initial analyzed parameters of MSW.

III. RESULTS AND DISCUSSION

A. Plant Analisys

a) Plant height and root depth: The plant growth was monitored on monthly basis where the length of plants/height of plants and root depth were measured manually. Monthly plant growth and root depth is presented in Table III. The growing plants also develops the efficient rooting systems which enhances the uptake of trace metals.

The basil's plant height was observed to be increased from 32 cm to 66 cm. Lily's plant height was increased up to 37 cm, and Mustard's height was found to be 49 cm in the March month. The root depth of basil was found 16 cm and lily and mustard attained depth of 8.3 cm and 13.2 cm respectively up till the March.

Fig. 6. Soil Used

TABLE II. ANALYSIS OF MUNICIPAL SOLID WASTE

Sr. No.	Initial Analysis of MSW	Result
1	Moisture Content	42%
2	Volatile solids	24%
3	Ash	0.22%
4	COD	4793.9 mg/l
5	pH	6.28

TABLE III. PLANTS HEIGHT AND ROOT DEPTH

Sr. no.	Plants	Month	Plant height (cm)	Root depth (cm)
1	Basil	November	32	6.5
		December	37	8
		January	47	11
		February	56	14.5
		March	66	16
2	Lily	November	Seeds	-
		December	5	1.8
		January	15	4
		February	28	6.7
		March	37	8.3
3	Mustard	November	Seeds	-
		December	9	2.3
		January	20	6
		February	39	9.5
		March	49	13.2

b) Plant roots uptake: The plant roots uptake is measured because the roots may accumulate the heavy metals/trace metals from the leachate and thereby mitigating the toxicity of leachate. The results shows that plants take active part in phyto-absorption. The amount of trace metals absorbed by the plants can be estimated by phyto-extraction of elements from the rooting systems. The concentration of the trace metals vary in range for instance, Fe range of 2000 ppm while Ni, Pb range below 300ppm. Thus, to simplify and explain root uptakes in a better way, percentage is used as a unit of measurement here. The amount of trace element uptake is presented in Table IV.

Plant's roots were analyzed for the uptake of heavy metals from the soil and/or leachate. Mustard showed the high accumulation of Ferrous, lead, chromium and copper metals. Lily showed high accumulation of cobalt and nickel metals. And tulsi showed the high accumulation of zinc and cadmium metals.

TABLE IV. ROOT UPTAKE OF HEAVY METALS

Sr. No.	Heavy metals (%)	Mustard	Lily	Tulsi
1	Zn	0.1116	0.1469	0.1523
2	Fe	38.52	25.68	12.90
3	Co	0.3334	0.4758	0.4642
4	Ni	0.01411	0.04154	0.01548
5	Pb	0.01311	0.01106	0.02202
6	Cd	0.00068	0.00077	0.000878
7	Cr	0.03523	0.03448	0.02463
8	Cu	0.07936	0.07847	0.1449

c) Chlorophyll Analysis: High accumulation of heavy metals in surrounding could show the differential growth, because of the effect on essential pigment production and metabolism. For this purpose the chlorophyll analysis of plants was also carried out by spectrophotometric determination method. Following is the procedure for chlorophyll analysis.

- The plant leaves were cut into small pieces and major veins and any tough, fibrous tissues were discarded.
- About 1 gm of fresh leaves pieces were ground into a mortar and add 10ml of 80% acetone till homogenate was obtained.
- The homogenate was centrifuge and supernatant was collected in fresh tube.
- The procedure was repeated till the residual pellet was completely colourless.
- Volume make-up was done to 100ml with 80% acetone. The absorbance was observed at 645, 663, 652 nm for all the samples, taking 80% acetone as blank.

TABLE V. CHLOROPHYLL ANALYSIS

Sr. No.	Plants	Chlorophyll a (mg)	Chlorophyll b (mg)	Total Chlorophyll (mg)
1	Mustard	2.15	0.665633333	2.815633333
2	Lily	2.3	0.696183333	2.996183333
3	Tulsi	2.45	0.726733333	3.176733333

Plants might likewise experience the stress an damage to root system due to LFG influence and excess heavy metals accumulation in the soil. The heavy metals like Pb, Cd, r, Ni and Cu shows the phyto toxicity towards plants inhibiting the growth of plants. To analyze the phyto toxic effect of the heavy metals, chlorophyll analysis which is major pigment contributing to the plant growth was carried out. If the chlorophyll if less than 2 mg in plants, the plant may suffer from toxicity. Here the results indicated in Table V shows that there is no adverse effect of the heavy metals on the root growth.

B. Leachate Charatcterisation

The regular tap water about 500 ml was applied in each planter containing on daily basis. The leachate was collected from each planters for each month and the parameters COD, pH, Heavy metals were characterized. P1and P2 are the planters that are containing the plants with the MSW in it. The P3 is the planter without plants, it contains only soil and MSW.

a) Estimation of COD: The Chemical Oxygen Demand (COD) test is widely used as a means of measuring the organic strength of domestic and industrial wastes. This test allows the measurement of waste in terms of the total quantity of oxygen required for the oxidation of the chemical organics to carbon dioxide (CO_2) and water. Most types of organic matter are oxidized by a boiling mixture of potassium dichromate ($K_2Cr_2O_7$) and sulfuric acids. A sample is refluxed in strongly acid solution with a known excess of potassium dichromate. After digestion, the remaining unreduced $K_2Cr_2O_7$ is titrated with ferrous ammonium sulphate to determine the amount of $K_2Cr_2O_7$ consumed and the oxidizable matter is calculated in terms of oxygen equivalent. The procedure for COD is:

- Wash culture tubes and caps with 20% H_2SO_4 before using to prevent contamination.
- Place sample (2.5 mL) in culture tube and Add $K_2Cr_2O_7$ digestion solution (1.5 mL).
- Carefully run sulphuric acid reagent (3.5 mL) down inside of vessel so an acid layer is formed under the sample-digestion solution layer and tightly cap tubes or seal ampules, and invert each several times to mix completely.
- Place tubes in block digester preheated to 150°C and reflux for 2 h behind a protective shield.
- Cool to room temperature and place vessels in test tube rack. Some mercuric sulphate may precipitate out but this will not affect the analysis.
- Add 1 to 2 drops of Ferroin indicator and stir rapidly on magnetic stirrer while titrating with standardized 0.10 M FAS.
- The end point is a sharp colour change from blue-green to reddish brown, although the blue green may reappear within minutes.
- In the same way reflux and titrate a blank with same procedure.

COD (mg O2 /L) = [(A-B) × M ×8000)]/(V sample)

Where,
A = volume of FAS used for blank (mL)
B = volume of FAS used for sample (mL)
M = molarity of FAS
V= Volume of sample (ml)

8000 = milli equivalent weight of oxygen (8) ×1000 mL/L.

The graphs for COD of leachate is shown in the Fig. 7. Initially due to prevailing anaerobic conditions, rapid degradation of waste occurs, thereby forming the leachate containing high levels of COD, trace metals and inorganic toxicities. Once the plants grow, they take up the nutrients and trace metals for their growth. Thus, COD decreases in later stages in leachate. It was found that the COD of P1 and P2 planters is decreased due to the uptake of chemicals by the roots of plants, while the COD of the control planter was found increasing as the decomposition of the municipal solid waste is undergone. The approximate COD was decreased by 99% in planter 1 and planter 2 by interference of plants.

b) Estimation of pH: pH is a term used universally to express the intensity of the aid or alkaline condition of the solution. It is a way of expressing hydrogen-ion activity. The pH ranges from 0 to 14. 0 to 7 of the pH value decreased in acid, 7 to 14 alkaline increase, 7 is neutral. Because of the fundamental relationship that exists between pH, acidity, alkalinity and chemical specification it is one of the fundamental tests for analysis.

pH is determined by measuring the electromotive force of a cell comprising an indicator electrode immersed in the test solution and a reference electrode.

As the decomposition takes place, the free carbon from the organic matter present in MSW is released into the leachate. Thus, the pH was found to be going towards the alkaline due to the increment of carbon content from the decomposed municipal solid waste as shown in Fig. 8.

c) Estimation of Heavy Metals: Heavy metals are present in municipal solid waste. With the decomposition of municipal solid waste, heavy metals remain in leachate, and the quality of groundwater will drop if it is infiltrated through landfill. In this laboratory scale study, nine heavy metals were studied in leachate. The concentrations of heavy metals cadmium, cobalt, chromium, copper, ferrous, manganese, nickel, lead and zinc are expressed in ppm by atomic absorption spectroscopy.

The technique is based upon the spontaneous emissions of photons from atoms and ions that have been excited in a RF (Radio Frequency) discharge. Liquid and gas samples may be injected directly into the instrument, while solid samples require extraction or acid digestion so that the analytes will be present in a solution. For determining the heavy metals content in the sample, the sample is first digested on hot plate using acids as required. The digestion sample is then filtered and heavy metals analysis is done in ICP-OES (Inductively Coupled Plasma Optical Emission Spectrometry).

The graphs in Fig. 9 to Fig. 17 shows the reduction of heavy metals from leachate in planter 1 and planter 2 during consecutive months

d) Estimation of Nutrients: The nutrients like Nitrate, Carbon, and Phosphate are analyzed in the leachate from all the planters.

Nitrate is the highest oxidized form of nitrogen compounds. The main sources of nitrate are fertilizers, rotting vegetables and animal substances, domestic sewage, sewage treatment land, industrial emissions, litter leachate and atmospheric scouring. The nitrate concentration was determined using a spectrophotometer, and the standard curve was prepared by using an appropriate aliquot of the standard nitrate solution. 1 ml of 1N HCl was added to the sample to prevent the hydroxide or carbonate concentration as high as 1000 mg / l as interference for $CaCO_3$ and analyzed at a wavelength of 220 nm in a spectrophotometer.

The presence of carbon in the waste is caused by the degradation of the substance containing the carbonaceous material was carried out of carbon using CHNS analysis. For CHNS analysis, the freeze-dried and pulverized samples were weighed (5-10 mg) and mixed with an oxidizing agent (vanadium pentoxide) in a tin capsule burned in a reactor at 1000° C. Samples and containers are melted, and tin promotes a violent reaction (flash) in a temporarily concentrated oxygen atmosphere. The combustion products were carried out at a constant flow rate of carrier gas (helium), which was maintained at 1000 ° C through an air column filled with an oxidation catalyst of sulfur trioxide and a copper reducing agent. The gas is separated by a 2-meter-long column. The chromatographic reaction was calibrated according to the pre-assay criteria. The analysis was performed on a 690 nm spectrophotometer.

The presence of phosphate in waste is of great importance. It promotes the breeding of microbial nuisance. Although phosphate is problematic in surface water, it is also necessary for biodegradation of waste water and solid waste. The phosphate was prepared using a spectrophotometer, a standard curve was prepared by using anhydrous K_2HPO_4, 0.5 ml of stannous chloride, and 2 ml of ammonium molybdate was added.

It was found that the plants uptake nutrients for their growth, and there-by decreasing the nutrients from 1st and 2nd planters. The 3rd planter had more nutrient content in leachate as there was no plant planted in it. The nutrient concentration in leachate is shown in 18, 19 and 20.

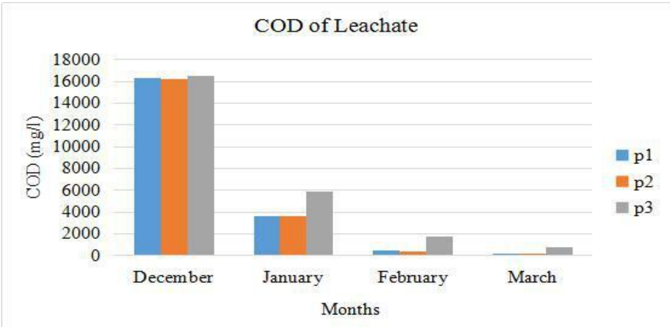

Fig. 7. COD of leachate

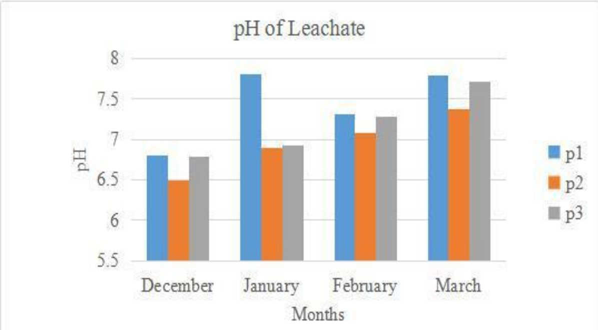

Fig. 8. pH profiling

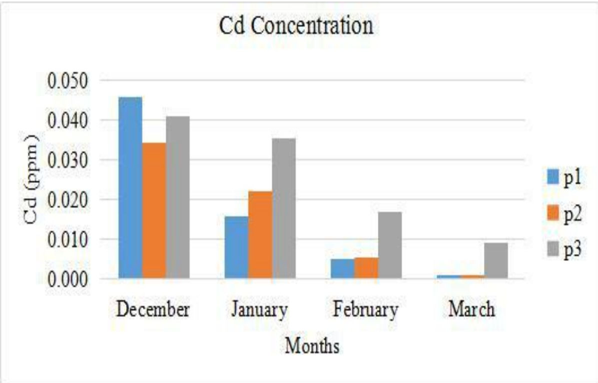

Fig. 9. Cd Profiling

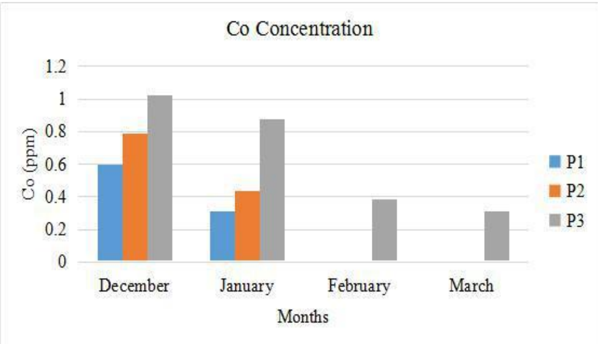

Fig. 10. CO Profiling

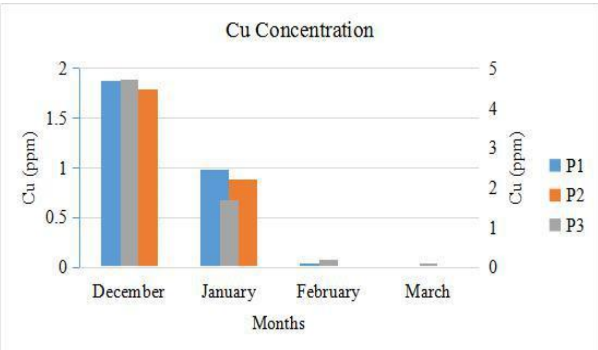

Fig. 11. Cu Profiling

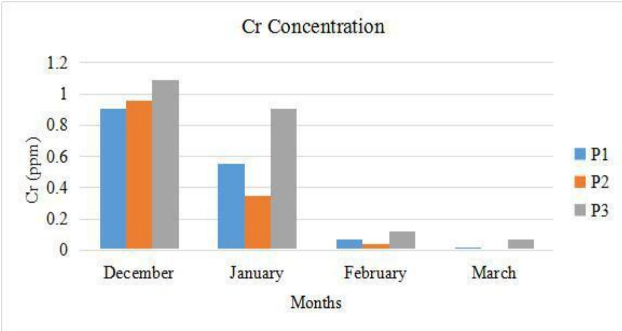

Fig. 12. Cr Profiling

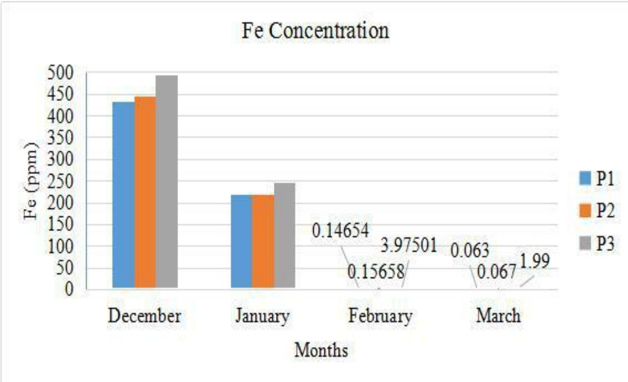

Fig. 13. Fe Profiling

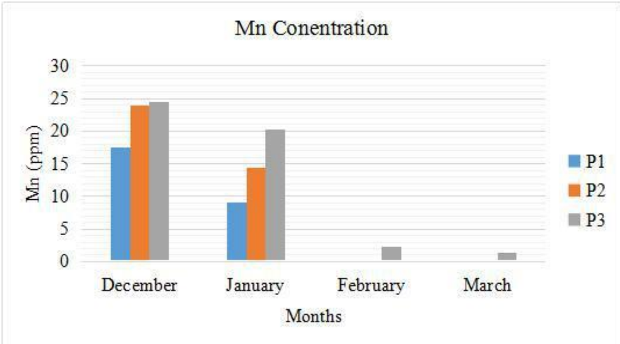

Fig. 14. Mn Profiling

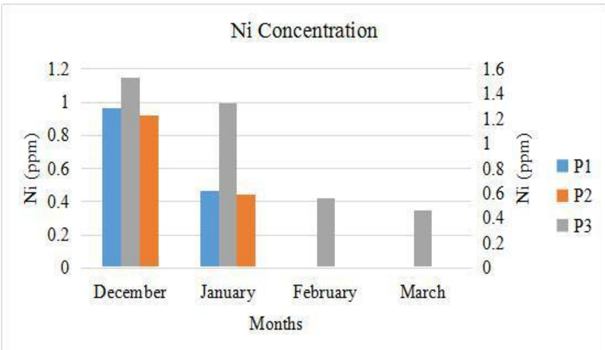

Fig. 15. Ni Profiling

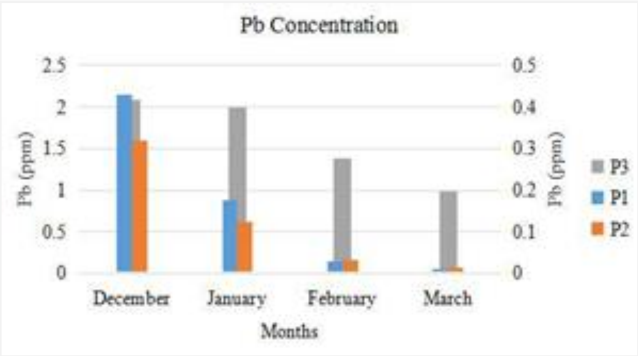

Fig. 16. Pb Profiling

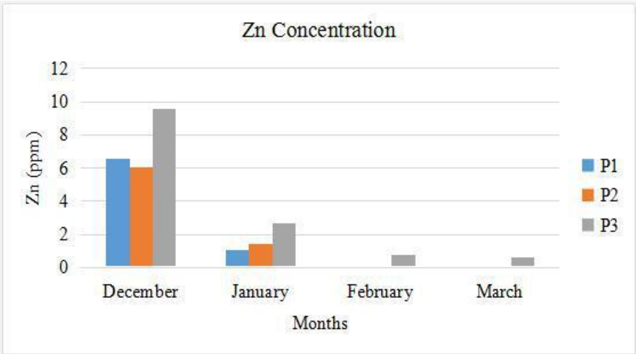

Fig. 17. Zn Profiling

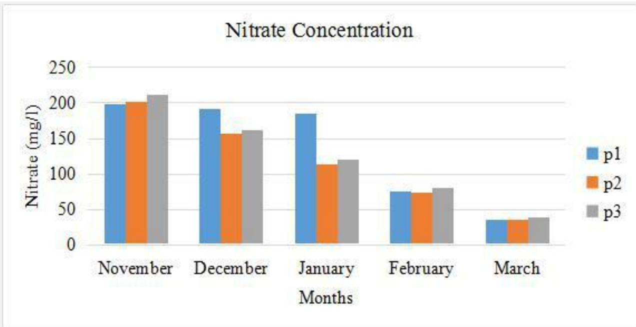

Fig. 18. Nitrate in leachate

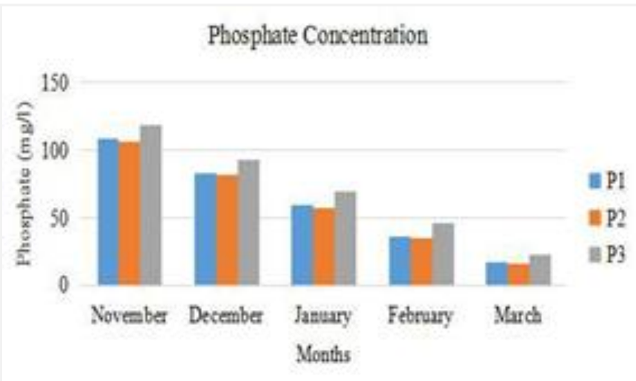

Fig. 19. Phosphate in leachate

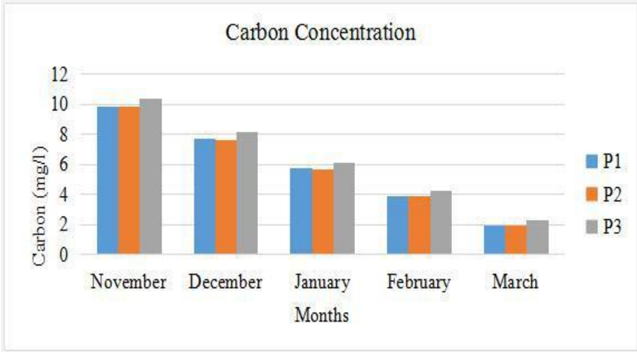

Fig. 20. Carbon in leachate

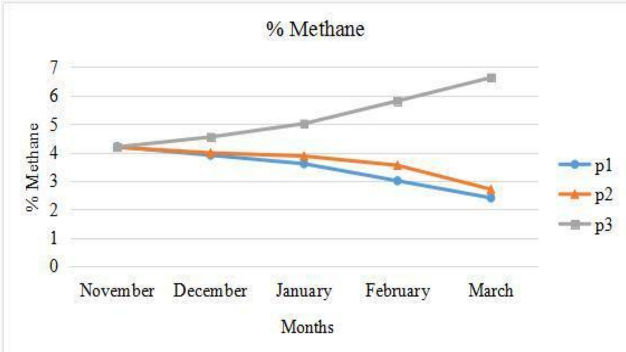

Fig. 21. Graphical representation of methane concentration

C. Methane Analysis

The methane was collected in the bag from each planter. The concentration of methane produced from the decomposition of waste in planters was analyzed by Gas Chromatography Mass Spectroscopy (GCMS) CH_4. The oxidation of CH_4 in the soil is natural phenomena, which occurs due to the action of methanotrops. Methanotrop uses the CH_4 as the only source of carbon and metabolize it into CO_2. Use of biotic system such as specialized plants also enhances the methane oxidation in soil. Roots of plants absorbs the essential nutrients from the soil leading to the bio-availability of oxygen for the methanotrops to oxidize the CH_4.

The results shown in Fig. 21 shows that the emission was reduced by 63% and 60% planter 1 and planter 2 respectively. While the emission was increased in the planter that did not contained plants..

D. Statistical Analysis

The multiple ANOVA (ANalysis Of VAriants) on the performance data was performed to predict the cause and effect relationship. Various parameters, such as COD concentration, pH, Nutrients concentration (Nitrate, Carbon, Phosphate), plant growth, root depth which influence the CH_4 oxidation in soil, were analyzed. Specifically, ANOVA analysis helped to understand how the typical value of the dependent variable (or 'criterion variable') changes when any one of the independent variables varied.

In Table VI, it can be noted that the f-value if less than the f critical value. It shows that the results and the study is effective. The F value is the measure between and within the group of variance (i.e. independent variables such as COD, pH, nutrient contents). If the F value is more than 1, the variation (overlap) is less The F critical value is the extent the value can be wronged. If the f-value is less than the f-critical value the results are effective.

TABLE VI. STATISTICAL ANALYSIS

Planters	F (Variance Co-efficient) value	F - critical value
P1	1.489966	2.456281
P2	1.445159	2.456281
P3	2.022313	2.456281

IV. CONCLUSION

This experiment demonstrates that CH4 oxidation can be achieved using phytocaps. The methane concentration was reduced by 63% and 60% in planter 1 and planter 2 due to methane oxidation at the root zone of plants that were planted. The COD reduction in planter 1 and 2 was by 99% in four months of plantation. The pH was found to be alkaline from neutral after four months due to release of free carbon by decomposition of municipal waste. The cadmium metal concentration was decreased in leachate by 97% in planter 1. And in planter 2 it was found 84% reduction. The cobalt metal concentration in leachate from planter 1 and planter 2 was found 99% reduction in cobalt metal. The chromium metal concentration in leachate from planter 1 and 2 is showing 97% reduction and 99% reduction. The copper metal concentration in leachate was reduced by 99%. The ferrous metal concentration in leachate was reduced by 100% and manganese and Nickle metal concentration was decreased in leachate by 99% in both the planters containing the plants. The lead metal concentration in leachate was reduced by 97% and 95% reduced in planter 1 and 2 respectively. The zinc metal concentration in leachate was reduced by 99% in leachate of both the planters containing plants. It was found that the nutrients nitrate, carbon, phosphate concentration in leachate from planter 1 and planter 2 was found to be decreased by 75%, 78% and 82% respectively. Mustard showed the high accumulation of Ferrous, lead, chromium and copper metals. Lily showed high accumulation of cobalt and nickel metals. And Tulsi showed the high accumulation of zinc and cadmium metals. The chlorophyll results indicate that there are no adverse effects of the heavy metals found on the root growth. Methane is found to be dominant greenhouse gas causing carbon footprint according to researches. Emission of methane gas was reduced by Phytocapping approach. Phytocapping approach can simultaneously contribute in reduction of carbon footprint making it a sustainable solution for covering sanitary landfill sites.

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AUTHOR PROFILE

Ms. Bhavya Shah is working as Deputy General Manager (Process Design) at GREEN Design & Engineering Services Pvt. Ltd., Surat. She has completed **M. E. in Environmental Engineering** from Gujarat Technical University, Surat. During her Masters she worked on Phytocapping As Covering For Sanitary Landfill Sites. She has acquired Gold Medal in the field of environmental engineering during her Masters in Engineering. Currently, she is engaged in various projects in process designs of Sewage Treatment Plants and Water Treatment Plants.
Besides of this, she has published two Research Papers in workshops and one research paper in International Journal of Engineering Research and Applications (IJERA) with impact factor of 3.741.

Dr Mehali Mehta is working as Post Graduation In charge of Environmental Engineering and faculty of Civil Engineering, Sarvajanik College of Engineering and Technology, Surat. She has 22 years of teaching experience at PG and UG engineering Courses. She has guided more than 24 dissertations. She has worked with the industries as a Schedule I auditor. She has been associated with NGO's working for environmental cause.
Besides of this, she has 4 SCI publications, 2 UGC journal publications, with -index of 6, i10-index of 4 and 165 citations (Google Scholar).

Mr. Abhishek Khapre is working as Senior Research Fellow at CSIR-NEERI, Nagpur. He has completed M. Tech in Biotechnology from VIT University, Vellore, Tamil-Nadu. During his Masters he worked on Genomics islands of microbes used for bioremediation as well as CCD4a & CCD4b Genes. He has joined Ph.D. program at CSIR-NEERI under AcSIR scheme. He is working in the field of Environmental Bioengineering with focus on Design of Phytocapping systems for sustainable management He represented India for the joint Indo-Swiss-Nepalese project for the sustainable rural development. He is also associated with Kathmandu University (KU), Nepal as Research Associate at Technical Training Centre (TTC). Currently, he is engaged in various projects in solid waste management domain.
Besides of this, he has published 12 Research Papers in SCI journals and 2 book chapters with total impact factor of 27.24, H-index of 5, i10-index of 4 and 95 citations (Google Scholar).