RESEARCH PAPER

Heavy Metal Accumulation by Plant Species at Fly-Ash Dumpsites: Thermal Power Plant, Gandhinagar, Gujarat

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DOI: 10.18811/ijpen.v5i02.7

Abstract

Naturally growing wild plant species were identified for accumulation of heavy metals at fly ash different disposal sites of Thermal Power Plant Gandhinagar. Cd, Fe, Zn, Cu, Ni, Pb and Cr metals were selected for studying accumulation by indigenous plants. Nine major weed species growing dominantly at fly ash dumpsite were identified i.e. Prosopis juliflora, Ipomea carnea, Calotropis procana, Nerium indicum, Abutilon indicum, Tephrosia purpunea, Cassia tora, Parthenium hysterphorus, Jatropha gossypifolia. Results showed significant accumulation of fly ash heavy metals by indigenous identified plants positive pattern of accumulation differed significantly in different weed species. Roots showed higher accumulation of heavy metals as compared with shoot in most of the plants but in some shoots also showed more accumulation compared to roots. Both translocation factor and bioaccumulation factor was calculated to determine metal translocation from site to roots and from root to shoot. Current results suggest that these plants species can effectively survive in harsh environment and can be used for eco-restoration purpose and also they can be used as potential phytoremediation species.

Keywords: Eco-restoration, Fly ash, Heavy metals, Phytoremediation, Weed species.

International Journal of Plant and Environment (2019)

Introduction

Coal based thermal power plants generating Fly ash is one of the major waste occupying valuable lands. Fly ash content of Indian coal is comparatively high in comparison to other coal types. Fly ash disposed off mainly by two methods: 1) Dry disposal system by trucks to landfill sites, 2) Wet disposal system through pipelines to the ash pond. Fly ash is a complex substance consists of many elements and some radioactive elements. The composition of fly ash indicates Ferro (%), Aluminium (%), Silicates (%) mixed with traces of elements arsenic, beryllium, boron, cadmium, chromium, hexavalent chromium, cobalt, lead, manganese, mercury, molybdenum, selenium, strontium, thallium, and vanadium, along with very small concentrations of dioxins and PAH compound (https://en.wikipedia.org/wiki/Fly_ash). True constituents depend upon the specific coal bed makeup but may include one or more of the elements or substances found in trace concentrations (up to hundreds ppm).

Phytoremediation a popular cost effective eco-friendly technology since past many years needs further research in terms of potential plants to accumulate heavy metals from fly ash dumpsite. Heavy metals inhibit various metabolisms like biomass production or other biochemical parameters in plant species. During uptake of metals from contaminated site, plants accumulate them in different plant parts. On sufficient growth of plant it is harvested resulting in removal of metal from site. Incineration of harvested plant tissue reduces the volume of the plant material requiring disposal. In some cases valuable metals can be extracted from the metal-rich ash and serve as a source of revenue, thereby offsetting the expense of remediation. Phytoremediation is an integrated multidisciplinary approach to the cleanup the environment which combines the disciplines of plant physiology, soil chemistry, and soil microbiology (Cunningham and Ow, 1996).

Interaction and uptake of fly ash heavy metals by plant species growing in area can be understood by studying various mechanisms in plant system. Movement of metals can be dependent factor of diffusion along the concentration gradient of metals in plant and in the vicinity of plants, secondly root interception where root volume replaces soil volume due to root growth, thirdly mass flow with motion towards the water potential gradient from the solution of bulk soil. Local distribution of heavy metal in plant species differ greatly according to different metal of interest. Uptake of metal in plants depends on various internal and external factors in general metal uptake increases in plants with the higher concentration of in the vicinity of plants.

Weed species, a promising preference for reclaiming heavy metal contaminated sites using potential plants with high affinity for metals accumulation. Weed plants can be considered as advanced flora with efficient system to overcome any kind of stress introduced to them either naturally or man-made stress. They have properties like low requirement of fertilizers, less water requirement, efficient anti stress (anti oxidant) system etc. they have ability to grow and develop in such harsh environment. In return they are beneficial in many ways like they are helpful in maintaining soil water conservation, have capacity to improve soil properties either with their root exudes or by forming association with microbes, thus they can be powerful soil conservers. They can be useful pioneer flora for restoration or revegetation of such barren dumpsites where normally no flora survives. Their potential for accumulation of heavy metals can be utilized for removal of potentially threatens metals for living beings.

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How to cite this article: Rawat, K., Pathak, B. and Fulekar, M.H. (2019). Heavy Metal Accumulation by Plant Species at Fly-Ash Dumpsites: Thermal Power Plant, Gandhinagar, Gujarat. International Journal of Plant and Environment, 5(2): 111-116.

Source of support: Nil

Conflict of interest: None

Submitted: 17/04/2018 **Accepted:** 30/04/2019 **Published:** 30/04/2019

Materials and Methods

Study area

Gandhinagar Thermal Power Station is a coal based power station in Gujarat located at 23°14′57″ N latitude and 72°40′15″ E longitude. It is located on the bank of Sabarmati River. There are two units of 120 MW each (Unit no. 1 & 2) and another three units of 210 MW each (Unit no. 3, 4 & 5) with a total installed capacity of 870 MW. Its primary fuel for energy generation is coal. GTPP is operated by Gujarat state electricity corporation limited which is public limited (Subsidiary of Gujarat Urja Vikas Nigam Limited).

Area has summer, winter and monsoon as the three main seasons with tropical wet and dry climate. Outside of monsoon season generally climate is dry. Weather is sever hot from March to June with maximum temperature range of 36 to 42°C (97 to 108°F), and minimum temperature of 19 to 27°C (66 to 81°F). Winter days are pleasant with chilling night during December to February. Average maximum temperature is around 29°C (84°F), minimum is 14°C (57°F), with extremely dry climate. The average annual rainfall is around 803.4 mm (31.63 in). Southwest monsoon brings a humid climate from mid-June to mid-September.

In present study fly ash dumpsite (Thermal Power Plant, Gandhinagar) was investigated for wild plants with great affinity for heavy metals. Nine dominant plant species were selected for metal accumulation. Seven heavy metals i.e. Cd, Fe, Zn, Cu, Ni, Pb and Cr were analysed from the selected samples of fly ash from dumpsites for accumulation study.

Sampling procedure and collection of plant samples

Random sampling of plants was done at the fly ash dumpsite. Sampling site was studied as five sites at ground level. Plant samples were collected as whole (leaves, flowers, stem and roots) from selected sites. Collected plant samples were of same physiological age, size and almost of same appearance.

Sample preparation for heavy metal analysis

Samples were brought to lab washed under tap water later by distilled water. Excess water was removed by the blotting paper. Plants were partitioned in root and shoot. Then oven dried, at 60°C to constant weight and dry weight was noted after 24 hr. Later samples were crushed made powder and samples were prepared for heavy metal analysis.

Thedried plant material was digested HNO_3: $HClO_4$ (5:1 v/v) with acid mixture on a hot plate to get a clear solution. The volume was made up with double glass distilled water (Singh *et al.*, 2008). It was filtered through Whatman filter paper no. 44. Volume of each digested sample was maintained to 25 ml with the addition of double distilled water. Different metals in sample solutions were analyzed with an Atomic Absorption Spectrophotometer (Shimadzu model AA6300).

Bioconcentration factor/Enrichment factor and translocation factor

Phytoremediation potential of plant is dependent on various factors such as availability of metals in the surrounding of plant, mobility etc. By calculating some of the factors assessment of plant potential for metal uptake can be these factors are:

BCF = Enrichment factor

Bioabsorption coefficient (BAC) = metal content in shoot/metal content in soil (1)

Bioconcentration factor (BCF) = metal content in root/ metal content in soil (2)

Translocation factor (TF) = metal content in shoot/ metal content in root (3)

Results

Nine plant species i.e., *Prosopis juliflora, Ipomea carnea, Calotropis procana, Nerium indicum, Abutilon indicum, Tephrosia purpunea, Cassia tora, Parthenium hysterphorus, Jatropha gossypifolia* found at fly ash dumpsites were collected. Heavy metals namely Cd, Fe, Zn, Cu, Ni, Pb and Cr were selected for study. Physico-chemical analysis of fly ash was done by standard methods (ASTM) (Table 1). The study reveals the alkaline nature of fly ash.

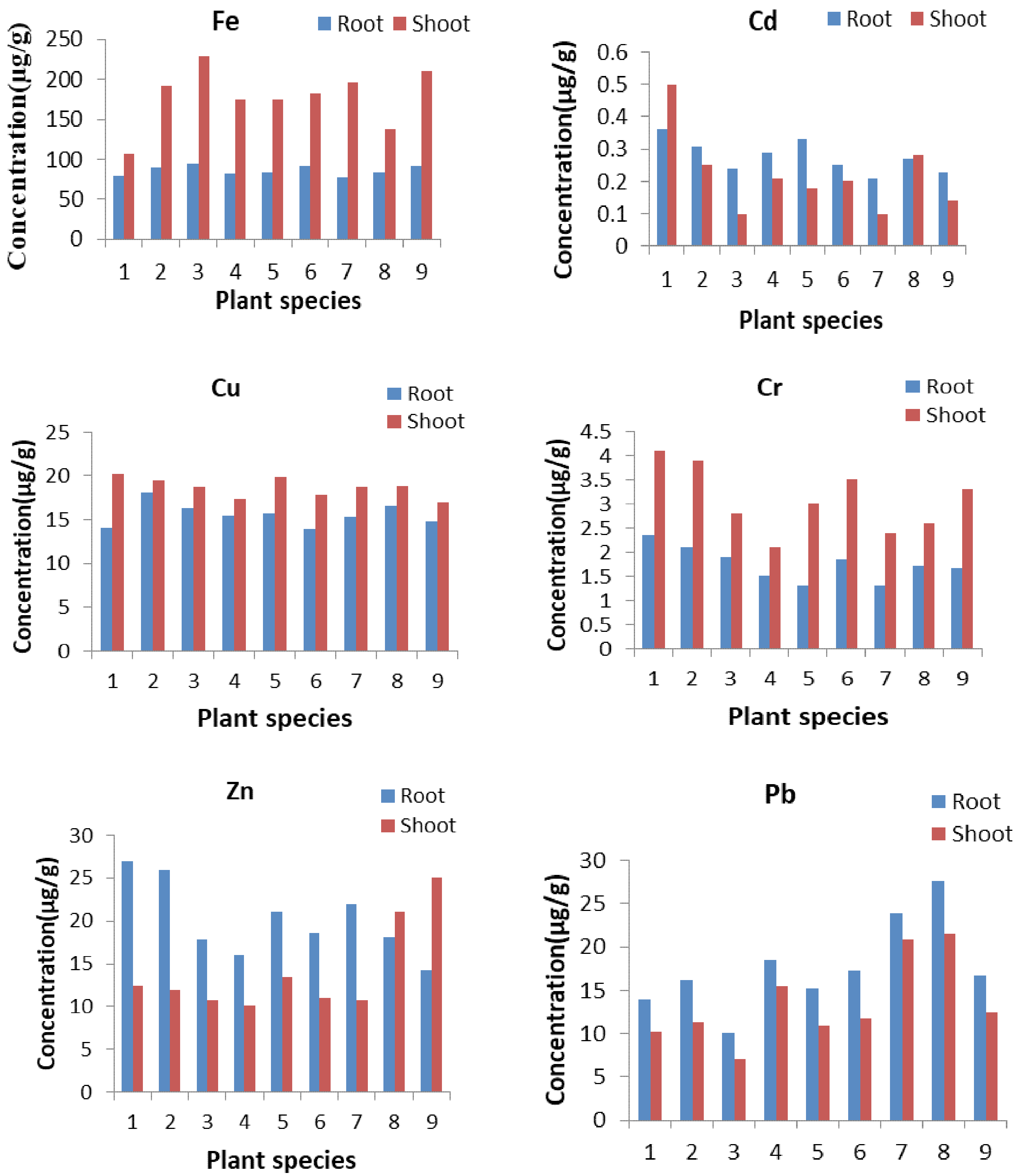
Heavy metal concentration was found in the order Fe>Ni>Zn>Pb>Cu>Cr>Cd for selected fly ash samples. Metal concentration in root and shoot was found in therange of Fe:78.2to 94.2 (μg g^{-1}) in root and 107 to 229 (μg g^{-1}) in shoot, Zn 14.3 to27 (μg g^{-1}) in root and 10.1 to 25.3 (μg g^{-1}) in shoot, Cu:14.1 to 16.53 (μg g^{-1}) in root and 17.3 to 20.5 (μg g^{-1}) in shoot, Pb: 10.1 to 27.6 (μg g^{-1}) in root and 7.1 to 21.6 (μg g^{-1}) in shoot, Ni:3.1 to 6.8 (μg g^{-1}) in root and 1.1 to 9.4 (μg g^{-1}) in shoot, Cr: 1.3 to 2.36 (μg g^{-1}) in root and 2.1 to 4.3 (μg g^{-1}) in shoot Cd: 0.21 to 0.36 (μg g^{-1}) in root and 0.10 to 0.5 (μg g^{-1}) in shoot. No visible symptoms of heavy metal toxicity were seen in plants. *Abutilon indicum* accumulated metals (i.e. Fe, Zn, Cu, Pb, Ni, Cr, Cd) in the range of 78.2 to 0.36 (μg g^{-1}) and 107 to 0.5 (μg g^{-1}) in root and shoot respectively. *Calotropis procana* accumulated metals (i.e. Fe, Zn, Cu, Pb, Ni, Cr, Cd) in the range of 89 to 0.31 (μg g^{-1}) and 191 to 0.25 (μg g^{-1}) in root and shoot, respectively. Metal accumulation in root and shoot of *Cassia tora* was in the range of 94.2 to 0.24 (μg g^{-1}) and 229 to 0.1 (μg g^{-1}), respectively. Metal accumulation in root and shoot of *Ipomea carnea* was 81.5 to 0.29 (μg g^{-1}) and 174 to 0.21 (μg g^{-1}), respectively. *Jatropha gossypifolia* showed metal accumulation in the range of 83.9 to 0.33 (*μg* g^{-1}) in roots while 175 to 0.18 (*μg* g^{-1}) in shoots, respectively. *Nerium*

Table 1: Physico-chemical analysis of fly ash.

S.N.	Parameters	*Fly ash site* Wet disposed fly ash	Dry disposed fly ash
	pH	8.35	6.7
	EC (μS M^{-1})	151.3	53.5
	TDS (Mg L^{-1})	75.9	26.73
	Alkalinity (Mg L^{-1})	45	16.6
	CEC	81.65	7.89
	Organic carbon (%)	10.58	6.47
	Sulphate (Mg L^{-1})	25.92012	3.83
	Nitrate(Mg L^{-1})	0.03	17.42
	Phosphate(Mg L^{-1})	0.23	0.45
	Heavy metal	Concentration (μg g^{-1})	
	Cd	0.47	0.58
	Pb	39	41
	Fe	231	342
	Zn	38	76
	Cu	26	40
	Ni	45	89
	Cr	15.2	37

indicum showed range of 91.1 to 0.25 (µg g^{-1}) for roots and 18.3 to 0.2 (µg g^{-1}) for shoots, respectively. *Parthenium hysterphorus* showed range of 76.8 to 0.21 (µg g^{-1}) for roots and 196 to 0.1 (µg g^{-1}) for shoots, respectively. *Prosopis juliflora* showed range of 84 to 0.27 (µg g^{-1}) for roots and 137 to 0.28 (µg g^{-1}) for shoots, respectively. *Tephrosia purpunea* showed range of 91.8 to 0.23 (µg g^{-1}) for roots and 211 to 0.14 (µg g^{-1}) for shoots, respectively (Fig. 1).

Maximum concentration of Fe found in *Cassia tora,* followed by *Tephrosia purpunea* and *Nerium indicum.* Zn concentration was highest in *Abutilon indicum* followed by *Calotropis procana* and *Parthenium hysterphorus*. *Calotropis procana* showed maximum accumulation of Cu followed by *Prosopis juliflora* and *Cassia tora. Prosopis juliflora* showed maximum accumulation of Pb and Cd. *Ipomea carnea* showed maximum Ni accumulation. *Abutilon indicum*



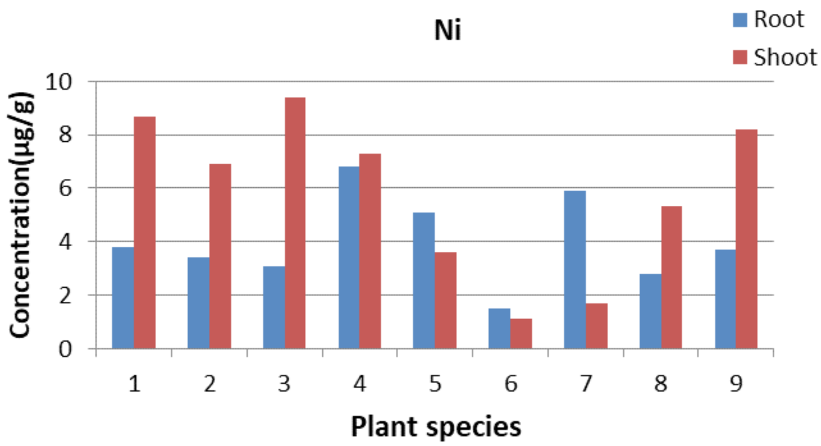


Fig. 1: Heavy metal content in selected plant species.
[1) *Abutilon indicum, 2) Calotropis procana, 3) Cassia tora, 4) Ipomea carnea, 5) Jatropha gossypifolia, 6) Nerium indicum, 7) Parthenium hysterphorus, 8) Prosopis juliflora, 9) Tephrosia purpunea*]

showed maximum accumulation for Cr followed by *Calotropis procana* and *Cassia tora.*

BCF and TF can assess the phytoextraction potential of plant. This value is different for different plants. If, translocation factor shoot: root (S/R), and leaf: shoot (L/S) is greater than 1, it implies that the metals are translocating from the lower part to the upper part and if it is less than 1 that indicate the metals are stored in the lower part (Singh *et al.,* 2010). The value was found variable for different plants in present study. BCF gives an idea about the biomagnification of metals (Maiti and Jaiswal, 2008). BCF value varied differently for different metals, this showed their better accumulation of heavy metals from contaminated surroundings in respect of other plant species (Fig. 2-3).

Discussion

Physico-chemical analysis revealed that fly ash at dumpsite was alkaline in nature due to low sulphur content of Indian coal and due to the presence of hydroxides and carbonates of calcium and magnesium (Misra and Shukla, 1986), which limits the plant growth but synergistic approach of primary succession like adequate microbial biodiversity like activity of *Thiobacillus thioxidane* reduced its alkalinity by depositing sulphur on FA dumps (Juwarker and Jambhulkar, 2008). Micronutrients of fly ash reveal the lower content of nitrogen, phosphorus and organic carbon. Economic evaluation of plant species selection for phytoremediation reveals that weed species can be considered as potential plant for efficient removal of contaminants such as heavy metals from the contaminated sites. These species have ability to survive in poor nutrient and contaminated sites. Annually they have high biomass luxuriant growth well developed root and shoot system. Present study showed that *Prosopis juliflora, Ipomea carnea, Calotropis procana, Nerium indicum, Abutilon indicum, Tephrosia purpunea*, *Cassia tora, Parthenium hysterphorus, Jatropha gossypifolia* growing naturally at fly ash dumpsite showed luxuriant growth and effective phytoaccumulation of heavy metals. All species accumulated almost all metals. Fe accumulation was high in comparison to other metals due to high bioavailability of this metal in fly ash. About 300 plant species hyperaccumulate Ni, 24 Cu, 16 Zn and one Cd (Brooks *et al*., 1998; Reeves and Baker, 2000).

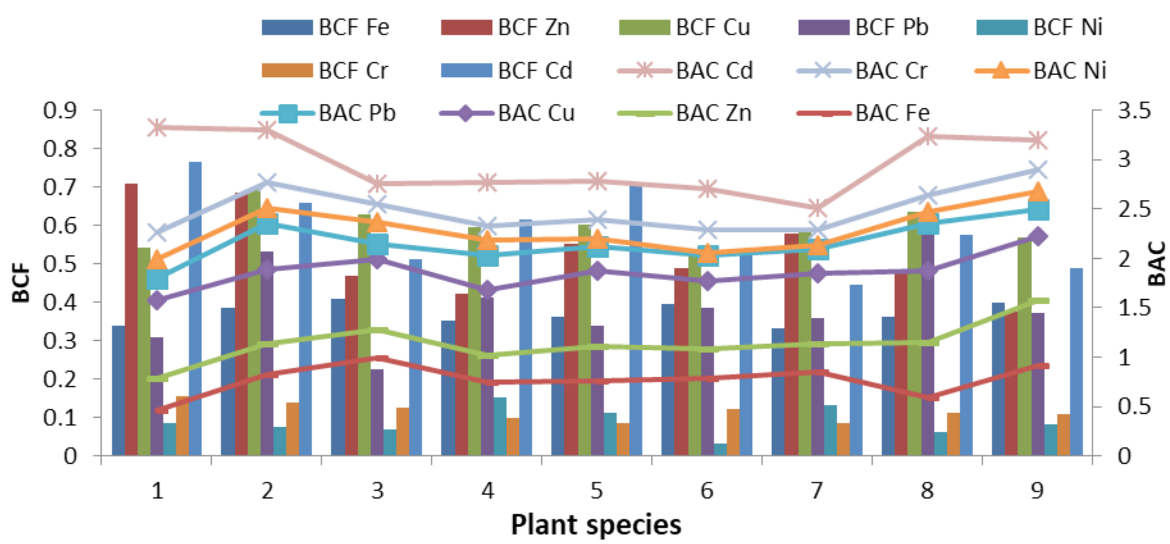


Fig. 2: BCF/BAC in root and shoot of plant species

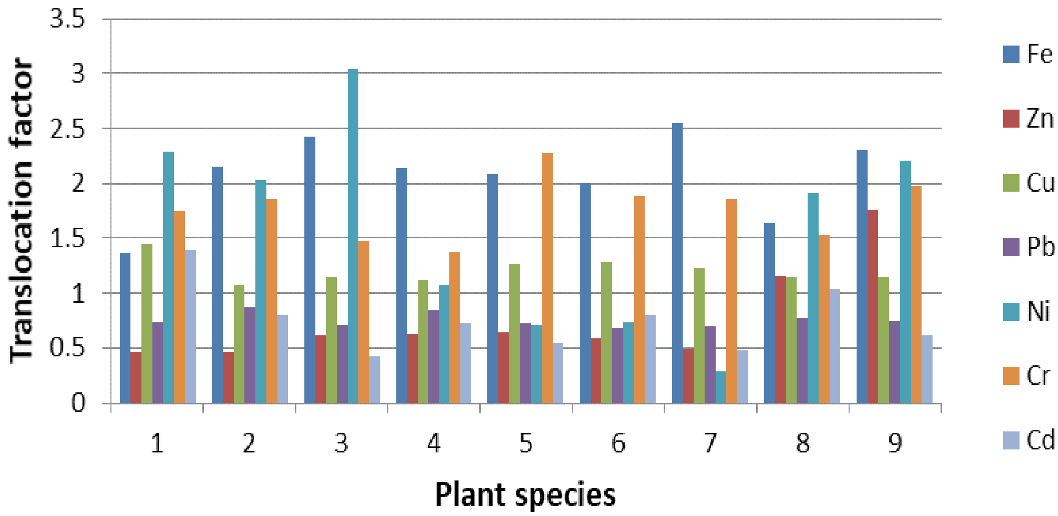


Fig. 3: Translocation factor of plant species
[1) *Abutilon indicum, 2) Calotropis procana, 3) Cassia tora, 4) Ipomea carnea, 5) Jatropha gossypifolia, 6) Nerium indicum, 7) Parthenium hysterphorus, 8) Prosopis juliflora, 9) Tephrosia purpunea*]

Pattern of metal accumulation varied significantly for different metal from plant to plant. Similar finding of tolerance of plants growing on fly ash was reported by Maiti and Jaiswal (2008) (*Typha latifolia* accumulated Pb 16.6 mg kg^{-1} in root 11.2 mg kg^{-1} in shoots). *Avena*, *Crotalaria*, *Crinum asiaticum* and *Calotropis procera*, lemongrass, and other wild grasses have been reported for heavy metal bioindicatoring and phytoremedial purposes (Uraguchi *et al.*, 2006; D'Souza *et al.*, 2010; Varun *et al.*, 2011). Weeds such as *Poa annua* (for Cu, As), *Tephrosia purpurea* (for Mn), *Cannabis sativa* (for Cr), *Solanum nigrum* (for Mn), *Dissotis rotundifolia* and *Kyllinga erecta* (for Pb), *Calotropis procera* (for Zn, Mn, Cd, Cu), *Withania somnifera* (for Cu, Mn, As), *Eclipta alba* (for Cu, Mn, As), *Heliotropium ellipticum* (for Cu, Mn, As), and *Cannabis sativa*, *Solanum nigrum*, and *Rorippa globosa* (for Cd) also showed good phytoremedial potential suggesting the use of these weedy plants for remediation of heavy metal-polluted soils (Varun *et al.*, 2012; Girdhar *et al.*, 2014; Lum *et al.*, 2014).

All selected plant species showed luxuriant growth despite of high metal accumulation. No visual phytotoxic symptoms seen in plants indicating that these species have specific metal detoxification mechanisms to detoxify high metal levels accumulated in the cell (Raskin *et al.*, 1994). Higher plants have developed different types of metal-binding legends such as amino acids, citric acid, malic acid and phytochelatins (Neumann *et al.*, 1994). Phytochelatins are metal-induced sluphohydril rich complex peptides, which appear to be dominant mechanism of metal detoxification in plants (Mehra and Tripathi, 2000).

Conclusions

In order to estimates potential accumulation of fly ash heavy metals indigenous plants were selected. Present study concluded that coal based thermal power plants have major impact on our environment one such issues is the concern related to fly ash heavy metals. Conventional methods are not very economical nor eco friendly thus approaches are made towards alternative techniques such as phytoremediation and bioremediation. Phytoremediation technique becomes more beneficial when weed species which are generally not part of food chain are utilized as potential plant species for phytoremediation. Also despite of higher ph value of fly ash weed species sustain in harsh conditions. This may be due to their adaptively for xerophytic conditions and resistivity to heavy metal. Potential weed species i.e. *Prosopis juliflora, Ipomea carnea, Calotropis procana, Nerium indicum, Abutilon indicum, Tephrosia purpunea, Cassia tora, Parthenium hysterphorus, Jatropha gossypifolia* from fly ash dumpsite can be used for surface stabilization of fly ash dumpsite also for remediation of fly ash heavy metals.

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Links

https://en.wikipedia.org/wiki/Fly_ash