Comparative analysis of Bioaccumulation Coefficient (BAC) in the three dominant grassy vegetation on fly ash in Mejia Thermal Power Station (MTPS)

[1]Upasana Datta, [2]Sufia Zaman, [3]Abhijit Mitra
[1]Research Scholar, [2]Associate Professor, [3]Associate Professor
[1] Department of Oceanography,
[1] Techno India University (TIU), West Bengal, Salt Lake, Sector -V, Kolkata - 700091, India.

Abstract : **Fly ash is a major hazard related to Thermal Power Stations and Mejia Thermal Power Station (MTPS) is no exception to this rule. We conducted a study on the biologically available heavy metal levels (Zn, Cu and Pb) and their bioaccumulation in the shoot of the three grassy species namely *Typha elephantina, Saccharum spontaneum* and *Phragmites karka* thriving on the dumped fly ash belt, during 2015 and 2016. There was significant variation in the Bioaccumulation Coefficient (BAC) between the three species with greater value in *Saccharum spontaneum* followed by *Typha elephantina* and *Phragmites karka* irrespective of the years and the heavy metals.**

Index Terms **- Mejia Thermal Power Station (MTPS); fly ash; grassy vegetation; Bioaccumulation Coefficient (BAC); heavy metal; phytoremediation**

I. INTRODUCTION

Fly ash is intricately related to coal combustion of Thermal power stations. Formation of fly ash depends on the quality of the coal used, which upon combustion produces a minimal amount of 30-40% of dry fly ash (Singh and Siddiqui, 2003). Reaction in the flue gas scrubbers with slurried limestone (lime) and the gaseous SO_2 produces the final end product of $CaSO_3$. Discharge of fly ash is an issue of great concern as it has severe adverse effects on the environment. The hazardous effect of fly ash cannot be completely eliminated as we cannot circumvent the Second Law of Thermodynamics. The by-products of any Thermal Power Plants are the fly ashes, which are the sources of heavy metals in the surrounding environment. These heavy metals bioaccumulate within the flora surviving in and around the Thermal Power Plant. Fly ash is a rigid source of pollution that is fast depleting not only the atmosphere but also the soil, water and biotic components of the environment at large (Jena. S, 2011). This wind borne pollutant is fast deposited in and around the production belt often causing detrimental efficacies on the soil and aquatic ecosystems because of their toxic mineralogical composition and granular nature (Lokeshappa and Dikshit, 2011). Studies on the environmental pollutants in the present century have revealed that dusts from industries have a greater potency towards causing allergic diseases in humans than the natural ones (Obtulowicz, *et al.*, 1996). The Mejia Thermal Power Plant, has the largest power generating capacity, amongst all the other thermal power plants in the state of West Bengal and as well as among the other DVC power plants. It produces a huge quantum of fly ash for meeting its power generating capacity which amounts to 2340 MW annually. (https://en.wikipedia.org/wiki/Mejia_Thermal_Power_Station).

The generated fly ash has a widespread negative impacts on biota, the forestry tree species and plants growing mainly in and around the power plant (Smołka-Danielowska, 2006; Fulekar and Dave, 1986; Querol *et al.*, 1995; Chirenje and Lena, 1999; Jablonska *et al.*, 2003; Xu *et al.*, 2003; Fytianos *et al.*, 1998). Fly ash usually contains considerable amount of heavy metals like Zn, Cu, Mn, Fe, Co, Ni, and Pb etc. Natural vegetation by virtue of their bioaccumulation capacity accumulates these heavy metals when they grow on these dumped fly ash sites.

Macrophytes growing in and around the fly ash discharge site are the dominant producers of the ecosystem. They consist principally of aquatic vascular flowering plants but also include aquatic mosses, liverworts, ferns and the larger micro-algae (Chambers *et al.*, 2007). Macrophytes being predominantly primary production sources play an important role in energy input, nutrient budgeting and recycling (Algesten *et al.*, 2004), biofiltration (Dhote, 2007) and sedimentation processes in the water bodies. 'Green Clean' – a popular term for phytoremediation is an acceptable and ecofriendly in situ alternative to conventional remediation approaches (Rai, 2008). It can be an ecologically responsible practice to detoxify, remove, sequester and stabilize persistent pollutants in aesthetic manner (Meagher, 2000) effectively in water bodies (Peng *et al.*, 2009). Phytofiltration uses plants to remove contaminants from water (Arthur *et al.*, 2005). Macrophytes have been evaluated not only for stripping nutrients (Gottschall *et al.*, 2007) but also in altering physicochemical environment of water bodies. For instance, nutrient assimilation during photosynthetic productivity reflects alkaline pH (Hart *et al.*, 2002). Pertinently submerged macrophytes are least pollution and stress resistant species (Pulido *et al.*, 2011; Sierszen *et al.*, 2012). An important parameter used in environmental toxicology and risk assessment is the Bioaccumulation Coefficient (BAC) (Badr *et al.*, 2012). Bioaccumulation Coefficient (BAC) is also called Bioconcentration Factor (BCF) and both are the metrics traditionally used by regulatory agencies (Burkhard *et al.*, 2011), but BCFs are generally standardized, laboratory-based bioaccumulation indicators (Brisebois, 2013). BAC is used in the determination of the degree of intake and component storage of toxic compounds in plants and animals (Connell, 1997). The BAC refers to the ratio of plant metal concentration in roots tissues to the soil or polluted environment [(Metal) root/ (Metal) polluted environment or substrate]. While, (Nowell and Capel, 1999) have defined the BAC as the ratio of contaminant concentration measured in biota in the field (or under multiple exposure conditions) to the concentration measured in the surrounding water. This ratio should be greater than one for inclusion into the hyperaccumulator category (Badr *et al.*, 2012).

Saccharum spontaneum also called as 'kans grass' is a grass native to the Indian Subcontinent. It is a perennial grass, growing up to three meters in height, with spreading rhizomatous roots. The fibrous root system aids in higher uptake potency of water and mineral nutrients from the mother soil on which it grows. *Phragmites karka* shows bioaccumulation of heavy metals in the plant tissues and up takes 35-56% of heavy metals like Cu, Zn, Fe, Hg, Ni etc, from the polluted water bodies (Muhammad Masud *et al.*, 2007). It is found to grow mostly in swamps or shallow water bodies, along streams and irrigation canals (Cook, 1996). *Typha elephantina* is a rampant colonizer species found to grow in wetland habitats where there is a fair supply of water. The plant has long roots with an aggressive capacity to spread. It requires a little management, but it is planted by the environmentalists in the East Kolkata Wetlands, Ramsar site for effluent treatment and for mitigating the pollution problem in the aforementioned wetland habitat (Bhattacharya *et al.*, 2012). The present paper is an attempt to monitor the level of heavy metals in the fly ash dump site as well in the dominant vegetation growing on the fly ash infested zone. The Bioaccumulation Coefficient (BAC) has been used in this paper as proxy to bioaccumulation potential of the selected grassy species.

II. RESEARCH METHODOLOGY

The present program was conducted in the premonsoon, monsoon and postmonsoon months of 2015 - 2016 and consists of three separate phases namely a) monitoring the biologically available heavy metals in reclaimed fly ash bed, b) Analysis of the heavy metals in the shoot of selected vegetation (*Typha elephantina*, *Phragmites karka* and *Saccharum spontaneum*) c) Evaluation of the Bioaccumulation Coefficient (BAC) for the selected species.

a) Monitoring the biologically available heavy metals in reclaimed fly ash substratum

Fly ash samples were collected from two ash ponds namely - fly ash pond I and fly ash pond II. While fly ash pond I contains fly ash dumped from the power plant directly, fly ash pond II consists of reclaimed fly ash site with natural vegetation growth on them. Samples were collected from both the ash ponds especially from the root zone of the selected grass species (1 cm depth) in fly ash pond II. They were collected by using an acid washed scrapper and sealed immediately in sterile polythene bags. The samples were then washed individually with double distilled water and oven dried at 105^{o}C for a time duration of 5 – 6 hours. Gravel and dirt particles were consecutively sieved off from the samples which were then powdered by using a clean pestle and mortar. Then the ground samples were allowed to re-dry. To analyze the biologically available heavy metals (Pb, Cu, Zn) 1 gm of each of the samples were digesting them with 0.5 (N) HCl as per the standard procedure outlined by Malo (1977). The resulting solutions were then set aside to be aspirated in the flame Atomic Absorption Spectrophotometer (Perkin Elmer: Model 3030) for the determining the heavy metal concentrations. Trace metals were not detected in the reagent blank. Analysis of the NIES Sargasso sample was done to assure the quality of the data (Table 1).

Table 1: Analysis of reference material (NIES Sargasso sample) for sediments obtained from the National Institute of Environmental Studies, Japan

Element	Certified value (μg g^{-1})	Laboratory results (μg g^{-1})
Zn	28.6	26.2
Cu	14.9	13.7
Pb	2.4	2.9

b) Analysis of heavy metals in the selected vegetation

For analyzing the metal concentration in the dominant grassy vegetation, 10 gm of each of the two species were dried at 105°C overnight. 1 gm on dry weight basis of each dried sample was then digested in a solution of nitric acid and hydrogen peroxide and hydrochloric acid was later added to it. After completion of the digestion procedure the two samples were analyzed for Zn, Cu and Pb against their standard metal concentrations by AAS (Grimshaw *et al.*, 1989) on a Perkin Elmer Atomic Absorption Spectrophotometer (Model 3030). The Spectrophotometer had an HGA-500 graphite furnace atomic background corrector and a deuterium background corrector. Blank corrections were done to maintain the accuracy of the results.

c) Evaluation of Bioaccumulation Coefficient (BAC)

The Bioaccumulation Coefficient (BAC) is considered as the ratio between the metal concentration in any organ of an organism and its concentration in the ambient media (soil or water). Thus, BAC = Pollutant concentration in stem or root of selected grassy species (in ppm) / pollutant concentration in fly ash basal medium (in ppm) (Conesa *et al.*, 2007).

III. Results and discussion

a) Heavy metals in fly ash

In Mejia Thermal Power Station (MTPS), the fly ash from the power plant is mixed with the waters of the Damodar River to form a fly ash slurry which is then discharged into the fly ash ponds. The old ponds (fly ash pond II) have lush natural vegetation growth on them, and show less heavy metal concentration as compared to the ponds deprived of vegetation belt. Figure 1(a) – Figure 1(f) represent the seasonal variation of biologically available heavy metals in the fly ash substratum.

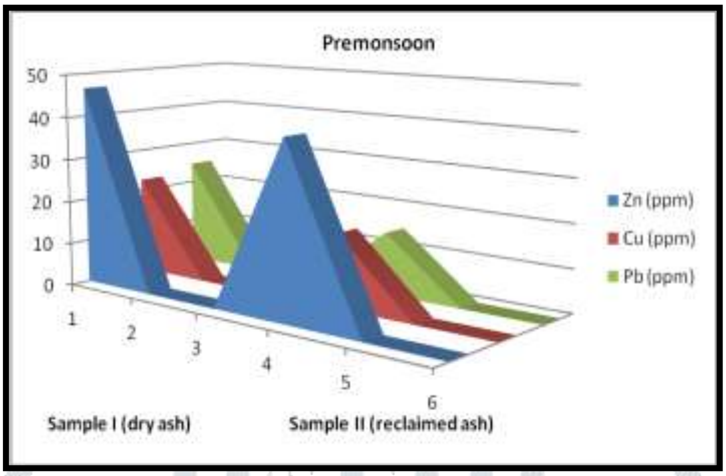

Figure 1(a): Bioavailability of heavy metals in the fly ash substratum in premonsoon, 2015

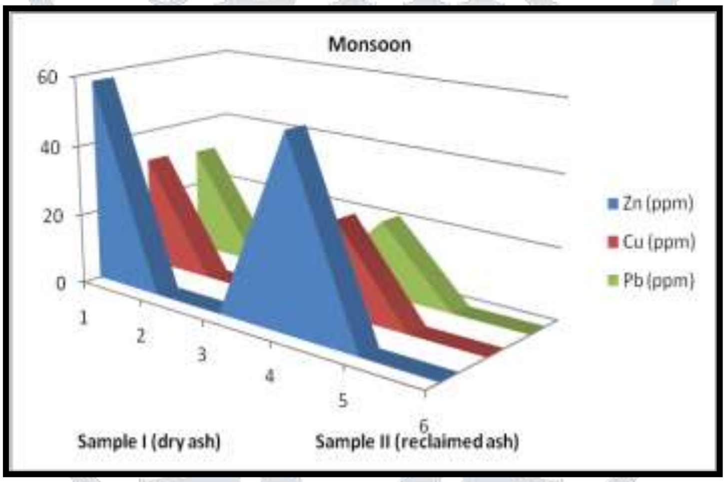

Figure 1(b): Bioavailability of heavy metals in the fly ash substratum in monsoon, 2015

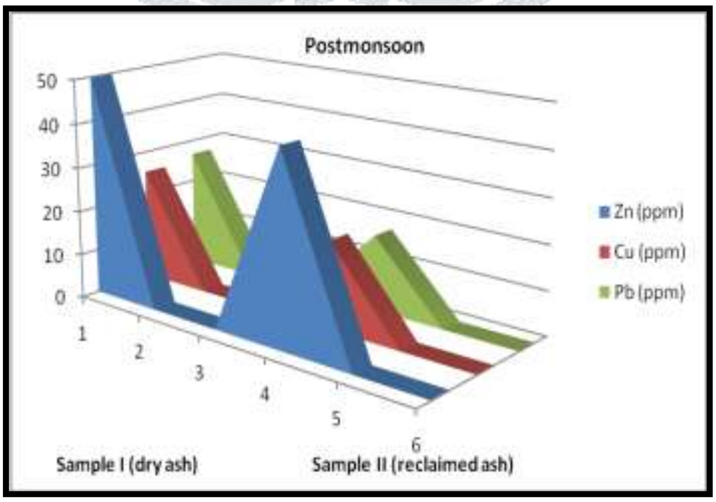

Figure 1(c): Bioavailability of heavy metals in the fly ash substratum in postmonsoon, 2015

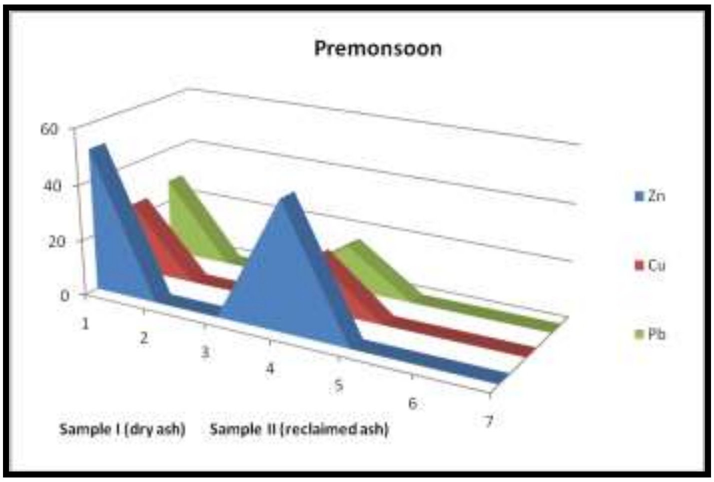

Figure 1(d): Bioavailability of heavy metals in the fly ash substratum in premonsoon, 2016

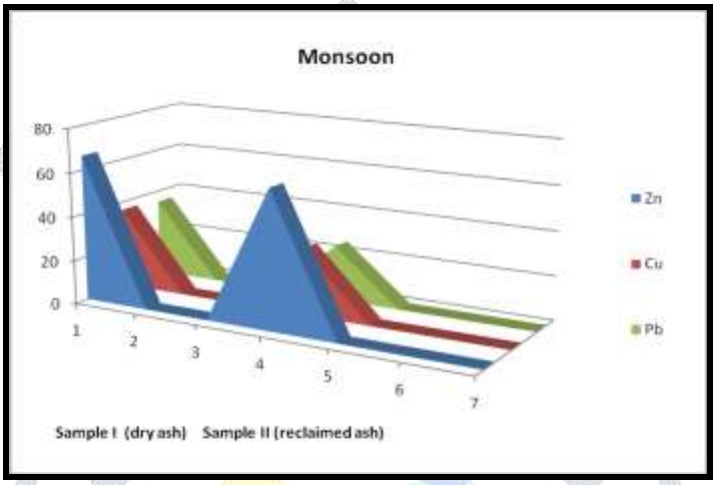

Figure 1(e): Bioavailability of heavy metals in the fly ash substratum in monsoon, 2016

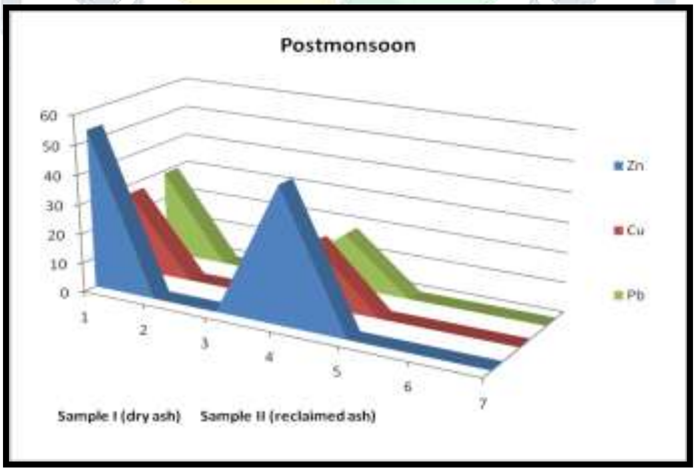

Figure 1(f): Bioavailability of heavy metals in the fly ash substratum in postmonsoon, 2016

The biologically available heavy metal concentration is comparatively more in the dry fly ash zone than in the fly ash zone with vegetation cover irrespective of seasons and years.

In premonsoon and postmonsoon seasons, for both the years, it is observed that the bioavailability of the heavy metals in dry fly ash bed (Sample I) follows the order of Zn > Pb > Cu; whereas in the reclaimed fly ash bed (Sample II) the order of bioavailability is Zn > Cu > Pb. During the monsoon season, the bioavailability of metals in both dry fly ash (Sample I) and reclaimed fly ash bed (Sample II), follow the order of Zn > Cu > Pb for 2015 and 2016.

b) Heavy metals in three selected grassy species

The heavy metal concentration in each of the three grassy species for the three seasons in the shoot region have been analyzed and presented for both the years 2015 and 2016, in Figure 2(a) – Figure 2 (f).

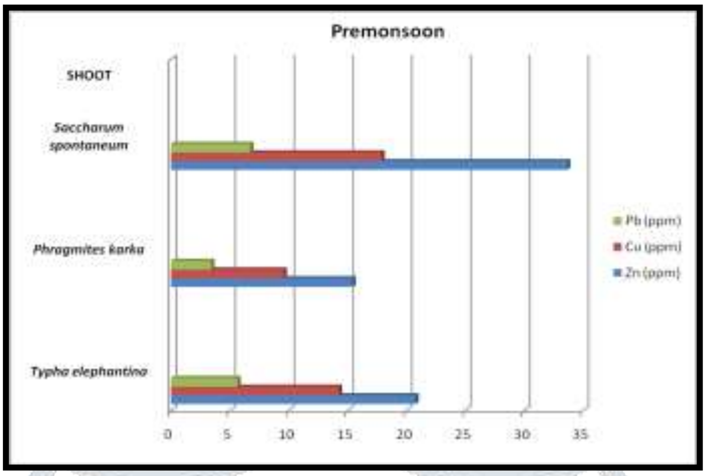

Figure 2(a): Accumulation of heavy metals in the shoot of selected grassy vegetation in premonsoon, 2015

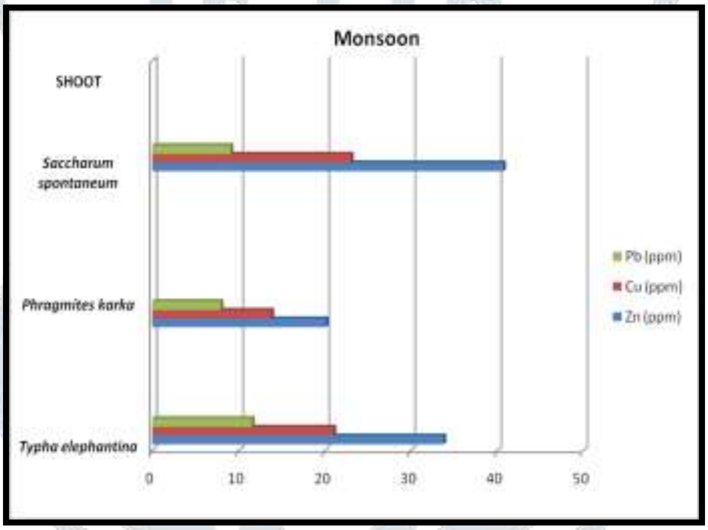

Figure 2(b): Accumulation of heavy metals in the shoot of selected grassy vegetation in monsoon, 2015

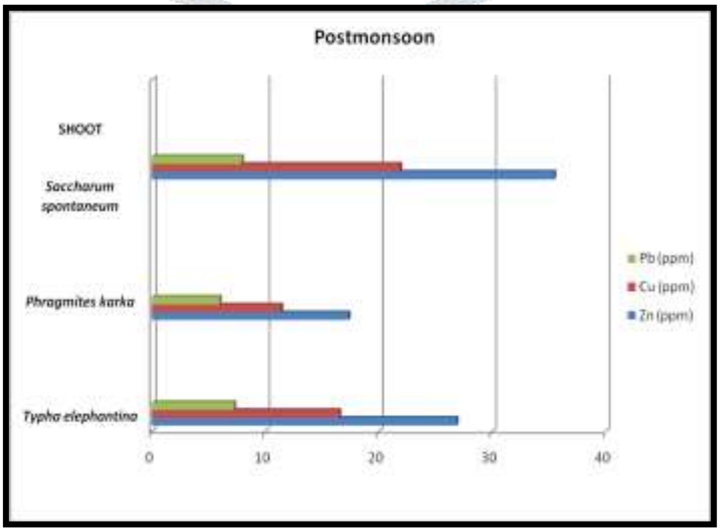

Figure 2(c): Accumulation of heavy metals in the shoot of selected grassy vegetation in postmonsoon, 2015

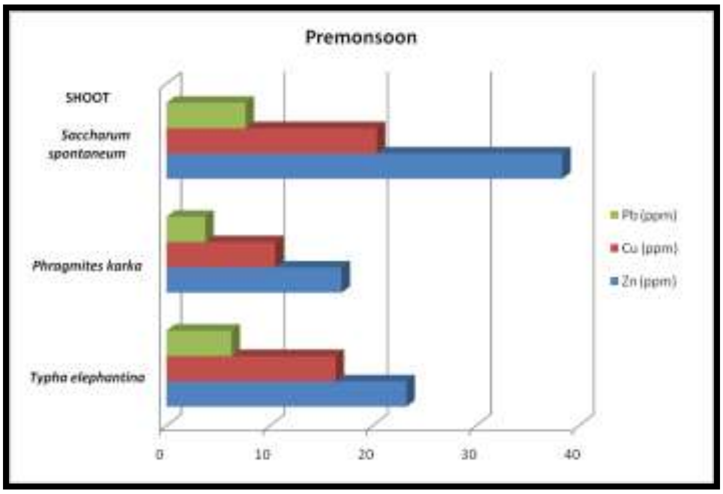

Figure 2(d): Accumulation of heavy metals in the shoot of selected grassy vegetation in premonsoon, 2016

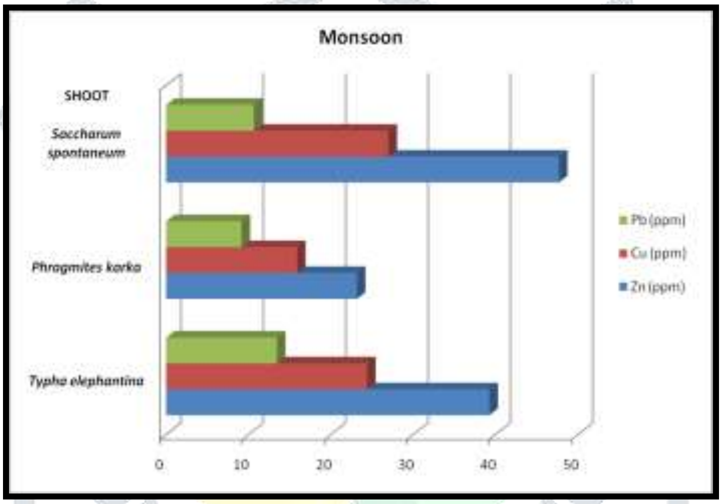

Figure 2(e): Accumulation of heavy metals in the shoot of selected grassy vegetation in monsoon, 2016

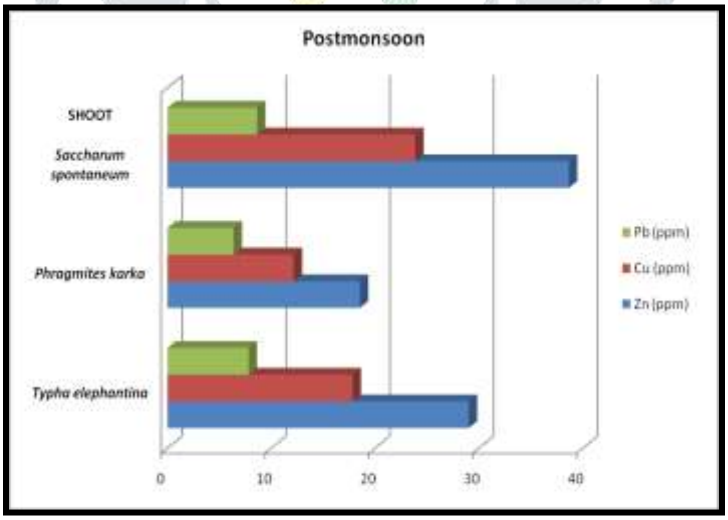

Figure 2(f): Accumulation of heavy metals in the shoot of selected grassy vegetation in postmonsoon, 2016

The heavy metal accumulation in all the three selected grassy species (*Typha elephantina*, *Phragmites karka*, *Saccharum spontaneum*) exhibited the order Zn > Cu > Pb in the shoot of the selected species irrespective of seasons and years.

c) Estimation of Bioaccumulation Coefficient (BAC)

The Bioaccumulation Coefficient (BAC) is directly proportional to the level of heavy metals in the vegetative parts and inversely proportional to the level of heavy metals in the ambient media. The BAC calculated over a period of two years (2015 and 2016) for the shoot regions is highly species-specific as evident from the present study [Figure 3(a) – 3(f)].

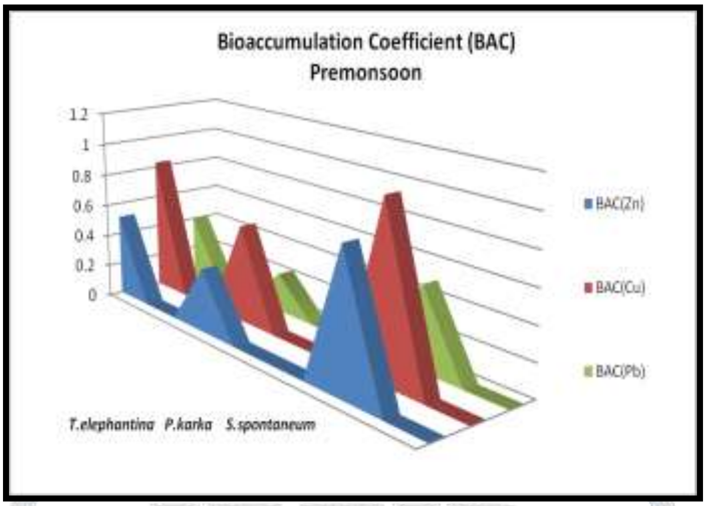

Figure 3(a): Bioaccumulation Coefficient (BAC) in the shoot of selected grassy vegetation in premonsoon, 2015

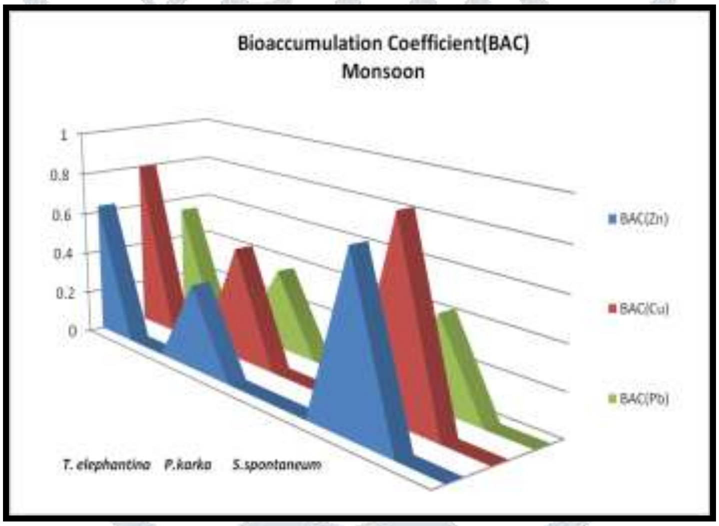

Figure 3(b): Bioaccumulation Coefficient (BAC) in the shoot of selected grassy vegetation in monsoon, 2015

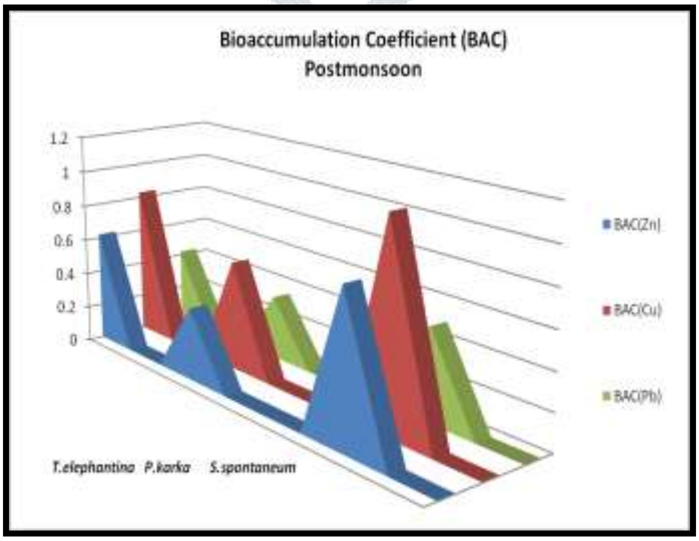

Figure 3(c): Bioaccumulation Coefficient (BAC) in the shoot of selected grassy vegetation in postmonsoon, 2015

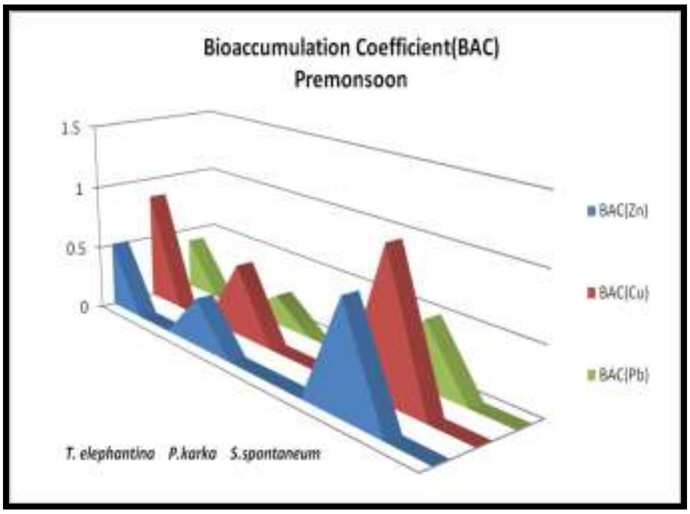

Figure 3(d): Bioaccumulation Coefficient (BAC) in the shoot of selected grassy vegetation in premonsoon, 2016

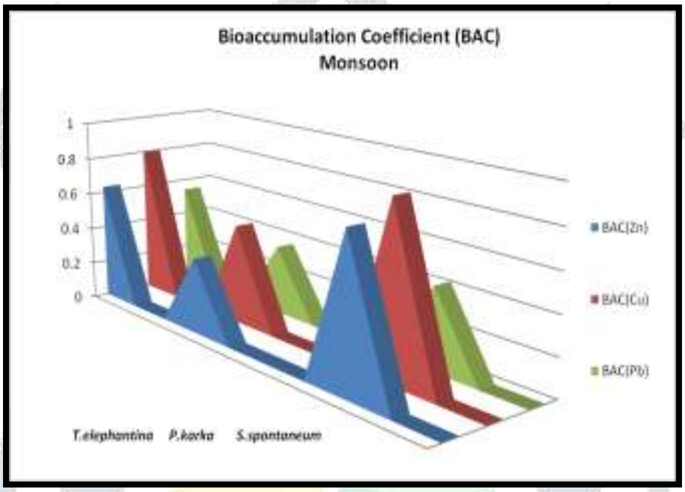

Figure 3(e): Bioaccumulation Coefficient (BAC) in the shoot of selected grassy vegetation in monsoon, 2016

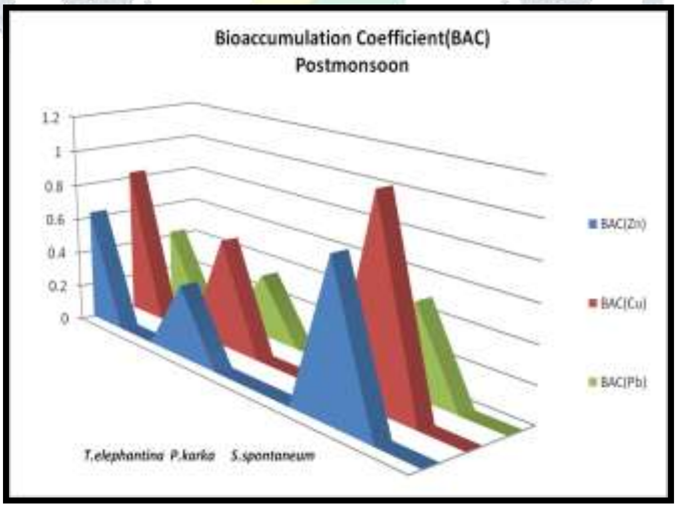

Figure 3(f): Bioaccumulation Coefficient (BAC) in the shoot of selected grassy vegetation in postmonsoon, 2016

In both the years the BAC of the grassy species for the shoot regions follows the order *Saccharum spontaneum* > *Typha elephantina* > *Phragmites karka* for Zn irrespective of the seasons.
The BAC for the shoot regions of the selected species shows the trend *Saccharum spontaneum* > *Typha elephantina* > *Phragmites karka* in case of Cu irrespective of seasons and years.
In case of Pb in the premonsoon and postmonsoon season the BAC shows the trend *Saccharum spontaneum* > *Typha elephantina* > *Phragmites karka* in the shoot regions. In the monsoon the order is slightly reversed whereby the BAC of shoot follows the order: *Typha elephantina* > *Saccharum spontaneum* > *Phragmites karka.*

d) Statistical Analysis (ANOVA)

ANOVA results computed for heavy metals (Zn, Cu, Pb) accumulated in the Above Ground Biomass (AGB) of all the three selected grassy species for all the three seasons of 2015 and 2016 exhibit significant variations in the selected metal concentrations in shoot biomass of *Typha elephantina* between seasons, but not between years (Table 2 – Table 4).

(i) ANOVA for heavy metal concentrations in the shoot biomass of Typha elephantina

Table 2: ANOVA for *Typha elephantina* AGB Zn

Source of Variation	SS	df	MS	F	P-value	F crit
Between Seasons	213.57	2	106.78	66.50	0.014815	19
Between Years	16.83	1	16.83	10.48	0.083603	18.51
Error	3.21	2	1.61			
Total	233.61	5				

Table 3: ANOVA for *Typha elephantina* AGB Cu

Source of Variation	SS	df	MS	F	P-value	F crit
Between Seasons	59.25	2	29.62	56.23	0.017474	19
Between Years	7.75	1	7.75	14.71	0.061738	18.51
Error	1.05	2	0.53			
Total	68.06	5				

Table 4: ANOVA for *Typha elephantina* AGB Pb

Source of Variation	SS	df	MS	F	P-value	F crit
Between Seasons	46.87	2	23.43	92.48	0.010697	19
Between Years	1.591	1	1.60	6.28	0.129107	18.51
Error	0.51	2	0.25			
Total	48.97	5				

(ii) ANOVA for heavy metal concentrations in the shoot biomass of Phragmites karka

ANOVA results exhibit significant variations in the selected metal concentrations in shoot biomass of *Phragmites karka* between seasons, but not between years (Table 5 – Table 7).

Table 5: ANOVA for *Phragmites karka* AGB Zn

Source of Variation	SS	df	MS	F	P-value	F crit
Between Seasons	31.19	2	15.59	33.56	0.028935	19
Between Years	5.55	1	5.55	11.94	0.074497	18.51
Error	0.93	2	0.46			
Total	37.66	5				

Table 6: ANOVA for *Phragmites karka* AGB Cu

Source of Variation	SS	df	MS	F	P-value	F crit
Between Seasons	23.89	2	11.94	49.11	0.019957	19
Between Years	2.42	1	2.42	9.95	0.087527	18.51
Error	0.49	2	0.24			
Total	26.79	5				

Table 7: ANOVA for *Phragmites karka* AGB Pb

Source of Variation	SS	df	MS	F	P-value	F crit
Between Seasons	24.66	2	12.33	110.77	0.008947	19
Between Years	0.63	1	0.63	5.63	0.140903	18.51
Error	0.22	2	0.11			
Total	25.51	5				

(iii) ANOVA for heavy metal concentrations in the shoot biomass of Saccharum spontaneum

From the ANOVA results we can see that the Zn and Cu levels in the shoot of *Saccharum spontaneum* exhibit variations between years and also between seasons (Table 8 and Table 9).

Table 8: ANOVA for *Saccharum spontaneum* AGB Zn

Source of Variation	SS	df	MS	F	P-value	F crit
Between Seasons	80.13	2	40.07	22.65	0.042281	19
Between Years	36.65	1	36.65	20.72	0.045023	18.51
Error	3.54	2	1.77			
Total	120.33	5				

Table 9: ANOVA for *Saccharum spontaneum* AGB Cu

Source of Variation	SS	df	MS	F	P-value	F crit
Between Seasons	35.74	2	17.87	35.15	0.027659	19
Between Years	11.73	1	11.73	23.08	0.0407	18.51
Error	1.02	2	0.51			
Total	48.49	5				

ANOVA results for Pb exhibit significant variations in the shoot biomass of *Saccharum spontaneum* between seasons, but not between years (Table 10).

Table 10 ANOVA for *Saccharum spontaneum* AGB Pb

Source of Variation	**SS**	**df**	**MS**	**F**	**P-value**	**F crit**
Between Seasons	*7.31*	*2*	*3.66*	*38.80*	*0.025123*	*19*
Between Years	*1.71*	*1*	*1.71*	*18.11*	*0.051017*	*18.51*
Error	*0.19*	*2*	*0.09*			
Total	*9.20*	*5*				

In this study we have compared the increment in the metal bioaccumulation in the shoot regions of three selected grassy species growing in the fly ash dump of Mejia Thermal Power Station (MTPS), Bankura, West Bengal. The percentage of increase in the shoot regions was highest in *Saccharum spontaneum* followed by *Typha elephantina* and *Phragmites karka*. This picture is common in all the three seasons and thus can be concluded that *Saccharum spontaneum* can be used as the potential species for bioremediation in the study region not only because of its availability throughout the year, but also because of the magnitude of metal the species accumulates in its body tissues (compared to other two grassy species).

The overall results suggest that considerable levels of heavy metals have accumulated in the grassy vegetation, and the pattern of accumulation points towards the species specificity for a particular type of metal. For *Typha elephantina*, the order of metal accumulation in the shoot is Zn > Cu > Pb irrespective of all the seasons throughout the study period. Similarly in *Phragmites* *karka* and *Saccharum spontaneum*, the order is Zn > Cu > Pb irrespective of the season and the year. This pattern clearly emphasizes on the seasonal pattern of bioaccumulation by the selected grassy species in the study site.

The heavy metals are basically drawn from the underlying substratum of fly ash (fly ash pond II) where the biologically available heavy metals varies as per the order Zn > Cu > Pb irrespective of the seasons during the study period. The synchronization of the seasonal variation of the biologically available heavy metals in underlying fly ash substratum with the accumulated heavy metals in the grassy species (*Typha elephantina*, *Phragmites karka*, *Saccharum spontaneum*) clearly depicts the role of these species in the process of bioremediation. The grassy species at the end of their life cycle may be withdrawn and converted into compost which may act as organic fertilizer provided the concentration of Pb is below the permissible limit. The heavy metal saturated vegetative parts of the selected species can be used as compost, which can be a possible source of minerals (except Pb). Measured doses of fly ash (contaminated with heavy metals) mixed with soil can dilute the heavy metal levels in the mixed substratum, which can be used as a growth promoter (fertiliser amendment) for crops and various floral species. The fly ash amended land sites can be further converted to afforested plots, upholding the economy and biotic and abiotic community in one go. Such an effort can in turn, support not only the economic needs of the local human inhabitants, increasing profit for the whole community, but also help in eco-restoring and sustaining the affected environment.

IV. ACKNOWLEDGEMENT

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