DEVELOPING SUSTAINABLE MEASURES TO RESTORE FLY ASH CONTAMINATED LANDS: CURRENT CHALLENGES AND FUTURE PROSPECTS

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Abstract

Land degradation is one of the major global environmental issues that need serious attention. The land itself is a complex system regulating myriads of processes and perturbation in anyone these would certainly lead to the stimulation of land degradation. Among these, fly ash (FA) dumping is one of the common-practices, which has been adopted to overcome land-use disruption and other health hazards. However, this practice has become a driving factor for FA-induced land degradation. Therefore, in purview to tackle this issue, the present article is aimed to identify and suggest plausible sustainable practices to restore and manage FA contaminated sites. It preliminarily deals with the systematic exploration and identification of FA-based and associated contaminated lands via geospatial technology with a brief focus on monitoring its different contaminant profiles in the FA and soil systems. Moreover, the article emphasizes identifying the potential local plant species in the FA-contaminated regions to understand the local people's demands. Following this, it would suggest the major sustainable approaches to expedite the restoration of FA contaminated lands along with the key highlights of their bottlenecks, while the ground implementation. Nevertheless, the article aimed to unravel the recommended prospects to

address those bottlenecks to develop an efficient restoration enterprise during the Decade on Ecosystem Restoration (2021-2030).

Keywords: Land degradation, Ecological restoration, Fly ash management, Sustainable measures, UN-SDGs.

1. INTRODUCTION

With the advent of industrial revolution, human beings has escalated the exploitation of fossil fuels including the coal extraction from the mother earth. Subsequently, the coal production has been raised from 3.55 billion tons in the 1978 to 7.81 billion tons in 2018 (www.iea.org). Recent updates about coal production by major countries are mention in Figure 1. The demands of growing worldwide human population can be viewed from that around 40% of global electricity is derived via the coal-based combustion process (Smith et al., 2013). As a result, the process leads to flyash (FA) generation, which is aby-product of the coal combustion andits total production is about 750 million tons year^{-1} globally (Blissett and Rowson, 2012). The composition of FA depends on the mode and stage of coalcombustion, and coal quality (NRC, 2006). Thus, FA contains several types of compounds, which is hazardous to the environment and human health. It contains oxides of metals (i.e., silica, ferric, calcium, zinc, etc.), micro and macro elements (K, P, Mg, Cd, Hg, Pb Se, and As, etc.), and organic compounds such as PAHs and PCBs (Blissett and Rowson, 2012). Besides, toxic heavy metals and organic pollutants, FA also possesses the presence of various radioactive elements, which makes it hazardous at higher levels. Therefore, it has been suggested to utilize the FA to reduce its amount before dumping and land filling. However, only about 26% of FA is utilized via the formation of bricks, road, etc., in few developing and developed nations (Blissett and Rowson, 2012).Subsequently, during its mismanaged disposal, the land gets contaminated thereby raising serious concern at the local, regional as well as national scale. Therefore, it is the need of the hour to remove the noxious nature of FA immediately via suggestive and feasible approaches and developing the FA-contaminated lands (FA-CL) into revitalized state. Moreover, the restoration of degraded and contaminated lands is of prime significance of various international agencies and global initiatives have been formulated such as UN- Sustainable Development Goals (UN-SDGs) and Bonn Challenge. Considering these initiatives, about 350 million ha (Mha) of degraded lands is under target to bring under restoration by 2030 (www.sdgs.un.org). Natural grown vegetation and indigenous plant species (IPS) can survive, restore the contaminated land and enable the sustainable management of FA-CL.

There are ample shreds of evidence, which suggest that diversified strategies in the phytoremediation approaches certainly help in the restoration of FA-CL (Gupta and Sinha, 2008; Juwarkar and Jambhulkar, 2008; Rai et al., 2004; Cheung et al., 2000). These strategies are emerging nowadays and attracting the attention of remediation experts. For instance, Gupta and Sinha (2008) identified *Sida cardifolia, Chenopodium album* and *Phaseolus vulgaris* as a potential plant species for the remediation of FA-CL. Moreover, Juwarkar and Jambhulkar (2008) utilized apposite organic amendments like farmyard manure for the phytoremediation via *Prosopis juliflora*, whereas Rai et al. (2004) used pressmud, sewage sludge and the sludge from the paper mills. Furthermore, efficiency evaluations of *Leucaena leucocephala* and *Acacia* sp. have been performed under different organic amendments (representing N-fixing bacteria). The organic amendments are used to reduce the toxic effects of FA in polluted land (Cheung et al., 2000). Fast growing species like Willow has also attracted the attention of phytoremediation scientists as it can be regularly harvested and yield can be obtained up to 15 dry ton ha^{-1} yr^{-1} (Riddel-Black, 1993). Mycorrhizal technology has also gained wider popularization for the reclamation of FA-CL (Pandey et al., 2009). The reclamation of FA-CL area of 3900 m^2 was done by the exploitation of mycorrhizal technology at the Badarpur Thermal Power Station, Delhi in India (Pandey et al., 2009).

In purview to this, the present article is aimed to provide a state-of-the-art related the FA generation and predicting the land area that could be prone towards FA contamination and suggest sustainable measures to overcome this global issue. Therefore, the article focuses on (i) Geospatial assessment of FA prone land areas, (ii) monitoring the noxious nature of FA by considering its inorganic, organic and radioactive contents, (iii) restoration of FA-CL through candidate plant species and suggestive measures and challenges.

2. GEOSPATIAL ASSESSMENT OF FA AND ASSOCIATED CONTAMINATED LANDS

Prior to large-scale FA restoration initiative, an intense and strategic regional geospatial assessment should be conducted to understand the behavior and characteristics of the region. It is influenced by the fact that it helps in making the priorities according to the areas and levels of contamination. If large numbers of area of lands are affected by FA-based contamination, then those areas should be strategically prioritized for overcoming the underlying issues. To this, a concrete understanding of the source of FA generation is necessary as well as the area, which is getting affected by that source. Fundamentally, the FA generation is related directly or indirectly to the coal production or combustion in the region. In purview to this, factors like coal extraction, production, washing of the coal, combustion and dumping of its residues regulate the FA-based land contamination. For the sake of current discussion, this section emphasizes on the coal combustion residues (CCR) or coal ash dumps or FA and associate contaminated lands. Cumulatively, the main coal-producing countries are responsible for generating around 3.7 billion tons coal ash per annum (IEA, 2016). Australia itself produce around 11 million tons coal ash per annum (EJA, 2019) and has more than 400 million tons of ash deposited in dumpsites across the country (ADAA, 2018; EJA, 2019).Vietnam produces 11.8 million tons of coal ash per annum from its existing 20 coal-fired power plants (Thenepalli et al., 2018). Moreover, burning around 5.4 tons of coal generates 0.9 tons of coal ash (Ritter, 2016). Out of the total generated coal ash, FA contributes to around 75% and rest is the bottom ash (Jarusiripot, 2014).According to analysis, each tons of FA covers around 0.30 hectares of land (He et al., 2012). By this, considering the net FA production in China to around

171 million tons in 2015 (Ge et al., 2018), it would have occupied around more than 51 Mha of land. United States individually produced around 38 million tons of FA in 2016, which gradually reduced to 29 million tons in 2019 (ACAA, 2019). Figure 1 and 2 explicitly depict that the country with greater coal production and consumption are more prone to contaminate their viable lands via various means. Majority of it includes the mismanaged disposal and dumping. Similarly, a regional analysis must be conducted to assess the severity of the issue according, which the management strategy could be formulated.

3. MONITORING THE CONTAMINANT PROFILES IN FA CONTAMINATED SOIL

a. Critically toxic heavy metal elements

Besides, major elements such as aluminum (Al), calcium (Ca), iron (Fe), etc., FA also comprises critical heavy metals like antimony (Sb),arsenic (As), cadmium (Cd), chromium (Cr), copper (Cd), lead (Pb), mercury (Hg), nickel (Ni), zinc (Zn), which could potentially affects environment, human health and well-being (Sun et al., 2016; Lee et al., 2006). Escalated Cr (VI) levels are deleterious to circulatory system that may lead to carcinogenicity. Accumulated Cr in plants directly affects the plant growth. Pb content has serious consequences, as it is harmful to both animals and humans especially infants (Jambhulkar et al., 2018). Concentration of As in FA usually lies between 4 and 440 $mgkg^{-1}$nevertheless, based on the coal quality the levels may attain to 1000 $mgkg^{-1}$(Huggins et al., 2007). Similarly, boron (B) levels in FA also differs depending on the coal quality. It varies from 22 to 60 $mgkg^{-1}$ and can reach maximally to 250 $mgkg^{-1}$. If its concentration crosses more than 30 $mgkg^{-1}$, it is considered significantly toxic (Haynes, 2009).From the figure 3 a & b), it can be deduced that, the levels of critically toxic heavy elements are much higher in FA as compared to the soil. Therefore, monitoring the FA contaminated soil and screening the different levels of toxic heavy metals in it is highly needed to adopt strategic measures. It is driven by the fact that if the stakeholders would not be able to identify the strength of contamination, selection of site-specific remediation measures could be implemented effectively.

b. Organic pollutants

The concentration and types of organic pollutants in FA (OPs-FA) depends on the physico-chemical properties of coal and different operational combustion conditions (Kosnar et al., 2016). OP-FA might be a macro-or micro–molecule. A macromolecule of OPs-FA is a condensed aromatic, hydro-aromatic compounds, where as micro-molecule of organic pollutants belongs to the group of hydrocarbons having the polycyclic or hydroxyl-polycyclic aromatic, aliphatic or aromatic or heterocyclic structure (Sahu et al., 2004; Liu et al., 2013). Usually, OP-FA contains poly-aromatic hydrocarbons (PAHs) and polychlorinated biphenyls(PCBs), generates in coal combustion through radical condensation or cyclisation, and reacts with halo (-Cl) groups, respectively (Liu et al., 2013). Both PAHs and PCBs are carcinogenic at a specific concentration, induce adverse effects on living organisms, and mediate via free radical reactions (Shaheen et al., 2014). Sahu et al., (2009) demonstrated that the PAHs and Benzo-pyrene found in FA range from 0.043 to .936 mg kg^{-1} and 0.82 to 18.14 mg kg^{-1}, respectively. PAHs such as Benzo-pyrene, a rich component of OPs-FA varied with temperatures (Liu et al., 2013).Similarly, PCBs exist with a range from 7.3 to 178.7 kg^{-1} as OP-FA (Sahu et al., 2009). The significant variation of PAHs concentration was observed in PCBs due to the diversity of coal's-feature reported in literature (Sahu et al., 2009). PCBs such as polychlorinated dibenzofurans (PCDFs), polychlorinated dibenzo-p-dioxins (PCDDS) are more common in FA. Liuet al. (2013) illustrated that the poly-chlorinated-dibenzo-furans cover a major percentage, of the persistent organic pollutants in the FA. Liu et al., 2013 also reported about, persistent-organic-pollutants, which belong to the family of polychlorinated compounds such as dibenzofurans, dibenzo-p-dioxins, naphthalenes, Penta, and hexachlorobenzene. Monitoring of PAHs can be based on certified reference material, which uses for combustion in the industrial sector regarding FA-generation, in China, certified value 2.0±0.8, 7.1±2.6, 1.3±0.3,7.0±2.0, 7.4±1.9 $\mu g g^{-1}$ for anthracene, phenanthrene, benzopyrene, pyrene, and fluoranthene, respectively reported by Cao et al., (2001). The certified reference value of coal can beminimizing the PAHs level in FA. On the other hand, OPs like PAHs and PCBs in FA-CL can bemonitor and manage through native vegetation or plant species. OPs can be entering in animal food via the first tropic level organism (plants) and induces adverse effects on human health (Fryer and Collins, 2003; Li et al., 2005). Several studies suggest that photo-degradation and rhizo-mediation of selective-plant species can be suitable for minimizing the adverse impact of OPs of FA-CL. Taoet al. (2004) reported the maximum concentration of PAHs in cauliflower (*Brassia oleracea*) ascompared with *Festuca arundacea, Lolium multiflorum, Daucus carota,* etc. This result indicatesthat PAHs-translocation was more in cauliflower and the rest of the species have a potential phyto-degradation mechanism for PAHs. Similarly, Kolb and Harms (2002) demonstrated that PCBs such as fluoranthene degrades by metabolites of plant root of *Triticum aestivum, Lactuca sativa,*and *Lycopersicon*. Rhizomediation strategies for PAHs and PCBs can achieve by native plant species like *Cynodon dactylon, Festuca rubra, Trifolium prenne, Agrophyron, Metilotus officinalis,* etc. (McCutcheon and Schnoor, 2003). Therefore, the monitoring and managementof OPs in FA-CL can be the effective strategies to restore FA-CL through (i) the use of certified material for combustion purposes at a large-scale (ii) screening and selection of phyto-degradation and rhizo-mediation mechanism-based native plant species to grow in FA-CL.

c. Radioactive elements

The presence of radio-nuclei in FA is less reported in current scenario (Cujic et al., 2015). The radio-nuclei such as ^{228}Ac, ^{40}K and ^{226}Ra, ^{220}Ru, ^{222}Ru, thorium, Uranium, etc., are found in FA (Mittra et al., 2005, Mathur et al., 2008). The toxic effect of radio nuclei can be observed over high doses of FA, while Basu et al. (2009) reported that radio nuclei of K, Ra, and Ac emit radiation within the permissible limits. Similarly, Mathur et al. (2008) illustrate that radioactivity exists within the limit in FA, and the radioactivity range was 205 to 385 Bq Kg^{-1} for K and 145 to 610 Bq Kg^{-1} for radium, respectively. In general, The Indian coal showed fewer radioactivities and found below the permissible limit in FA as compared to other countries (Kant et al., 2010). The radioactivity range from 145 to 188 Bq Kg^{-1} for ^{232}Th, 92 to 203 Bq Kg^{-1} for ^{238}U, and 355 to 516 Bq Kg^{-1} for ^{40}K, 214 to 590 Bq Kg^{-1} radon, and 317 to 610 Bq Kg^{-1} for radium in different FA samples (Kant et al., 2010). Ozden et al., (2018) studies radio nuclei in two coal-thermal power-plants (CTPP) in Turkey and reported that the radioactivity of ^{210}Po and ^{210}Pb exists between 56 to 1174 Bq Kg^{-1} and 186 to 1153 Bq Kg^{-1}, respectively in the FA. Significant attenuation ^{210}Po and ^{210}Pb radioactivity shown at lowering the temperature of CTPP, and lesser density of FA suggests the application of FA can be safe after a few times with less concentration (Ozden et al., 2018).

4. Identifying the indigenous potential plant species and understanding local demands

The introduction of IPS is considered as promising approach to restore soil health even in FA contaminated land (FA-CL) (Jambhulkar et al., 2018). Both essential and toxic elements present in the fly ash, which highly concern for selective plant species for restoration of FA-CL. The IPS has developed coping mechanism against diverse environmental conditions such as toxic hazardous metals (THMs). Naturally, plant species perform nutrient and heavy metal uptake through specialized root-channel system, selection and transportation of nutrient and heavy metal by plant root mediates through root bio-filter mechanism. Root bio-filter mechanism facilitates plant growth and avoid to hazardous metal uptake in plant. Similarly happen, in fly-ash contaminated land with indigenous plant species (Table 1). The adverse grown effect was observed in leafy vegetables due to heavy metal stress in FA-CL, and Singh et al. (2008) similarly observed in *Beta vulgaris* plant. The perfect candidate IPS for restoration of FA-CL should have phytoremediation potential (Qadir et al., 2019; Panda et al., 2020a). Gajic et al., (2018) illustrates that phyto-remediation potentials are based on four criteria such as phyto-stabilization (P-S), phyto-extraction (P-X), phyto-degradation (P-D), and rhizo-degradation (R-D) The P-S mechanism of plants reduces the mobility of toxic hazardous metals (THMs) or organic pollutants (OPs) in the root from rhizospheric soil region. P-S mechanism containing plants capable to limit the uptake of THMs and OPs through avoiding or excluding mechanism mediate complex transport system (Table 2). The P-X mechanism is important for the extraction of THM due to its more accumulation in plant areal part, in the general hyper-accumulator plant have distinguished coping mechanism to survive against high concentration of THM or OPs. THM or OPs enter the vacuole of plant cells via a specialized channel through the root system and accumulate at high concentrations.

The P-S and P-X capability of plant play a key role in restoration and adaptation with FA-CL(Table 1), and IPS adaptation with high THM and OPs based on PS and PX potential, which evaluated through bio-concentration factor (BCF) and translocation factor (TF) (Dwivedi et al., 2014;Panda et al., 2020a). BCF examine by comparing elemental ratio of plant to soil, and ratio of leaves to plant root of elements refer to as TF. Suitable P-S mechanism plant exhibits the value of BCF>1 and TF<1; BCF<1 and TF>1.P-X potential of plant shows greater than one (>) for BCF and TF both (Gajic et al., 2018). Plant P-D is based on components of root exudates, plant root secrets about 5 to 21% of photosynthetic matter, which contains sugars, amino acid, phenolics, secondary metabolites, and organic acids, etc., commonly known as root exudates (Badri et al., 2013). Root exudates induce the redox reaction insight the root environment, mediate activation and transformation of THM and OPs, and triggers conjugation/storage of THM and OPs of contaminated soil land. The root exudates provide the carbon source as a nutrient for microbes and rise root-associated microbial population (RAMP). The RAMP and root exudates jointly participate in the degradation and transformation of THM and OPs called rhizo-degradation.

IPS grows in particular area and has characteristic to adapt local condition, do not require human intervention for growth, which help restoring and landscaping studies (Doner, 2002). Literatures suggested for successful restoration achieved by self-sustain mixed vegetation with grass and legumes followed by herbs, shrubs and tree (Gajic et al., 2016). Legumes are the key species in nitrogen deficient FA-CL for restoration. Soil health restoration in FA-CL should be suitable for economic concern. The application of FA-CL for the growth of plants that belong to agriculture, forestry, economic yield tree, and ornamental purposes covers major thrust area to attain SDG. Miati and Prasad, (2016) illustrated that growth of *Dendrocalamus strictus*, *Eucalyptus*, *Leucaena leucoephate* in FA-CL can achieve economic benefits. Similarly, economic benefits obtained by the plant such as *Tectona grandis*, *Dalbergia sissoo*, *Populus euphractica* grown in FA-CL (Juwakar and Jambhulkar, 2008; Miati and Prasad, 2016).

The presence and grown vegetation of IPS indicate natural succession. IPS has an inherent coping mechanism against adjacent environments and established suitable micro-environmental conditions between the root and rhizospheric soil. Plant root and rhizospheric soil interaction have complex mechanisms mediate through microbes and root exudates. Root-associated microbes enhance plant growth and adaptation in an adverse environment, through phyto-stimulation and bio-control activity. Root-associated beneficial microbes are plant growth-promoting microbes (PGPM) such as plant growth-promoting rhizobacteria, and plant growth-promoting fungi. PGPM releases phytohormones such as indole-3-acetic acids, gibberellins, etc., and produces organic acids, siderophore, ACC-deaminase and other antibiotics. (Upadhyay et al., 2009, 2019. In spite of that, PGPM can survive under heavy metal stress (Bhojiya et al., 2021). The microbial population and soil enzymes activities hampered at high concentration of FA (Singh and Pandey, 2012), while the growth of optimum bacterial population and soil dehydrogenase activity maintained at the level of 10t/ha FA application in soil (Jala and Goyal, 2006; Kohli and Goyal, 2010). The bacterial species such as *Azospirillum, Azotobacter, Bacillus,* etc., are reported by several workers in old FA-CL (Jambhulkar et al., 2018).

5. SUGGESTIVE SUSTAINABLE APPROACHES TO FACILITATE RESTORATION OF FA CONTAMINATED LANDS

Natural vegetation growth observed in FA-CL usually takes about at least a decade (Pandey et al., 2012).Long-duration helps to rise the free elemental interaction of FA and land with the help of climatic factors (temperature, rainfall, wind, etc.) and leads to microbial development. Once the microbial growth is established, the soil-biochemical function would be triggered, and nutrient would become available to the plant (Ram et al., 2008; Rajkumar et al., 2010). This condition can be suitable for the growth of first vegetation in FA-CL. Generally, fresh FA does not support microbial growth however, microbial population is observed after a time in FA-CL (Singh and Pandey, 2012). Initial vegetation covers are the key step of restoration of FA-CL, and grasses are reported as initial vegetation under nutrient-poor soil (Maiti and Prasad 2016). The growth of the grasses is observing the versatile nature of the environment even in FA-CL(Gajic et al., 2016).Grasses have an adventitious root system with the fast-growing ability and cover a large surface area of contaminated land, which could be harnessed for the application in soil restoration (Gupta et al., 2013). This initial vegetation raises the soil fertility for the next vegetation. However, with the absence of nitrogen content in FA, the growth of the higher plant is a major bottleneck. Naturally occurring legume-plants can be a better option to address the aforesaid issue in FA-CL. Therefore, the application of grass cover in FA-CL can be considered as one of the promising first step followed by application of legumes and economic yielding plants (Brindle, 2003; Jambhulkar and Juwarkar, 2009). The fulfilment of nitrogen content in grasses induces nitrogen fixation by legumes; grasses can use 3 to 102 kg N/ha/yr of fixed nitrogen (Milcu et al., 2008). Both grass and legumes vegetation raising the soil nutrient cycling, maintain C:N ratio, and restoring soil health for next plant spices (Mati and Maiti, 2015).Legume-grass can fix nitrogen from about 13 to 682 kg N/ ha/yr in FA-CL (Maiti and Prasad , 2016) and similarly lemon grass (*Crotalaria juncea*) can potentially fix 1.1 kg/ha N in just 9 to 12 week (Akhila, 2010).

Jambhulkar and Juwarkar (2009) reported that *Cassia siamea*can adopt and grow in field of FA-CL, and after three-year restoration of FA-CL following further flourishment. Similarly, Qadir et. al., (2019) illustrates that *Pithecellobium dulce* can fit for growing in FA-CL and can induce reclamation of FA-CL due to enhanced ability of antioxidant mechanism against free radicals and stress conditions. Sustainable restoration initiatives for FA-CL through the application of vegetation can be estimated via mathematical models for selecting the suitable plant species (Mendez and Maier, 2008). Maiti and Prasad, (2016) illustrated the mathematical models such as BAF (Bioaccumulation factor), BCF, TF, MPI (Metal pollution index), Ef (Enrichment factor), Ei (Enrichment index) and Igeo (Geo-accumulation index). Singh et al., (2010) earlier applied mathematical models such as MCI, EF, and TF in FA-CL for screening suitable restoration correlation among the grown plant root-shoot. Kishu et al., (2018) illustrate mathematically to screening the efficient candidate restoration plant species for restoration in FA-CL, FA-CL heavy metal concentration (μg^{-1}) of Cd (2.9), Cr (9.5), Ni (13.6), Pb (25.4), Mn (60.6), Zn (134.8) and Fe (909.4)and soil enrichment factors Zn and Cd was 1.9 and 2.7,respectively.Out of twelve grown species in this FA-CL sites enrichment factors for all plant root and shoot exhibits 3.8 and 4.3 for Zn and 3.5 and 3.8 for Cd, respectively, only six plant species (*Saccharum ngrum* , *S. Munja, Parthenium hysterophorus, Ipomea carnea and Typha Angustifolia*) shows P-S and P-X behavior for Cd, Cr, Ni, Pb, Cu, Mn, Zn and Fe.

Eco-friendly sustainable amendments with FA can be a power full technique to restore FA-CL and overcome problem of THM and OPs in agriculture field, forestry and growth of other plants. The application of eco-friendly sustainable amendments restores FA-CL in lesser time as compare with natural succession process. Spontaneous colonization of *Calamagrostis epigejous* grass in FA-CL, fall under PS- and P-X (for boron and arsenic) category takes thirteen years to restore the FA-CL for vegetation (Mitrovic et al., 2008). Similar finding was demonstrate by Pandey et al., 2012, after eleven year FA-CL restore and fit for vegetation practices through spontaneous colonization of IPS *saccharum munja*. *Saccharum munja* is an important P-S and P-X category plant and can imply for restoration in FA-CL (Pandey et al., 2012). Eco-friendly sustainable amendments such as manure, cow-dung, poultry bio-solid, epigenic earthworm, wheat straw, and PGPM in FA are some of the suitable components for managing the problems of THM and OPs and restore FA-CL faster (Reynolds et al., 1999; Gaind and Gaur, 2002; Pati and Sahu, 2003; Jamil et al., 2009; Lau and wang, 2001;Upadhyay et al., 2021). Punshon et al., (2002) demonstrated that co-application of fly ash (1120 tons ha^{-1}) and poultry bio-solid (10 tons ha^{-1}) significantly influence biomass of grasses*Panicum amarum*, *Lespedeza cuneata*, and *Eragrostis curvula*over 3-years ofthe study, and found that no harmful effects of THM in plant as well as inthe aquifer.Upadhyay et al. (2021) demonstrated that alkaline nature of FA induces significant growth-performance of Chickpea plant under acidic soil (pH 6.1) followed by neutral and alkaline.However, the maximum concentration (40%) of FA utilization triggers by eco-friendly augmentation (Upadhyay et al., 2021).Similarly, Dwivedi et al., (2007) screened for FA tolerance and metal uptake behavior in three rice varieties

(Saryu-52, Sabha-5204, and pant-4). Around 25% of FA with garden soil reveled significant plant growth and metal accumulation obtained as Fe>Si>Mn>Zn>Cu>As. Results indicate that Pant-4 is less tolerance as Saryu-52 and Sabha-5204 under high concentration of FA. Saryu-52 and Sabha-5204 plant have sound rhizofilter mechanism as pant-4, which provides coping mechanism against THM and OPs of FA.

6. CHALLENGES IN GROUND IMPLEMENTATION: WIDE-SCALE PERSPECTIVE

Though above-mentioned suggestive approaches have promising future, still it may subject to few challenges while implementing on the ground. Addressing these issues would certainly help in achieving efficient remediation and thereby attaining UN-SDGs. Indeed selecting indigenous plant having fast growing traits in harsh condition could have broaden prospects, but growth rate usually slows down during the implementation in the heavily contaminated sites (Patra et al., 2020). The impact of contamination is directly observed in the plant biomassdue to the stunted growth. Occurrence of pest attacks further perturbed the restoring ecosystems of contaminated sites, which often affect predicted expectations (Mahar et al., 2016). Importantly, the major concern is the post-harvest efficient utilisation, as the harvested biomass could often reflect low quality (Gerhardt et al., 2009). The burgeoning issue of global warming is yet another challenge for the acclimatization of the planted species for the restoration initiatives. Hence, the restoration of heavily contaminated sites still unravelled. Under seldom instances, if the highly contaminated sites would be mainstreamed into the phytoremediation, there would also be a genuine apprehension of transfer of critically toxic heavy metals in the food chain. Inappropriately adopted agronomic practices or the application of inefficient soil amendments might adversely affects contaminants mobilization here are other technological and funding limitations, which decelerates the process of restoration initiatives. It could be further affected by the inappropriate policies or the lack of strict regulations (Odoh et al., 2019).

7. CONCLUSIONS AND WAY FORWARD

Though our current perception and approaches to restore the FA induced contaminated land is progressively developing, still we are in midst of numerous burgeoning challenges, which needs immediate action to avoid any downfall. Addressing the challenges discussed in the abovementioned section could certainly help in ensuring the success of undertaken initiatives for the reclamation and restoration FA-CL. We have to focus and develop a kind of decentralized and distributed system to counter this global issue at multiple fronts. For example, the technologies of checking the excess FA generation must be adopted immediately across worldwide perspective. Following this the generated FA should efficiently utilised for other multifaceted purposes. In this way, we can reduce the amount of FA that is subjected for dumping into the land systems. Moreover, it will reduce the pressure on the land system and enable it to be less prone for the heavy contamination. Further, the utilisation of sustainable measures discussed in the previous sections could be the promising approaches to restore the contaminated sites successfully. Besides, there are other underestimated challenges, which can appear while the implementation of restoration initiatives, for which the remediation experts and the implementing bodies should prepared accordingly. For example, the societal acceptance and the socio-political issues could be raised in the regions of people with diverse mental attitude. Moreover, the incentivisation should be promoted to enhance public participation, which could be made flexible enough to overcome any shortcomings during the restoration programme.

Acknowledgments: The first authors are grateful to the Department of Environmental Science, V.B.S. Purvanchal University, Jaunpur, Uttar Pradesh, India and School of Liberal Arts and Sciences, Thapar Institute of Engineering & Technology, Patiala, Punjab, India for providing Institutional support to conduct the work.

Conflict of interest: The authors declare that they have no conflict of interest, no competing financial interests or personal relationships that have appeared to influence the work reported in this work.

Author contributions: SAE and SKU: Conceptualization, Visualization, Writing-original draft, and review and editing.

References

ACAA (American Coal Ash Association). (2019). Beneficial Use of Coal Combustion Products: An American Recycling Success Story.

Akhila, A. (2010). Essential Oil-bearing Grasses: The genus *Cymbopogon*. Medical and aromatic plants-industrial profile. - Taylor and Francis Group, L.L.C.

Ashfaque, F., and Inam, A. (2019). Interactive effect of potassium and flyash: a soil conditioner on metal accumulation, physiological and biochemical traits of mustard (Brassica juncea L.). Environ Sci Pollut Res Int, 26(8),7847-7862. doi: 10.1007/s11356-019-04243-w

Badri, D.V., Chaparro, J.M., Zhang, R., Shen, Q., and Vivanco, J.M. (2013). Application of natural blends of phytochemicals derived from the root exudates of Arabidopsis to the soil reveal that phenolic-related compounds predominantly modulate the soil microbiome. J. Biol. Chem, 288,4502-4512.

Bashir, K., Ishimaru, Y., and Nishizawa, N. K. (2012). Molecular mechanisms of zinc uptake and translocation in rice. Plant Soil, 36, 189–201. doi: 10.1007/s11104-012-1240-5.

Basu, M., Pande, M., Bhadoria, P.B.S., Mahapatra, S.C., 2009. Potential fly ash utilization in agriculture: a global review. Prog. Nat. Sci. 19, 1173e1186.

Bhattacharya, .S.S and Chattopadhyay, G.N. (2002). Increasing Bioavailability of Phosphorus from Fly Ash through Vermicomposting. Journal of Environmental quality, 31, 2116-2119.

Blissett, R. S., and Rowson, N. A. (2012) A review of the multicomponent utilisation of coal fly ash. Fuel 97, 1−23.

Brindle, F.A. (2003). Use of native vegetation and biostimulants for controlling soil erosion on steep terrain. - Journal of the Transportation Research Board, 1, 203– 209.

Cao, X., Xu, X., Cui, W. And Xi, Z (2001). Development and certification of a coal fly ash certified reference material for selected polycyclic aromatic hydrocarbons, Fresenius J Anal Chem, 370(8), 1035-40.

Cheung, K. C., Wong, J. P. K., Zhang, Z. Q., Wong, J. W. C., & Wong, M. H. (2000). Revegetation of lagoon ash using the legume species Acacia auriculiformis and Leucaena leucocephala. *Environmental Pollution*, *109*(1), 75-82.

Clemens, S. (2006). Toxic metal accumulation, response to exposure and mechanisms of tolerance in plants. Biochimie, 88, 1707–1719. doi: 10.1016/j.biochi.2006.07.003.

Cujic M., Dragovic S., Dragovic M, Dragovic R, Gajic B and Miljanic S (2015).Radionuclides in the soil around the largest coal-fired power plant in Serbia: radiological hazard, relationship with soil characteristics and spatial distribution. Environ Sci Pollut Res Int.;22(13),10317-30.doi: 10.1007/s11356-014-3888-2.

Dorner, J. (2002). *An Introduction to Using Native Plants in Restoration Projects*. Plant Conservation Alliance, Bureau of Land Management, US Department of Interior, US Environmental Protection Agency, 65.

Dwivedi, G.K., Upadhyay, S.K., Mishra, A.K. and Singh, A.K. (2014). Hyper accumulation of cadmium in S*olanum nigrum* L. and their effects on phyto-chemicals and antioxidant enzymatic activities. Int J Pharm Sci Res, 5(4),1424-1430. http://dx.doi.org/10.13040/IJPSR.0975-8232.5(4).1424-30.

Dwivedi, S, Tripathi, R.D., Srivastava, S, Mishra, S., Shukla, M.K., Tiwari, K.K., Singh, R., Rai, U.N. (2007).Growth performance and biochemical responses of three rice (Oryza sativa L.) cultivars grown in fly-ash amended soil Chemosphere, 67(1),140-51.

EJA (2019) Unearthing Australia's toxic coal ash legacy. Environmental Justice Australia (EJA). Available at: www.envirojustice.org.au

Fryer M, Collins CD (2003) Model intercomparison for the uptake of organic chemicals by plants. Environ Sci Technol 37:1617–1624.

Gaind, S. and Gaur, A.C. 2002. Impact of fly ash and phosphate solubilising bacteria on soybean productivity. Bioresour. Technol. 85, 313-315.

Gaind, S., Gaur, A.C. (2003). Quality assessment of compost prepared from fly ash and crop residue. Bioresource Technology, 87,: 125–127.

Gajaje, K., JrUltra, V.U., David, P.W., Rantong, G. (2021). Rhizosphere properties and heavy metal accumulation of plants growing in the fly ash dumpsite, Morupule power plant, Botswana. Environ Sci Pollut Res Int, doi: 10.1007/s11356-020-11905-7.

Gajic, G., Djurdjevic, L., Kostic, O., Jaric, S., Mitrovic, M. and Pavlovic, P. (2018). Ecological Potential of Plants for Phytoremediation and Ecorestoration of Fly Ash Deposits and Mine Wastes. Front. Environ. Sci., 6,124. doi: 10.3389/fenvs.2018.00124.

Gajic, G., Djurdjevic, L., Kostic, O., Jaric, S., Mitrovic, M., Stevanovic, B., et al. (2016). Assessment of the phytoremediation potential and an adaptive response of Festuca rubra L. Sown on fly ash deposits: native grass has a pivotal role in ecorestoration management. Ecol. Eng., 93, 250–261. doi: 10.1016/j.ecoleng.2016.05.021.

Ge, J. C., Yoon, S. K., & Choi, N. J. (2018). Application of fly ash as an adsorbent for removal of air and water pollutants. *Applied Sciences*, *8*(7), 1116.

Gerhardt, K. E., Huang, X. D., Glick, B. R., & Greenberg, B. M. (2009). Phytoremediation and rhizoremediation of organic soil contaminants: potential and challenges. *Plant science*, *176*(1), 20-30.

Gupta, A. K., & Sinha, S. (2008). Decontamination and/or revegetation of fly ash dykes through naturally growing plants. *Journal of Hazardous Materials*, *153*(3), 1078-1087.

Gupta, A.K., Verma, S.K., Khan, K., Verma, R.K. (2013). Phytoremediation using aromatic plants: a sustainable approach for remediation of heavy metals polluted sites. - Environmental Science and Technology, 47, 10115–10116.

Hall, J. L., and Williams, L. E. (2003). Transition metal transporters in plants. J. Exp. Bot. 54, 2601–2613. doi: 10.1093/jxb/erg303.

Haydon, M. J., Kawachi, M., Wirtz, M., Hillmer, S., Hell, R., et al. (2012). Vacuolar nicotianamine has critical and distinct roles under iron defciency and for zinc sequestration in *Arabidopsis*. Plant Cell, 24, 724–737. doi: 10.1105/tpc.111.095042.

Haynes, R. J. (2009). Reclamation and revegetation of fly ash disposal sites–Challenges and research needs. *Journal of environmental management*, *90*(1), 43-53.

He, Y., Luo, Q., & Hu, H. (2012). Situation analysis and countermeasures of China's fly ash pollution prevention and control. *Procedia Environmental Sciences*, *16*, 690-696.

Hirshi, K. D., Korenkov, V. D., Wilganowski, N. L., and Wagner, G. J. (2000). Expression of *Arabidopsis CAX2* in Tobacco. Altered metal accumulation and increased manganese tolerance. Plant Physiol., 124, 125–134. doi: 10.1104/pp.124.1.125.

Huggins, F. E., Senior, C. L., Chu, P., Ladwig, K., & Huffman, G. P. (2007). Selenium and arsenic speciation in fly ash from full-scale coal-burning utility plants. *Environmental science & technology*, *41*(9), 3284-3289.

IEA (2016) International Energy Agency. Key coal trends, excerpt from: Coal information. Available at: https://www.iea.org/publications/freepublications/publication/KeyCoalTrends.pdf. Accessed on 05 March 2021.

Inoue, H., Kobayashi, T., Nozoye, T., Takahashi, M., Kakei, Y., et al. (2009). Rice OsYSL15 is an iron-regulated Iron(III)-deoxymugineic acid transporter expressed in the roots and is essential for iron uptake in early growth of the seedlings. J. Biol. Chem., 284, 3470–3479. doi: 10.1074/jbc.M8060 42200.

Izquierdo, M., and Querol, X. (2012) Leaching behaviour of elements from coal combustion fly ash: An overview. Int. J. Coal Geol. 94, 54−66

Jala. S., Goyal, D. (2006). Fly ash as a soil ameliorant for improving crop production – a review. Bioresour. Technol, 97,1136-1147.

Jambhulkar, H. P., Shaikh, S. M. S., & Kumar, M. S. (2018). Fly ash toxicity, emerging issues and possible implications for its exploitation in agriculture; Indian scenario: A review. *Chemosphere*, *213*, 333-344.

Jambhulkar, H., and Juwarkar, A. A. (2009). Assessment of bioacumulation of heavy metals by different plant species grown on fly ash dump. Ecotoxicol. *Envirion. Saf.* 72, 1122–1128. doi: 10.1016/j.ecoenv.2008.11.002.

Jamil, S, Abhilash, P.C., Singh, N., Sharma, P.N. (2009).Jatropha curcas: a potential crop for phytoremediation of coal fly ash. J Hazard Mater,172(1):269-75.

Jarusiripot, C. (2014). Removal of reactive dye by adsorption over chemical pretreatment coal based bottom ash. *Procedia Chemistry*, *9*, 121-130.

Jayasinghe, G.Y. and Tokashiki (2012). Influence of coal fly ash pellet aggregates on the growth and nutrient composition of *Brassica campestris* and physicochemical properties of grey soils in Okinawa, Japan. Journal of plant nutrition, 35(3), 453-47https://doi.org/10.1080/01904167.2012.639924.

Juwarkar, A. A., & Jambhulkar, H. P. (2008). Restoration of fly ash dump through biological interventions. *Environmental monitoring and assessment*, *139*(1), 355-365.

Kim, Y. Y., Choi, H., Segami, S., Cho, H. T., Martinoa, E., et al. (2009). AtHMA1 contribites to the detoxification of excess Zn(II) in *Arabidopsis.* Plant J., 58, 737–753. doi: 10.1111/j.1365-313X.2009.03818.x.

Kisku, G.C., Kumar, V., Sahu, P., Kumar, P., Kumar, N. (2018). Characterization of coal fly ash and use of plants growing in ash pond for phytoremediation of metals from contaminated agricultural land. Int J Phytoremediation, 20(4),330-337.

Kohli, S.J., Goyal, D. (2010). Effect of fly ash application on some soil physical properties and microbial activities. Acta Agrophys,16,327-335.

Kolb, M., and Harms, H. (2000). Metabolism of fluoranthene in different plant cell cultures and intact plants. *Environ. Toxicol. Chem*. 19, 1304–1310. doi: 10.1002/etc.5620190512.

Kosnar Z., Mercl F., Perna I., Tlustos P (2016). Investigation of polycyclic aromatic hydrocarbon content in fly ash and bottom ash of biomass incineration plants in relation to the operating temperature and unburned carbon content Sci Total Environ. 2016 Sep 1; 563-564:53-61.

Kumar, A., Ahirwal, J. Maiti, S.K. and Das, R. (2015). An Assessment of Metal in flyAsh and TheirTranslocation and Bioaccumulation in Perennial Grasses Growing at the Reclaimed Opencast Mines Int. J. Environ. Res., 9(3),1089-1096.

Kumari, A., Pandey, C. V., Rai, N. U. (2013). Feasibility of fern *Thelypteris dentata* for revegetation of coal fly ash landfills. - Journal of Geochemical Exploration ,128, 147–152.

Lanquar, V., Ramos, M. S., Lelievre, F., Barbier-Brygoo, H., Krieger-Liszkay, A., et al. (2010). Export of vacuolar manganese by AtNRAMP3 and AtNRAMP4 is required for optimal photosynthesis and growth under manganese deficiency. Plant Physiol.152, 1986–1999. doi: 10.1104/pp.109.150946.

Lau, S.S.S., Wong, J.W.C. (2001). Toxicity evaluation of weathered coal fly ash amended manure compost. - Water Air and Soil Pollution, 128, 243–254.

Lee, H., Ha, H. S., Lee, C. H., Lee, Y. B., & Kim, P. J. (2006). Fly ash effect on improving soil properties and rice productivity in Korean paddy soils. *Bioresource technology*, *97*(13), 1490-1497.

Li H, Sheng GY, Chiou CT, Xu OY (2005) Relation of organic contaminant equilibrium sorption and kinetic uptake in plants. Environ Sci Technol 39:4864–4870.

Li, L., Tutone, A. F., Drummond, R. S. M., Gardner, R. C., and Luan, S. (2001). A novel family of magnesium transport genes in *Arabidopsis.* Plant Cell,13, 2761–2775. doi: 10.1105/tpc.13.12.2761.

Liu, G., Liu, W., Cai, Z., Zheng, M., (2013). Concentrations, profiles, and emission factors of unintentionally produced persistent organic pollutants in fly ash from coking processes J Hazard Mater2013 Oct 15;261:421-6.

Looney, B. (2020). Statistical Review of World Energy, 2020.

Lopareva-Pohu, A., Pourrut, B., Waterlot, C., Garçon, G., Bidar, G., Pruvot, C., ... & Douay, F. (2011). Assessment of fly ash-aided phytostabilisation of highly contaminated soils after an 8-year field trial: part 1. Influence on soil parameters and metal extractability. *Science of the total environment*, *409*(3), 647-654.

Ma, J. F., Yamaji, N., Mitani, N., Xu, X. Y., Su, Y. H., McGrath, S. P., et al. (2008). Transporters of arsenite in rice and their role in arsenic accumulation in rice grain. Proc. Natl. Acad. Sci. U.S.A.105, 9931–9935. doi: 10.1073/pnas.0802361105.

Mahar, A., Wang, P., Ali, A., Awasthi, M. K., Lahori, A. H., Wang, Q., ... & Zhang, Z. (2016). Challenges and opportunities in the phytoremediation of heavy metals contaminated soils: a review. *Ecotoxicology and environmental safety*, *126*, 111-121.

Maiti, D., and Prasad, B. (2016). Revegatation of flyash-A review on grass-legume plantation and biochemical accumulation of metals. Applied Ecology and Environmental research,14(2),185-212.

Maiti, S. K., Maiti, D. (2015). Ecological restoration of waste dumps by topsoil blanketing, coir-matting and seeding with grass–legume mixture. - Ecological Engineering, 77, 74-84

Mathur, A.K., Kumar, R., Mishra, M., 2008. An investigation of radon exhalation rate and estimation of radiation doses in coal and fly ash samples. Appl. Radiat. Isot. 66 (3), 401e406.

Mati, S. and Jaiswal (2008).Bioaccumulation and translocation of metals in the natural vegetation growing on fly ash lagoons: a field study from Santaldih thermal power plant, West Bengal, India Environ Monit Assess,136(1-3),355-70.

McCutcheon, S. C., and Schnoor, J. L. (2003). *Phytoremediation: Transformation and Control of Contaminants*. Hoboken, NJ: John Wiley and Sons, Inc. doi: 10.1002/047127304X.

Migocka, M., and Malas, K. (2018). Plant responses to copper: molecular and tegulatory mechanisms of copper uptake, distribution and accumulation in plants, in *Plant Micronutrient Use Efficiency. Molecular and Genomics Perspectives in Crop Plants,* eds M. A. Hossain, T. Kamiya, D. J. Burritt, L.-S. Phan Tran, and T. Fujiwara (London: Academic Press; Elsevier, Inc.), 71–86.

Milcu, A., Partsch, S., Scherber, C., Weisser, W.W., Scheu, S. (2008). Earthworms and legumes control litter decomposition in a plant diversity gradient. - Ecology ,89,1872–1882.

Mitrovic, M., Pavlovic, P., Lakusic, D., Djurdjevic, L., Stevanovic, B., Kostic, O., Gajic, G. (2008). The potential of *Festuca rubra* and *Calamagrostis epigejos* for the revegetation of fly ash deposits. - Science of the total environment ,407, 338-347.

Mittra, B.N., Karamkar, S., Swain, D.K., Ghosh, B.C., 2005. Fly ash a potential source of soil amendment and a component of integrated plant nutrient supply system. Fuel 84, 1447e1451.

Mukherjee, I., Campbell, N. H., Ash, J. S., and Connolly, E. L. (2006). Expression profiling of the *Arabidopsis* ferric chelate reductase (*FRO*) gene family reveals differential regulation by iron and copper. Planta,223, 1178–1190. doi: 10.1007/s00425-005-0165-0.

National Research Council (2006) Coal Combustion Residues, in Managing Coal Combustion Residues in Mines, pp 27−58, The National Academies Press, Washington, DC.

Nozoye, T., Nagasaka, S., Kobayashi, T., Takahashi, M., Sato, Y., et al. (2011). Phytosiderophore efflux transporters are crucial for iron acquisition in graminaceous plants. J. Biol. Chem., 286, 5446–5454. doi: 10.1074/jbc.M110.180026.

Odoh, C. K., Zabbey, N., Sam, K., & Eze, C. N. (2019). Status, progress and challenges of phytoremediation-An African scenario. *Journal of environmental management*, *237*, 365-378.

Ozden B, Guler E, Vaasma T, Hoevath M, Kisk M, Kovacs T (2018). Enrichment of naturally occurring radionuclides and trace elements in Yatagan and Yenikoy coal-fired thermal power plants, Turkey, J Environ Radioact, 188:100-107. DOI: 10.1016/j.jenvrad.2017.09.016.

Panda, D., Mandal, L., Barik, J. (2020a).Phytoremediation potential of naturally growing weed plants grown on fly ash-amended soil for restoration of fly ash deposit. Int J Phytoremediation, 11,1195-1203.

Panda, D., Mandal, L., Barik, J., Padhan, B., Bisoi, S.S. (2020b). Physiological response of metal tolerance and detoxification in castor (*Ricinus communis* L.) under fly ash-amended soil. Heliyon, 16;6(8),e04567.

Pandey, V. C., Abhilash, P. C., & Singh, N. (2009). The Indian perspective of utilizing fly ash in phytoremediation, phytomanagement and biomass production. *Journal of environmental management*, *90*(10), 2943-2958.

Pandey, V.C. (2013). Suitability of *Ricinus communis* L. cultivation for phytoremediation of fly ash disposal sites. - Ecological Engineering, 57, 336–341.

Pandey, V.C., Prakash, P., Bajpai, O., Kumar, A., Singh, N. (2014). Phytodiversity on fly ash deposits: evaluation of naturally colonized species for sustainable phytorestoration. -Environmental Science and Pollution Research ,22(4), 2776-2787.

Pandey, V.C., Singh, K., Singh, R.P., Singh, B. (2012). Naturally growing *Saccharum munja* on the fly ash lagoons: a potential ecological engineer for the revegetation and stabilization. -Ecological Engineering ,40, 95–99.

Pati, S.S. and Sahu, S.K. (2003). CO_2 evolution and enzyme activities (dehydrogenase, protease and amylase) of fly ash amended soil in the presence and absence of earthworms (Drawida willsi Michaelson) under laboratory conditions. Geoderma.

Patra, D. K., Pradhan, C., & Patra, H. K. (2020). Toxic metal decontamination by phytoremediation approach: concept, challenges, opportunities and future perspectives. *Environmental Technology & Innovation*, *18*, 100672.

Pedas, P., Hebbern, C. A., Schjoerring, J. K., Holm, P. E., and Husted, S. (2005). Differential capacity for high-affinity manganese uptake contributes to differences between barley genotypyes in tolerance to low manganese availability. Plant Physiol.139, 1411–1420, doi: 10.1104/pp.105.067561.

Punshon, T., Adriano, D.C., Weber, J.T. (2002). Restoration of drastically eroded land using coal fly ash and poultry biosolid. Science of total environment, 196 (1-3),209-25.

Qadir, S.U., Raja, V., Siddiqui, W.A., Zafar, M., Allah, E.F., Hashem, A., Alam, P., Ahmad, P. (2019).Fly-Ash Pollution Modulates Growth, Biochemical Attributes, Antioxidant Activity and Gene Expression in *Pithecellobium Dulce* (Roxb) Benth . Plants (Basel).12,528.

Rai, U. N., Pandey, K., Sinha, S., Singh, A., Saxena, R., & Gupta, D. K. (2004). Revegetating fly ash landfills with Prosopis juliflora L.: impact of different amendments and Rhizobium inoculation. *Environment International*, *30*(3), 293-300.

Rajkumar, M., Ae, N., Prasad, M.N.V, Freitas, H. (2010). Potential of siderophore producing bacteria for improving heavy metal phytoextraction. - Trends in Biotechnology, 28, 142–9.

Ram, L.C., Jha, S.K., Tripathi, R.C., Masto, R.E., Selvi, V.A. (2008). Remediation of fly ash landfills through plantation. – Remediation, 18,71–90.

Reynolds, K.A., Kruger, R.A. and Rethman, N.F.G. (1999). The manufacture and evaluation of an artificial soil prepared from fly ash and sewage sludge. Proc. Intl. Ash Utiliz. Sympos. Lexington, Kentucky, U.S.A., pp. 378-385.

Riddell-Black, D. (1993). A review of the potential for the use of trees in the rehabilitation of contaminated land. WRc Report CO 3467. *Water Research Centre, Medmenham*.

Ritter, S. K. (2016). A new life for coal ash. *Chemical & Engineering News*, *94*(7), 10-14.

Sahu, S.K., Bhangare, R.C., Ajmal, P.Y., Sharma, S., Pandit, G.G., Puranik, V.D., 2009. Characterization and quantification of persistent organic pollutants in fly ash from coal fuelled thermal power stations in India. Microchem. J. 92,92e96.

Sahu, S.K., Pandit, G.G., Sadasivan, S., 2004. Precipitation scavenging of polycyclic aromatic hydrocarbons in Mumbai. India. Sci. Total Environ. 318, 245e249.

Sasaki, A., Yamaji, N., Yokosho, K., and Ma, J. F. (2012). Nramp5 Is a major transporter responsible for manganese and cadmium uptake in rice. Plant Cell, 24, 2155–2167. doi: 10.1105/tpc.112.096925.

Shaheen, S. M., Hooda, P. S., & Tsadilas, C. D. (2014). Opportunities and challenges in the use of coal fly ash for soil improvements–a review. *Journal of environmental management*, *145*, 249-267.

Shigaki, T., Pittman, J. K., and Hirschi, K. D. (2003). Manganese Specifity Determinants in the *Arabidopsis*Metal/H+Antiporter CAX2. J. Biol. Chem., 279, 9091–9096. doi: 10.1074/jbc.M209952200.

Siddiqui Shazia,, Ahmad A, Hayat S 2004.The fly ash influenced the heavy metal status of the soil and the seeds of sunflower. A case study . J Environ Biol. 25(1):59-63.

Sinclair, S. A., and Krämer, U. (2012). The zinc homeostasis netweork of land plants. *Biochim.* Biophys. Acta,1823, 1553–1567. doi: 10.1016/j.bbamcr.2012.05.016.

Singh, A., Sharma, R.K., Agrawal, S.B. (2008). Effects of fly ash incorporation on heavy metal accumulation, growth and yield responses of *Beta vulgaris* plants. - Bioresource Technology , 99, 7200–7207.

Singh, R., Singh, D.P., Kumar, N., Bhargava, S.K., Barman, S.C. (2010).Accumulation and translocation of heavy metals in soil and plants from fly ash contaminated area J Environ Biol, 4,421-30.

Singh, S.J., Pandey, C.V. (2013). Fly ash application in nutrient poor agriculture soils: Impact on methanotrophs population dynamics and paddy yields. - Ecotoxicology and Environmental Safety, 89, 43–51.

Singh. J, and Pandey, V.C. (2012). Fly ash application in nutrient poor agriculture soils: impact on methanotrophs population dynamics and paddy yields. PMID: 23260239 DOI: 10.1016/j.ecoenv.2012.11.011.

Smith, K. R., Frumkin, H., Balakrishnan, K., Butler, C. D., Chafe, Z. A., Fairlie, I., Kinney, P., Kjellstrom, T., Mauzerall, D. L., McKone, T. E., McMichael, A. J., and Schneider, M. (2013) Energy and human health. Annu. Rev. Public Health 34, 159−188.

Sun, Z., Li, H., Bao, W., & Wang, C. (2016). Mineral phase transition of desilicated high alumina fly ash with alumina extraction in mixed alkali solution. *International Journal of Mineral Processing*, *153*, 109-117.

Tao, S., Ciu, Y. H., Xum, F. L., Li, B. G., Cao, J., Liu, W. X., et al. (2004).Polyclic Aromatic Hydrocarbons (PAHs) in Agricultural Soil and Vegetables from Tianjin. *Sci. Tot. Environ*. 320, 11–24. doi: 10.1016/S0048-9697(03) 00453-4.

Thenepalli, T., Ngoc, N. T. M., Tuan, L. Q., Son, T. H., Hieu, H. H., Thuy, D. T. N., ... & Ahn, J. W. (2018). Technological solutions for recycling ash slag from the Cao Ngan coal power plant in Vietnam. *Energies*, *11*(8).

Tripathi, R. D., Srivastava, S., Mishra, S., Singh, N., Tuli, R., et al. (2007). Arsenic hazards: strategies for tolerance and remediation by plants. Trends Biotechnol. 25, 158–165. doi: 10.1016/j.tibtech.2007.02.003.

Tripathi, R.D., Dwivedi, S., Shukla, M.K., Mishra, S., Srivastav, S., Singh, R., Rai, U.N., Gupta, D.K. (2008).Role of blue green algae biofertilizer in ameliorating the nitrogen demand and fly-ash stress to the growth and yield of rice (Oryza sativa L.) plants. Chemosphere, 70(10),1919-29.

Tripathi, R.D., Vajpayee, P., Singh, N., Rai, U.N., Kumar, A., Ali, M.B., Kumar, B., Yunus, M. (2004). Efficacy of various amendments for amelioration of fly-ash toxicity: growth performance and metal composition of Cassia siamea Lamk, Chemosphere, 54(11),1581-8; doi: 10.1016/j.chemosphere.2003.09.043.

Ultra, V.U. (2020).Growth and yield of lemongrass (*Cymbopogon citratus*) in fly ash with nutrient amendments and Mycorrhiza for three-ratoon period. Int J Phytoremediation, 14,1551-1561.

Upadhyay SK, Singh DP, Saikia R (2009) Genetic Diversity of Plant Growth Promoting Rhizobacteria Isolated from Rhizospheric Soil of Wheat under Saline Condition. Curr Microbiol 59:489–496. https://doi.org/10.1007/s00284-009-9464-1.

Upadhyay, S.K., Ahmad, M., Srivastava, A.K., Abhilash, P.C., Sharma, B. (2021) Optimization of eco-friendly novel amendments for sustainable utilization of Fly ash based on growth performance, hormones, antioxidant, and heavy metal translocation in chickpea (*Cicer arietinum* L.) plant. Chemosphere, 267,129216. https://doi.org/10.1016/j.chemosphere.2020.129216.

Upadhyay, S.K., Saxena, A.K., Singh, J.S., Singh, D.P. (2019). Impact of Native ST-PGPR (*Bacillus pumilus*; EU927414) on PGP Traits, Antioxidants Activities, Wheat Plant Growth and Yield under Salinity. Clim Change Environ Sustain, 7(2),157-168.

Verbruggen, N., Hermans, C., and Schat, H. (2009). Mechanisms to cope with arsenic or cadmium excess in plants. Curr. Opin. Plant Biol. 12, 1–9. doi: 10.1016/j.pbi.2009.05.001.

Wong, C. K. E., and Cobbett, C. D. (2009). HMA Type ATPAses Are the Major Mechanism for Root to Shoot Translocation in *Arabidopsis thaliana*. New Phytol., 181, 71–78. doi: 10.1111/j.1469-8137.2008.02638.x.

Wu, Z., Liang, F., Hong, B., Young, J. C., Sussman, M. R., et al. (2002). An Endoplasmatic reticulum-bound Ca2+/Mn2+Pump, ECA1, supports plant growth and confers tolerance to Mn2+stress. Plant Physiol.130, 128–137. doi: 10.1104/pp.004440.ADAA (2018) Annual Production and Utilisation Survey Report. Ash Development Association of Australia (ADAA), http://www.adaa.asn. au/resource-utilisation/ccp-utilisation, accessed 08 March 2021.