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Impacts of Fly Ash on Different Vegetation Near Industrial Areas: A Review

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ABSTRACT

Fly ash pollution is created close to Chhattisgarh's coal-fired thermal power plants, which annually produce 8.7 million metric tonnes of fly ash. Chhattisgarh's thermal power plants have a number of negative effects, including water contamination from fly ash, soil pollution, and air pollution. Waste from thermal power plants, known as fly ash, poses a number of environmental hazards when released into the atmosphere. On the other hand, because of its high porosity, large specific surface area, and other unique characteristics, fly ash can also be used as a low-cost and highly efficient adsorbent for the treatment of environmental pollutants. There are several methods used to control the spreading and disposal of fly ash. Plants have the capacity to establish fly ash in the soil and also control its spreading. These reviews focus on the impact of fly ash on vegetation and their disposal methods.

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INTRODUCTION

Fly ash is a waste product that is produced by coal-fired thermal power stations after generating large amounts of energy. About 57% of the electricity in India is generated by thermal power plants using coal as fuel, where it includes significant levels of ash (up to 40%), sulfur (0.2–6%), and various quantities of heavy metals such as Hg, Mn, Cu, Pb, Ni, Fe, Cr and Cd (Pandey 2015). When coal is burned to produce heat, fly ash and bottom ash make up around 80% and 20%, respectively. According to Murugan and Vijayarangam (2013), fly ash is a finely partitioned waste produced by the burning coal and conveyed by the fuel gases of boilers fueled by pulverised coal. Its current disposal technique, which required large tracts of land as disposal sites, resulted in several environmental issues, such as declining groundwater quality, less productivity of soils, effects on human and animal health, and also effects on the correct functioning of higher plants (Tiwari *et al.* 2019). As fly ash particle sizes range from 0.01 to 100 m (Bhatt *et al.* 2019), it remains above ground when carried by the wind or carried to the dumpsite by trucks.

Although the environmental consequences of waste fly ash are extremely intricate, further investigation and study have been conducted regarding the beneficial and negative impacts of fly ash on different plants and soils. Fly ash deposited on the surface of soil can cause nutritional imbalances and harm microbial populations, diversity, and functions due to its high pH and high metal concentration (Panda 2020). Fly ash promotes the utilization of nutrients by plants, but it also contributes to metal deposits in plants (Gupta *et al*. 2002). Whenever fly ash is applied to soil, comparatively higher quantities of minor minerals such as As, B, Cd, Cr, Ni, Mo, and Se tend to exist (Sharma *et al.* 2002, Manoharan *et al.* 2007). As reported by Yu *et al.* (2019), applying fly ash reduced biomass from plants by an average of 15.2%. Plant biomass was considerably reduced by 45.8% when fly ash was applied at a large rate (50–100%), whereas the medium rate (25–50%) had no noticeable effect on the plants. In response to the application of fly ash, the rate of seedling emergence, stem length, root length, and plant height were reduced (Liu *et al.* 2022).

As a result, to prevent the spreading of contaminants from fly ash, these sites should be properly managed and maintained. Thermal power plants produce different air pollutants (SO_2 and NO_2) through air pollution, which causes acid rain that corrodes structural surfaces. Fly ash has changed from a "hazardous waste" to a beneficial "resource material" as an industrial waste (Dogar *et al.* 2020).

Configuration of fly ash

The thermal energy process inexorably produces by-products, such as fly ash (20%) and bottom ash (80%), which include organic compounds, heavy metals, and chlorides (Dontriros *et al.* 2020, Chen *et al.* 2017). Bottom ash can be used as a building material as it is thought to be less harmful and challenging than fly ash. Since fly ash containing heavy metals can lead to serious health issues, its release is an immediate cause for anxiety (Atanes *et al.* 2019). The burning of coal in the generation of electricity results in enormous amounts of fly ash. The characteristics of fly ash are influenced by the coal's physico-chemical qualities, the method of burning, and other elements i.e., source of coal (Saikia *et al.* 2006). The qualities and chemical nature of fly ash are additionally influenced by the environment, collecting techniques, combustion structure, provenance, and kind of coal supply (Steenari *et al.* 1999). The elements silicon, calcium, aluminium, iron, magnesium, and sulfur oxides are often found in fly ash, along with carbon and a variety of minor elements like Co, Cd, As, Se, Zn, Mo, Mn, Pb, B, Cu and Ni as shown in Table 1. These elements are present in fly ash because of their high melting temperatures, which result in their not volatilizing, and the short period of time spent in the flame through their combustion (El-Mogazi *et al.* 1988). While the inorganic minerals melt and change into liquids or volatiles or interact with oxygen, they also condense as a protective layer on the particles or create solid crystals when they cool (Lubna 2015).

Table 1. Heavy metal concentration in fly ash.

Elements	Concentration (milligram per kg)
Cu	0.92-2.17
Zn	0.77-2.09
Mn	0.68-19.3
Fe	5.90-62.7
Pb	0.06-3.10
Ni	0.43-4.90
Co	0.03-0.46
Cr	BDL-0.54
Cd	BDL-0.28
As	<0.05

The primary fly ash substances typically decrease in the following order : Zn > Pb > Ni >Cu > Noteworthy is the fact that Ni is less volatile than Zn, Cd, Pb, Hg, and As. Because Pb and Zn are quite volatile, they can be converted during the combustion process into $PbCl_2$ and $ZnCl_2$, which will vaporize (Wang *et al.* 2019, Zhang *et al.* 2014). However, Zn is typically contained in stable crystalline form or found in fly ash as Zn_2SiO_4 or $ZnAl_2O_4$, although the synthesis of $ZnCl_2$ is limited (Shi *et al.* 2018, Mojtaba *et al.* 2022).

Coal types affect the component concentration in fly ash

The constituents of fly ash emissions from various coal combustion units are diverse. Coal ash contains all elements with atomic numbers less than 92. Every day, a 500 MW-capacity thermal power plant has emitted 200 million metric tonnes of SO_2, 70 metric tonnes of NO_2, and 500 metric tonnes of fly ash. Fly ash may be used to create zeolite, alum, and precipitated silica due to its high amount of silica (60–65%),

Table 2. Composition of fly ash in different types of coal. Source: https://en.wikipedia.org/wiki/Fly_ash#:~:text=The%20minor%20constituents%20of%20fly,%2C%20lead%2C%20manganese%2C%20mercury%2C.

Component (%)	Types of coal		
	Bituminous	Sub-bituminous	Lignite
SiO_2	20-60	40-60	15-45
Al_2O_3	5-35	20-30	20-25
Fe_2O_3	10-40	4-10	4-15
CaO	1-2	5-30	15-40
LOI	0-15	0-3	0-5

alumina (25–30%), magnetite, and Fe_2O_3 (6–15%) in its chemical composition. Fly ash also has several significant physico-chemical properties that make it an effective adsorbent, including bulk density, particle size, porosity, water holding capacity, and surface area (Tudjono *et al.* 2014). The composition of fly ash depends on the types of coal used by the thermal power plants (Table 2).

Fly ash is made up of particulate matter, which is a source of air pollution. There are several side effects observed due to fly ash, like heart disease, lung disease, respiratory distress, kidney disease, reproductive issues, gastrointestinal illness, birth deformities, and reduced bone growth in children. Fine particles penetrate the pulmonary region of the lungs and stay there for extended periods of time, acting as cumulative toxins. Submicron particles penetrate deeper into the lungs and are deposited on the alveolar walls, where they cause damage (Park *et al.* 2021). Fly ash is employed in a variety of construction projects, such as land filling and restoration, as well as the safe use of fly ash in agricultural areas. Through various biochemical processes and microbial participation, several field and experimental investigations have indicated that fly ash amendment is effective to neutralize soil pH, improve soil texture, and improve the water holding capacity (Alterary and Marei 2021).

Plants provide adequate leaf area for effective adsorption, accumulation, or impingement of air pollutants, reducing pollutants in the surrounding environment. Their capabilities are different for different species (Yadav and Fulekar 2018). The impact of air pollution on a variety of chemical factors such as ascorbic acid concentration, chlorophyll content, and relative water content has been studied (Kamesh *et al.* 2023). According to monitoring studies, dust covers the stomata of vegetation as it spread, having a major effect on the vegetation (Agrawal and Agrawal 2023). Heavy metal leaching into the surrounding soil, as well as surface and groundwater can be controlled by plants that can store metals in their roots or translocation metals from fly ash to the plant's upper portions. Green plant photosynthesis is limited by impediments due to fly ash. Re-vegetation of landfills with fly ash-tolerant plants, which serve the goal of stabilization and producing a pleasing landscape, is a cost-effective and environmentally friendly approach recommended for the management of fly ash (Maiti and Prasad 2016). Fly ash is a byproduct of coal combustion that must be disposed of properly.

Effect of fly ash on soil and plants in the vicinity of a thermal power plant

Effect on soil physico-chemical properties

Various studies were carried out previously on the properties of fly ash. Dwivedi *et al.* (2008) examined the physico-chemical properties of fly ash from the dumping site of NTPC, Tanda, India. Fly ash showed high electrical conductivity, bulk density, strong water holding capacity, and deficiency in other nutrients such as nitrogen, phosphorus, potassium (Table 3). Qadir and Siddiqui (2014) reported the physico-chemical parameters of fly ash around the thermal power plant in Badarpur and found the contaminated sites were higher in metal concentration, pH, electrical

Table 3. Physico-chemical properties of fly ash from dumping sites of the thermal power plant, Tanda, India. (Source : Dwivedi *et al.* 2008).

Parameters	Fly ash
pH	7.77 ± 0.06
Porosity	70.18 ± 4.12
Water holding capacity (%)	61.47 ± 2.66
Total nitrogen (%)	0.048 ± 0.001
Phosphorus (%)	0.66 ± 0.02
Sulphate (%)	13.75 ± 0.58
Potassium (%)	0.97 ± 0.06
Chloride (%)	2.68 ± 0.18
Carbonate (%)	2.07 ± 0.26
Magnesium (%)	1.82 ± 0.09
Total organic carbon (ppm)	0.75 ± 0.007

conductivity, silt, and sand as compared to the uncontaminated sites. Fly ash also contains different essential elements, including both macronutrients P, K, Ca, and Mg and micronutrients Zn, Fe, Cu, Mn, B, and Mo for plant growth. The physico-chemical properties are fly ash depending on the composition of coal and their combustion procedure.

Previous research efforts and directions, as connected to the fly ash influence on diverse vegetation near an industrial site, were referred to base on the literature review. Zhang *et al.* (2019) studied vegetation surveys and the physico-chemical properties of soil around the Feroz Gandhi Unchahar Thermal Power Plant, India. Ten species were chosen for assessment of their relative tolerance to 100% fly ash based on the illustrated inspection of tolerance in the fly ash-polluted area. High biomass output and a deep root system are crucial characteristics to look for when choosing trees for the experiment (Srivastava *et al.* 2014).

The effect of fly ash on soil is mostly determined by the qualities of the specific coal and the soil in the problem area. By raising the quantities of soluble inorganic elements in the soil, fly ash boosts the electrical conductivity of the soil mixture dramatically (Panda and Biswal 2018). The quick release of Ca, Na, Al, and OH ions from fly ash was shown to increase soil pH after an alkaline fly ash treatment (Alterary and Marei 2021). Although fly ash does not retain water on its own, it considerably improves the water holding capacity of the soil combination with fly ash and also improves soil hydraulic conductivity with the addition of a small amount of water. Although fly ash improves the water-holding capacity of soil mixtures, it does not appear to considerably enhance the amount of water available to plants (Dhindsa *et al.* 2016).

Effects on plant growth

Qadir and Siddiqui (2014) studied the behavior of fly ash dust on various plant species at and around the Badarpur thermal power plant fly ash dumping site in Delhi. Three plant species, namely Neem (*Azadirachta indica*), jungle jalebi (*Pithecellobium dulce*), mast tree or Ashoka (*Polyalthia longifolia*), and Sheesham (*Dalbergia sisoo*), were selected for the assessment of leaf area, total chlorophyll, protein, and ascorbic acid content of the plant. The result was that the leaf area of plants decreased in comparison to the polluted and control sites, similarly, chlorophyll content, relative water, and ascorbic acid content of plants decreased in the fly ash dumped area as compared to the control site. Acid rain is caused by SO_2 and NO_2 emitted from thermal power plants, which corrode structural surfaces and may harm agriculture by yellowing green leaves (Sonwani *et al.* 2020). Plants were unable to use Fe and Al in excess; they converted soluble phosphorus molecules into insoluble phosphorus molecules. Strong biomass production, a deep root system, a high growth rate, and a high yield rate are all crucial characteristics to look for when choosing trees for the experiment. Because fly-ash particles are so small, they tend to stay in the air for a long time (Bhatt *et al.* 2019). Under particular humidity levels, fly-ash dust adheres to the leaves or fruits, causing chemical and physical lesions as well as little necrotic dark brown blotches. Fly-ash particles concentrate on the guard cell surface at lower fly-ash deposition rates, activate the stomatal control mechanism, and inhibit its conductance (Dwivedi *et al.* 2008). Thick coatings of fly ash obstruct the flow of water and reduce the light availability for the photosynthesis process, which reduces the rate of photosynthesis. Fly-ash-weighted leaves absorb heat more effectively, resulting in higher transpiration rates as a result of the higher leaf temperature. Shoots of various plant species were performing different functions that were affected by above-ground fly ash particles. Changes in soil characteristics generated by fly ash may have an impact on microbial activity and plant root growth, either directly or indirectly (Parab *et al*. 2015). Many chemical elements of fly ash have been shown to boost plant development in both field and greenhouse tests. Roots of *Beta vulgaris* were cultivated in a fly-ash-added environment. Soil at a modest dose of up to 2% (kg/m^2) was proven to be effective. In fly ash, higher sugar synthesis was stimulated, but lower sugar synthesis was inhibited. Several findings were supported by researchers, including that the doses of 4 and 8% of fly ash were inhibiting sugar synthesis. The negative effects of greater fly-ash applications on plants are mostly due to a change in the soil's chemical equilibrium. Plant roots and rhizospheres are harmed by the high alkaline pH and excess quantities of soluble elements produced by fly ash. The high pH in fly ash poses a threat to the key bacteria involved in nitrogen fixation as well as other crucial functions for plant growth (Ansari *et al.* 2022).

Concentration of metals in plants and their effect

Plants have detoxification or immobilization mechanisms against certain heavy metals, while on the other hand, fly-ash soils are a better option for reclamation. Roots were the first organs to come into contact with poisonous metals in the soil, and the majority of harmful metals can be accumulated in the tissues of the roots. Deposition of metals was hazardous to the root, leaves, and other organs of the shoot (Alengebawy *et al.* 2021). On a larger scale, the impact of fly-ash on plants has been investigated in selected fly-ash landfills or tree-covered regions of dewatered fly-ash landfills, where eight different tree and shrub types were planted. They discovered that survival rates varied between species (12 to 84%) and that significant amounts of B, Ni and Se were found in foliar tissues, as well as that, in some situations, As, Cd, Cu, and Zn were also present (Kafle *et al.* 2022). There were four different tree species planted in an isolated fly-ash basin in South Carolina with low natural vegetation. On the alkaline fly-ash site, plant survival was higher as compared to the control location in these field trials. They also found higher amounts of B, Cr, Co, Cu, and V in the trees grown on the fly-ash location, but lower levels of Mo and Mn (Ansari *et al.* 2022). Boron in fly ash is readily available to plants and has long been seen as a limiting issue in the use of plants cultivated in fly ash adjusted with press mud, which has the highest concentration of various metals, such as unweathered fly ash Cu, Fe, Zn and Ni (Sonwani *et al*. 2020). Metals readily available have already been linked to a decrease in the pH of fly ash after adding press mud, which can be found in fly ash. The accumulation of heavy metals and metalloids by the chosen plants indicated a distinct pattern of accumulation in different plant species, with a few exceptions. Diverse plants and algae showed the greatest concentration of iron.

Tree response against the fly ash

Plants have a dual effect of promoting and inhibiting growth. Because fly ash is nitrogen-deficient, its use, especially at greater concentrations, causes a severe nitrogen deficit in the soil and plant tissue, which is a major cause of small growth and production. Acacia species and *Leucaena leucocephala* have been demonstrated to tolerate and thrive in arid, infertile, metal-contaminated environments (Ssenku *et al.* 2017). Moreover, legume plants and symbiotic nitrogen-fixing bacteria can work together to help barren soils improve their nitrogen (N) content. Several agricultural crops and leguminous trees have benefited from the use of fly ash (Gajić *et al.* 2018). When *Cassia siamea*, *Acacia auriculiformis*, and *Leucaena leucocephala* are grown in fly-ash and fly-ash-supplemented soil, antioxidants and metal-detoxifying capacity have been discovered. The study also found higher levels of trace elements in sweet gum (*Liquidambar styraciflua*) and sycamore (*Platanus occidentalis* L.) trees cultivated in two coal fly ash basins. The impact of Phytoremediation was measured using plant morphology and biomass characteristics. In the *Bambusa textilis* region, plant growth was higher in the mixed plantations than in the monoculture plantations. The diameter at breast height, leaf width, and coverage of *Bambusa textilis* were limited in the mixed plantation due to species competition, but the total growth of *Miscanthus sinensis* and *Bambusa textilis* plantations was greatly improved (Zhang *et al.* 2019). Ssenku *et al.* (2017) were studied on ten tree species grown in a 100% fly ash site, and the results reported the best growth of *Bauhinia variegata*, *Cassia siamea*, *Leucaena leucocephala*, *Pithecolobium dulce*, *Prosopis julifora, Syzigium cumini* and *Terminalia arjuna* as compared to others such as *Azadirachta indica*, *Dalbergia sissoo, Delonix regia* and *Morus alba*.

Fly ash used for biosorption

Pollution of the air, soil, and water is a major problem in today's world, with the pollution of the water supply, in particular, raising serious concerns. Aside from a scarcity of water, the development of vast quantities of wastewater has placed a lot of strain on humanity (Aigbe *et al.* 2021). The burning of coal and biomass in thermal power plants produces massive quantities of ash residues. Globally, approximately 750 million metric tonnes of coal ash (CA) and 480 million metric tonnes of biomass ash are generated annually, according to conservative estimates (Dogar *et al.* 2020). A novel magnetic Schiff's based-chitosan-glyoxal/FA/Fe_3O_4 (Chi-Gly/FA/Fe_3O_4) NC prepared by the direct composition of magnetic Chi with FA powder particles and the subsequent cross linking reaction of Gly with Schiff's base formation was employed in the removal of reactive orange 16 (RO16) (Aigbe *et al.* 2021). Modified FA (MFA), prepared by using a 2-phase technique involving oxalic acid reduction, was used for the elimination of Cr (VI). The PSO and LIMs best define the sorption of Cr (VI) to the modified FA, and the maximum sorption capacity was 12.34 mg/g (Jiang *et al.* 2019). Pre-treatment of live *Aspergillus niger* biomass with sodium hydroxide, formaldehyde, dimethyl sulfoxide, and detergent resulted in considerable improvements in lead, cadmium, and copper biosorption as compared to live *Aspergillus niger* cells. Fly ash can also be used for sewage treatment (Ahmad *et al.* 2015).

Coal-based thermal power plants fly ash management

All of the heavy elements contained in fly ash (Ni, Cd, Sb, As, Cr, Pb, and so on) are poisonous in nature. There are two approaches to disposing of fly ash: Dry and wet. India : 44.76% for cement, 16.72% for reclaiming land, 9.1% for mine filling, 6.89% for raising ash dykes, 6.86% for bricks and tiles, 6.5% for roads and embankments, 0.7% for concrete, and 7.38% for other applications shown in Fig. 1 (Yao *et al.* 2015).

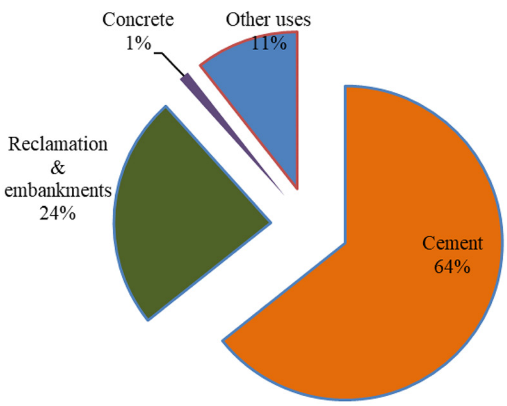

Fig. 1. Graphical representation of fly ash uses in India (Yao *et al.* 2015).

Wet disposal of this material, according to studies, does not safeguard the environment from metal migration into the soil. Heavy metals, unlike other organic trash, cannot be reduced naturally into harmless compounds. Qadir *et al.* (2021) reported several disposals and/or uses of coal fly ash, such as landfills, the construction of bridges, and making bricks. According to the Hazardous Waste Management and Handling Rules of 1989, fly ash is a non-hazardous substance. The current method of storing fly ash used by thermal power plant companies is in ash ponds (usually in the form of slurry) and dry, open areas. In 2020, the cost per MW of electricity was expected to be 0.6 hectares required for the dumping of fly ash.

Ash disposal method

An ash disposal system needs to be planned at the conceptual stage of any project. There are two types of ash disposal methods used (Harja *et al.* 2020), i.e., wet disposal or dry disposal system.

Dry disposal system: Dry extraction is used to provide dry ash without combining it with water. According to the dry ash extraction system, the ash that has accumulated in the ESP hoppers is extracted in dry form using either a vacuum system or a pressure system and then sent to a buffer hopper next to the ESP. Ash is put in a specified location and moved via conveyors in a restricted manner. Plantation is done to reduce the movement of dust (Ashfaq and Kaifiyan 2016).

Wet disposal system: The ash mixture is brought to the dumping area once the ash and water are fully combined. Lean concentration slurry disposal (LCSD) and high concentration slurry disposal (HCSD) are the two procedures used in wet disposal systems. Based on the technology scanning, discussion with experts, and visits to some of the power plants, the recent revolution in the area of wet disposal is HCSD with reduced water content (Nieva *et al.* 2019).

Management of ash disposal

Lagooning arrangements on the allowed area, disposal techniques, ongoing inspections, maintenance checks, and a commitment to safe disposal are all part of the management of safe ash disposal by wet disposal. Preventive actions are given top attention so as to reduce the probability of failure. The following are a few suggestions to aid in the effective management of fly ash in thermal power plant disposal areas (Naresh, 2010).

For a 500 MW unit, the MoEF has stipulated that the amount of land needed for backup fly ash storage at thermal power plants can be up to 50 hectares (or 125 acres).

To avoid groundwater pollution.

Toe drains are installed all along the outer dyke's perimeter to collect seepage water from storage lagoons and either direct it to the nearest natural drain or channel or pump it back to the OFL for recirculation in order to prevent pollution of neighbouring crops.

Decantation water escape structures, methods of disposal, and recirculation of decanted water are offered as needed.

When it comes to wet disposal, the type of dyke, building method, discharge planning, and dyke construction must all be done in a way that ensures the generation is never negatively impacted by a discharge's geographical region.

CONCLUSION

For the sake of the future, it is critical to manage fly ash from various sectors. There have been numerous articles indicating that fly ash is harmful to humans, plants, and the environment. There are different areas of disposal and uses of fly ash, such as the biosorption of pollutants, land filling, cement industries. Also, plants play a significant role in minimizing the adverse effects of fly ash. Re-vegetation of landfills with fly ash-tolerant plants, which serve the goal of stabilization and producing a pleasing landscape, is a cost-effective and environmentally friendly approach recommended for the management of fly ash.

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