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ASHES ON EARTH: ECOTOXICOLOGICAL EFFECTS OF FLY ASH ON NATURE'S WEB

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ABSTRACT

Ash is a by-product of Thermal Power Plant, now it has become one of the worst Environmental pollutants in the World. The amount of generated Quantity of Ash is more than the food production per day. Ash is generated into 3 forms i.e. Fly Ash, Medium Ash and Coarse Ash. Medium Ash and Coarse Ash is settleable due to the weight but Fly Ash is light as dust which is not able to capture in filters. This study focuses on the Fly Ash, basically Fly Ash contains Silica, Alumina, Iron Oxides, Heavy Metals and other trace elements such as Arsenic, Lead, Cadmium and Barium. The Fine particles of Ash are capable of Air borne, water borne and soil borne diseases. This study shows the Evaluation of Air, Water, Land, Biodiversity Flora and Fauna. The results shows that Adverse effect on the Ecosystem. The paper concludes that the Fly Ash pollution is not only an Environmental Issue but also a moral change demanding immediate sustainable management.

Keywords: Fly Ash, Heavy Metal, Pollution Control, Quantitative, Qualitative Analysis

1. INTRODUCTION

Coal based Thermal Power Plants nearly generates 70% of India's electricity but their carbon footprint is immense. The coal combustion generates a large volume of Ash; fine particle Fly Ash is more hazardous as compare to others. The Ash restudies poses long term Environmental Impact and Hazard. Fly ash concretes have displayed improved strength and durability. Capability of fly ash as a suitable reagent to sequester atmospheric carbon dioxide is established research finding. Fly ash after carbonation is referred to as carbonated fly ash, whose application areas are limited to few fields such as mines and agriculture. Use of carbonated fly ash in concrete has not yet been reported in literatures. In the present research feasibility of using carbonated fly ash as a part

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substitute of cement in concrete has been investigated. Newline in the present research and experiments are done to determine compressive strength, flexural strength, split tensile strength of carbonated fly ash concrete over a wide range of water curing age (Sanjukta Sahoo, 2016). According to Central Electricity Authority, India generates nearly 232 million tonnes of Fly Ash in 2022-23 of which approximately 35% remains unutilized. Usually, power stations dispose excess ash using water into ponds/dykes which is called as 'pond ash'. American Society for Testing and Materials (ASTM) categorized Fly ash into two types subject to the nature of raw coal used to burn for energy/electricity generation. The difference lying in types of Fly ash is based on amount of Silica Oxides (SiO2), Aluminium and Iron Oxides (Al2O3+Fe2O3) present in fly ash. If the amount total of these oxides is more than 65% it is identified as Class F Fly ash, but if the totality is between 50%-70% in that case it is Class C Fly ash (ASTM C 618, 1993). The major difference between Class 'F' and Class 'C' fly ash is in the amount of Calcium, Silica, Alumina, and Iron content in the ash. In Class 'F' fly ash, total Calcium typically ranges from 1 to 12 percent, mostly in the form of Calcium Hydroxide, Calcium Sulphate, and glassy components in combination with Silica and Alumina. In contrast, Class 'C' fly ashes have reported Calcium Oxide contents as high as 30 to 40 percent. Another difference between Class 'F' and Class 'C' is the number of Alkalis (combined Sodium and Potassium) and Sulphates (SO4) which are generally higher in the Class 'C' fly ash than in the Class 'F' fly ash (Raj Kishore Singh, 2013)

Ecotoxicology: It studies the impact of toxic substances on Ecosystem, it provides a framework for better understanding of Cause, Impact, Risk and Measures. Fly ash particles are particularly spherical in shape and are very fine with size varying from 0.01 to 100 µm. They are transparent and have glassy appearance as the Silicate in fly ash melts at the time of combustion (Young, 1993; Adriano et al, 1980). So, lower the content of carbon present on fly ash, lighter is the colour of its particles. The surface of fly ash particles is smooth, immensely porous and hydrophilic in nature (Campbell, 1999; Bosch, 1990; Iyer, 2002; Fatoba 2010). Mined coal conventionally has some trace number of toxic metals such as Ni, Pb, Cu, Cr, Co, As, Mo, Zn, Hg, Cd and other organic elements that are exposed during combustion of coal and therefore gets accumulated in fly ash. Fly ash contains several carcinogens and neurotoxins like Arsenic, Lead, Selenium, Mercury, Chromium. When these heavy metals leach out and enter water bodies they tend to bio accumulate in further trophic levels and in due course of time results in bio magnification too. Heavy metals present in fly ash have been identified to edge the survival and development of plants and microbes in soil (Rai et al, 2004).

Several studies highlight the severe consequences of Fly Ash contamination:

- Soil Impacts: The fly ashes have pozzolanic activity because they contain surplus amount of Silica, Alumina and Iron Oxide, they have a structure with very fine particles and amorphous. Materials with Silica and Alumina in the structure of fly ashes make additional

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Calcium Silicate Hydrate (C-S-H) by reacting with Calcium Hydroxide occurring as a consequence of hydration of the cement. The resultant C-S-H gels cause increase in strength of the concrete. Furthermore, the fact that flies' ash contains very fine particle increases compactness in the concretes or mortar and causes filling of the spaces. Using the fly ash in the concrete generally increases the workability of the fresh concrete, decreases the breading, decreases the hydration temperature, decreases the permeability of the hardened concrete, increases resistance of the concrete to the chemical effects, and decreases the costs (ACI Committee 1987; Erdogan 1997; Chindaprasirt et al. 2005; Toutanji et al. 2004).

- Water Impacts: The metals present in fly ash are in priority pollutants list as their leaching potentials have been expected to be high. It is recognized that health hazards and environmental impacts from thermal power plants result from the mobilization of toxic and radioactive elements from the residues, which intern mainly depends on meteorological parameters. Contaminated leachates from acidic fly ashes can pose the highest toxicity problem for aquatic environments (Roy et al., 1984). Nontoxic soluble elements will dissolve first in water or weak acids (Hulett et al., 1980), but long-term leaching of toxic trace elements is associated with slow mobility of elements from glass, magnetite and related minerals (Dayan and Paine, 2001)
- Air Impacts: Fly Ash contributes up to 30% of ambient PM10 in thermal power dominated cities (CPCB,2021). In general, the term 'particulate' refers to all atmospheric substances that are not gases. Particulate Matter includes those air pollutants, which may be in the form of solid particles or liquid droplets including fumes, smoke, fog, dust, pollen grains, bacteria, viruses and aerosols. This category includes about 5 percent of the weight of all pollutants present in the atmosphere. Natural dust forms about half of the total mass of particulate matter in the air. It is estimated that about 8 million tons solid particles penetrate into the atmosphere everyday (Sethi era/., 1991).
- Impacts on Flora: The chlorophyll a, chlorophyll b, total chlorophyll and carotenoid content in general was found to increase from control to T4 (80%, 184.76%, 43.32% and 44.4% respectively) followed by a 31 decrease in the same from T4 to T6 (81.9%, 86.74%, 79.48%, 57.91% respectively). Fly ash on addition in soil is reported to decrease bulk density, improve soil porosity, increase water-holding capacity, decrease surface encrustation change soil pH and increase the electrical conductivity of soil (Chang et al. 1977; Page et al. 1979; Elseewi et al. 1980).
- Impacts on Fauna: Dairy cattle grazing near disposal sites in Maharashtra showed elevated lead levels in milk, indicating Bioaccumulation.

  From a spiritual perspective, we have our 5 Elements *Prithvi* (Earth), *Jal* (Water), *Vayu* (Air), *Akash* (Sky) and *Agni* (Fire) as a sacred. Polluting these *Panchtatva* which is

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sustaining life elements of the Earth. Industrial Waste is not just a Concern but a breach of Humanity's responsibility to Nature.

2. METHODOLOGY

2.1 Sampling

Fly Ash samples were collected from Generator Units, Ash Pond First, Second, Third and Cooling tower. Fly ash particles constitute elements like Silicon, Calcium, Iron, Sulphur Oxides, Aluminium, Carbon and many trace metals like Cu, Co, Zn, Se, Pb, B, Ni, As, Cd, Mn and Mo. These trace elements are existing in fly ash owing to higher melting point as the other inorganic minerals melt during combustion forming fluids which react with oxygen and at the time of cooling that is post combustion zone form spherical, crystalline particles (Kutchko and Kim, 2006; Fatoba, 2010).

Image: Map of Koradi Power Plant and 3 Ash Ponds

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- Fly Ash sampling:

Sr. No	Location	In kgs	Type of Sample
1.	Koradi Power Plant (Fly Ash)	10kgs	Grab
2.	Koradi Power Plant (Medium Ash)	10kgs	Grab
3.	Koradi Power Plant (Coarse Ash)	10kgs	Grab

Soil Samples were collected from Koradi Village, Maha-Genco housing quarters, Ash Pond first, second and third. Fly ash pH mainly is determined by the sulphur amount in the parent/raw coal varying from 4.3 to 11.9 9 (Mattigod et al., 1990). As studied by (Adriano et al., 1980) fly ash is rich in lanthanum, mercury, chromium and cobalt which decreases with increasing particle size. In a study conducted by (Arivazhagan K. et al., 2011) on fly ash effect on agricultural crops it was revealed that fly ash use augmented the yield of cereal crops increasing it from 15-20%; for sugarcane it was 20-30%, in maize up to 40%, potato showed an increase of 25%, red gram to about 50%, various plantation crops and maize to 30%.

Soil sampling:

Sr. No	Location	In kgs	Type of Sample
1.	Panjara Colony	2kg	Composite (6 spots)
2.	Mahadula	2kg	Composite (5spots)
3.	Koradi Village	3kg	Composite (8 spots)

- Water samples were taken from Surface water, Koradi Lake, Koradi Training centre Pond, Mahadula Borewell, Panjara colony Borewell and well source.

Sr. No	Location	In Litres	Type of Sample
1.	Koradi Lake	15lit	Composite (3 spots)
2.	Koradi Training Centre Pond	15lit	Grab sample
3.	Mahadula Borewell	15lit	Grab sample
4.	Panjara Colony Borewell	15lit	Grab sample
5.	Ash Pond Borewell	15lit	Grab sample

- For BOD samples are collected in DO Bottle with fixers under controlled temperature.
- Air samples were taken from 100m and 500m distance for 8hours and 10m and 50m for 4 hours.
  High Volume Air Sampler is used for the sample collection.

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2.2 Parameter Studied

- Soil: Heavy Metals (Pb, Cr, Cd, Ni, As, Al, Si, Fe)

Image: Soil analysis by Gravimetric method

- Water: pH, TDS, DO, COD, BOD, TOC, Heavy Metals (Cr, Pb, S, Cd, Ni, Al, Si, Fe)
- Air: SPM, PM10, PM2.5 concentrations
- Fly Ash: Concentration in Soil and Water
- Heavy metals Analysis: Al, Pb, Cr, Cd, Ni, As, Co, Cu, Fe, Ba, Se, Mn, Si, Zn

2.3 Analytical Techniques

- Heavy Metals: Atomic Absorption Spectrophotometry, Induced Coupled Plasma - Mass spectrophotometer, ICP – Optical Emission Spectroscopy
- TS: Gravimetric Method
- COD: Closed Reflux Titrimetric Method
- BOD: 5-day BOD Test (Incubation and DO Method)
- TOC: TOC Analyzer
- SPM: High Volume Air Sampler (Gravimetric Method)

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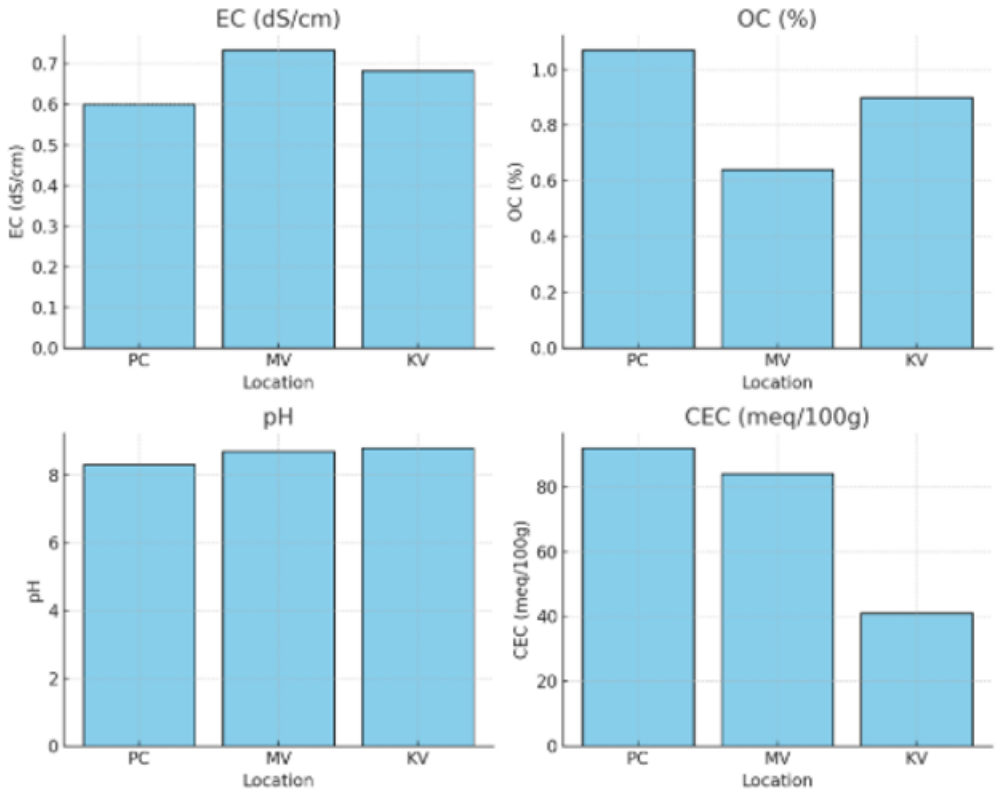
3. RESULTS

3.1 Soil Contamination

- Analysis and Interpretation by ANOVA



- Electrical Conductivity (EC):
  Highest at MV (0.734) → slightly more saline compared to PC and KV.
  Overall, all values are within safe limits (non-saline soil).
- Organic Carbon (OC):
  Highest at PC (1.07%), indicating richer organic matter and better fertility potential.
  MV has lower OC (0.64%), which suggests less organic content.
- pH:
  All soils are alkaline (8.3–8.8), slightly higher in KV and MV.
  Alkalinity could reduce micronutrient availability (like Fe and Zn).
- Cation Exchange Capacity (CEC):
  PC (92) has the highest nutrient-holding capacity, while KV (41) is much lower, indicating lighter or less fertile soil.

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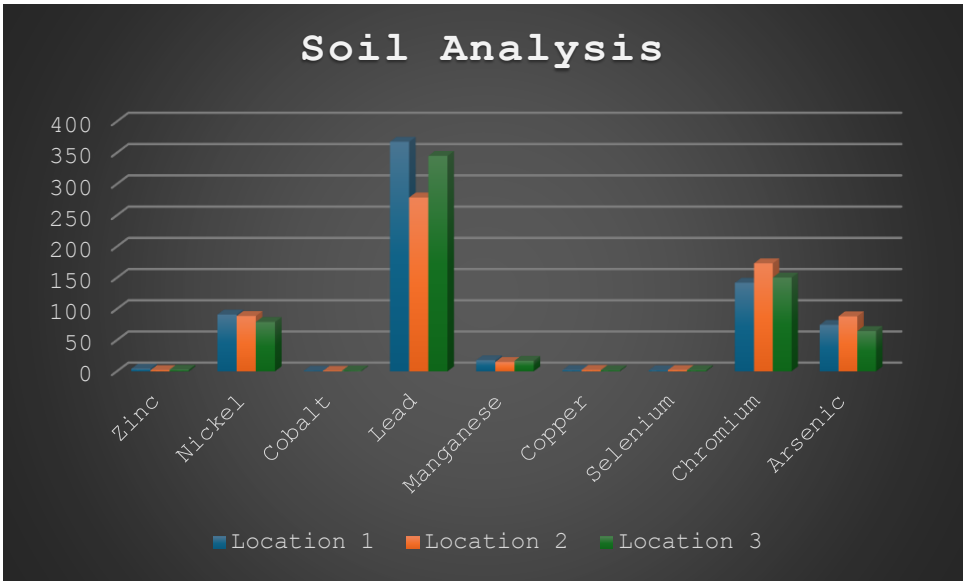
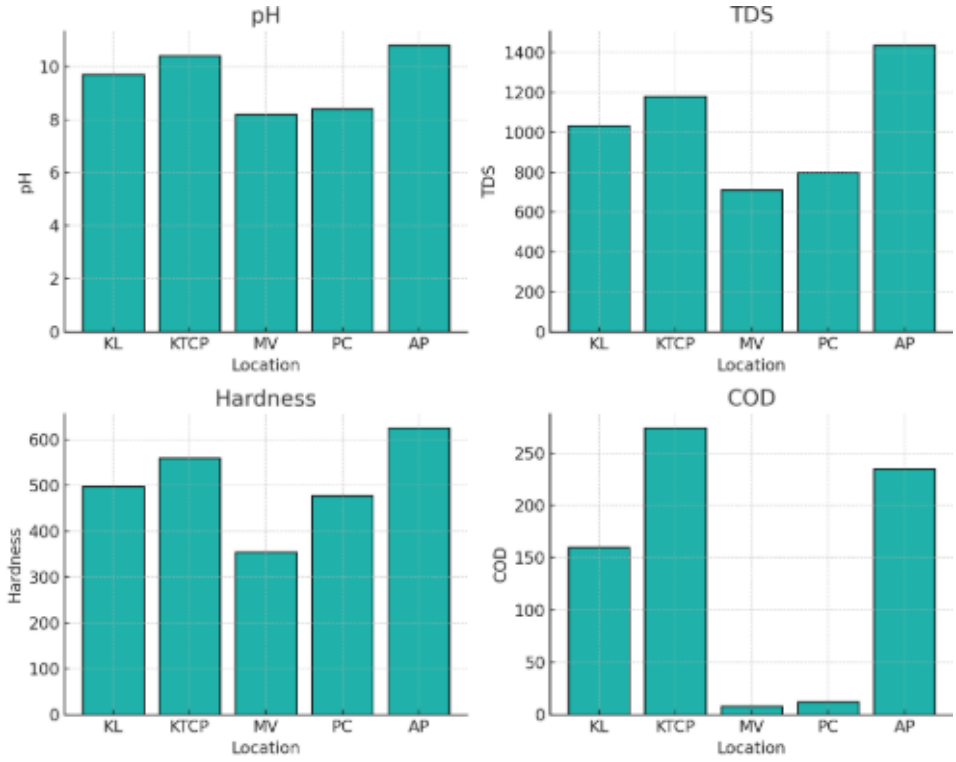


Graph: Heavy Metal analysis of Soil sample

3.2 Water Pollution

Analysis and Interpretation by ANOVA



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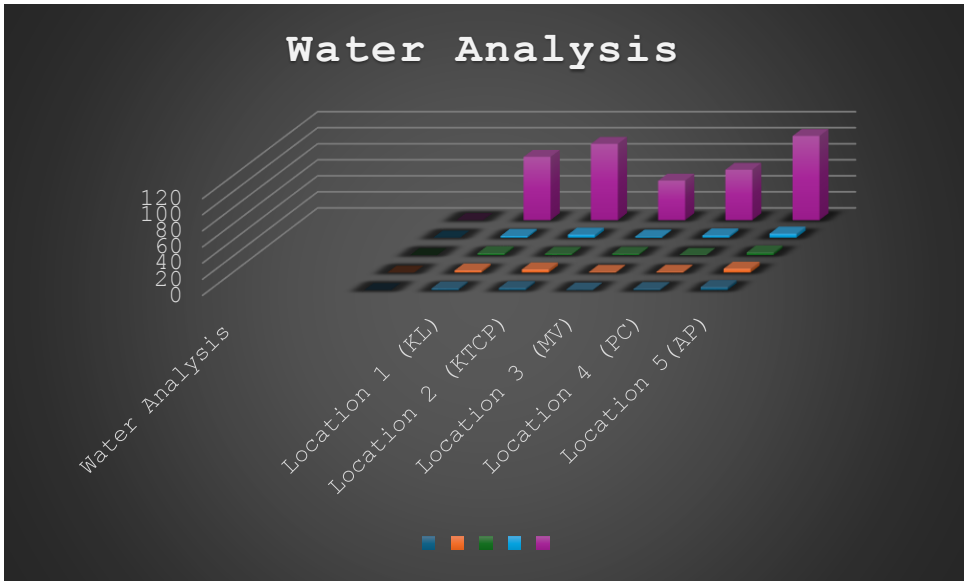
- pH:
  All samples are alkaline (8.2–10.8), exceeding the WHO safe limit of 6.5–8.5 for drinking water.
  Highest pH is at AP (10.8), indicating possible contamination from alkaline industrial waste or fly ash leaching.
- TDS (Total Dissolved Solids):
  Ranges from 712–1436 mg/L — most exceed the acceptable limit (500 mg/L).
  AP (1436) and KTCP (1179) have the highest TDS, implying higher mineral and ionic content, possibly due to saline or pollutant inflow.
- Hardness:
  Varies between 354–626 mg/L, all exceeding the permissible limit (300 mg/L), categorizing the water as very hard.
  High hardness could originate from calcium and magnesium leaching or fly ash interaction with groundwater.
- COD (Chemical Oxygen Demand):
  Drastically varies — KTCP (274) and AP (235) show very high COD, suggesting strong organic and chemical pollution.
  In contrast, MV (8) and PC (12) indicate much cleaner water.



Graph: Heavy Metal Analysis of water from 5 different locations nearby thermal power plant

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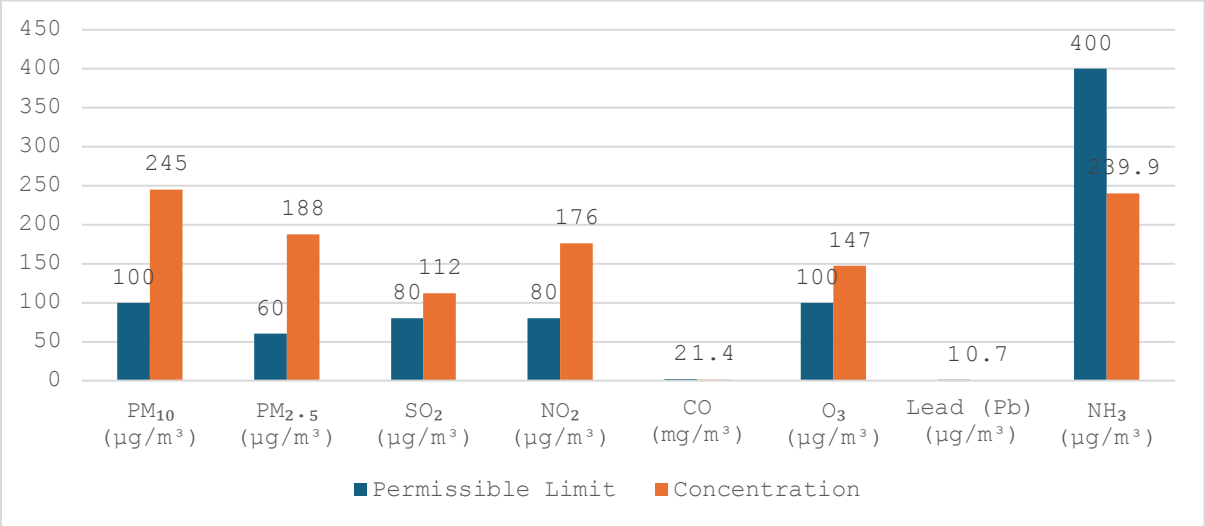
3.3 Air Quality

- Fine ASH particles carried up to 8km downwind



Graphical representation of Ambient Air Quality around Thermal Power Plant

3.4 Effects on Flora

- Tree shows the Leaf Chlorosis
- Reduction in Chlorophyll content and damaged roots
- Ash soil blocks the growth of Tree

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Image: Leaf Chlorosis due to Fly Ash Deposition

3.5 Effects on Fauna

- Dairy cattle grazing near Ash ponds:
- Reduction in Milk production of Cow, Buffalo and Goat
  Deformities in new born from recent 5,6 years
  Increasing cases of Infertility and Weight Loss
  Increase in number of Tumour cells and Cancer cell tumour
  Increase in Death of Cattle
  Skin Irritation and Eye Irritation
- Fish productivity:
- Decrease in survival rate of Fishes
  Increase in Death ratio
  Increase in sick fishes
  Increase in Weed production which leads to death of Fishes
- Migration of Bird species
- Decrease in number of Peacock

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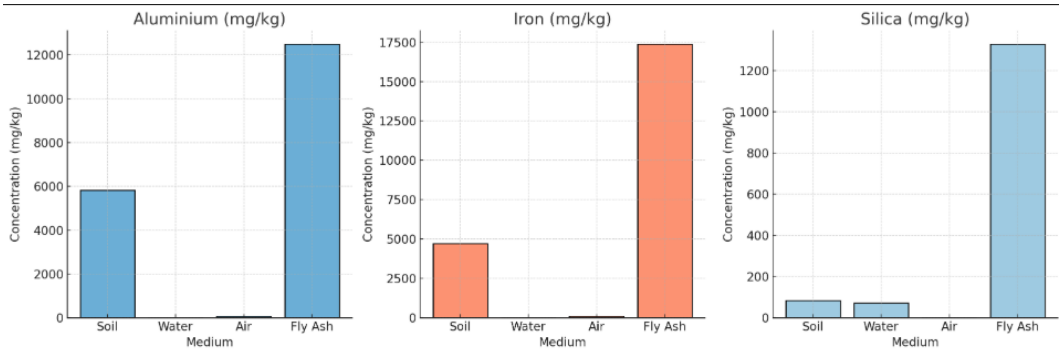
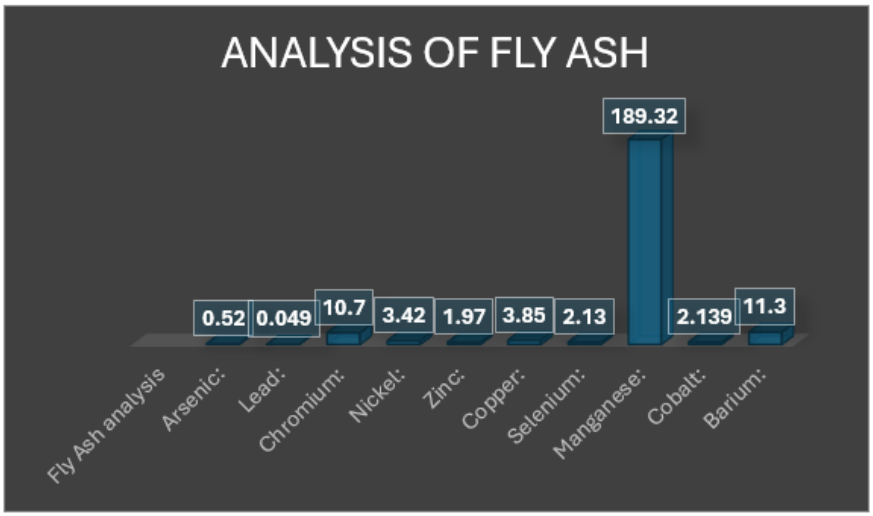
3.6 Fly Ash (Concentration)

- **Concentration of Oxides**



- Fly ash shows extreme enrichment of all oxides, particularly Iron (17,379.83 mg/kg) and Aluminium (12,498.32 mg/kg) — indicating heavy metal accumulation and particulate deposition from combustion residues.
- Soil has moderate concentrations, confirming secondary contamination due to fly ash leaching and deposition.
- Water exhibits trace oxide levels, but Silica remains relatively higher, likely due to solubilization from ash leachate.
- Air has low oxide concentrations, yet Iron dominates due to fine particulate suspension in emissions.
- Analysis of Fly Ash was found to be 4.07 mg/kg in sample.



Graphical representation of Heavy Metals in Fly Ash

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4. DISCUSSIONS

"Air, Water, Soil and Biota are tightly coupled through the deposition of runoff/leaching and biological uptake. The Results Confirm that fly Ash poses Heavy Metals and Toxic elements which poses high risks to Environment (5J) *Jal, Jameen, Jungle, Janwaar and Jan* i.e. Water, Land, Forest, Animals and People. The entire Biosphere is in Threat, Atmosphere, Lithosphere and Hydrosphere. The relationship between the Air, Water and Land makes the Environment living for Creatures. Nutrient enrichment from atmosphere and agriculture increases aboveground biomass but often reduces soil microbial diversity and changes functional gene profiles (favoring fast-growing microbes), which alters decomposition and carbon cycling (Yunfeng Yang 2022). The Air Pollution leads to Acid Rain, which pollutes Water and Land. Industrial/mining discharges produce heavy-metal loadings in soils and water; these transfer into food webs and pose human health risks (Zahra Pournuroz Nodeh 2024). The Process of evaporation helps in contaminating air; it adds volatile pollutants. Same contaminated water is used in agricultural practices which degrades fertility of soil and affects the count of microbes. Long-term N deposition changed microbial community composition and increased genes for labile C degradation (Ma X. et al., 2022 (Microbiome) — global/experimental sites). The Agricultural Dust and burning process pollutes air with volatile compounds and partially combustible dust. As Airborne pollutants move towards the water and land due to the gravitation. This is a cyclic process, directly three of them are in a chain; if one sphere gets polluted it contaminate other two sphere as well. Living Organisms are completed depended on Air, Water, Land. As plant absorbs the nutrients and water from the soil, the contaminated soil transfers the contamination to plant, it effects on animal and human health. Contaminated water increases the health risk and diseases. Airborne microplastics and PFAS get deposited into soils and water and persist, adding a cross-compartmental pollutant that affects organisms across trophic levels (Yuxin Wang, 2024). Air is the fastest means of transport to pollutants. Fly Ash, flies so fast and far with the air direction and speed. Airborne MPs/PFAS deposit to soils/water; environmental factors control deposition and persistence (Wang et al., 2024 Science of the Total Environment review). The Increase in Soil fertility leads to accumulation and percolation of Heavy metals. The contamination soil led to losing Root holding and Water holding capacity which gradually increase soil erosion and flooding. The Fly Ash Pond are in 11,782 sq. km area which contaminate the groundwater and aquifers via percolation. For the construction of Fly Ash Pond Forest land is deforested, the damage to flora and fauna is maximized. Air Quality is depleting due to continues 20 hrs of working with 3 steam cooling towers and 1 Fuel smoke tower. The Agricultural field get damaged due to the sedimentation which led to Leaf Chlorosis. The pH, EC and CEC were increased gradually as levels of fly ash were increased gradually in soil. The rise in pH actually depends primarily on soil buffering capacity. The increased pH was also observed in many studies when fly ash levels were increased gradually (Brahmachari et al., 1999; Khan and Khan, 1996; Menon et al., 1990; Page et al., 1979; Tripathy and Sahu, 1997).

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5. RECOMMENDATIONS

Fly ash has proven to be useful for agricultural purposes as opposed to current use by farmers that is almost negligible. Awareness must be created in farmers as supported by (Arivazhagan K. et al., 2011) for application of fly ash in agricultural purposes thus we can solve two problems at the same time primarily of disposal of fly ash and secondarily upgrading socioeconomic stature of farmers.

1. Safe Disposal of Fly Ash
   Cement companies should use all the 3 types of Ash which will reduce the amount and concentration of Cement in Building materials.
   Improve storage and Handling
   Design for fixed bed adsorption column in Cooling towers

2. Soil Remediation
   Conversion of Infertile soil to Fertile soil by Phyto-remediation.
   Use of Organic matter for restoration of soil

3. Water Pollution
   Construction of Wet Lands
   Regular Groundwater Monitoring and Testing
   Water Plants: Lotus, Duck weeds and other species
   Iron removal hand pump
   Filtration unit for Arsenic and Fluoride

4. Air Quality Management
   Use of Electrostatic Precipitators and Bag filters with regular maintenance and cleaning
   Tree Belt around power plant species: Sunflower, Tal, Bamboo, Sandalwood, Ashoka, Butea monosperma, Limonia ascidissima, Recinius communis, Ficus religiosa (*Peepal*), Ficus racemosa (*Avdumbar*) and Ficus benghalensis (*Banyan*)

5. Fauna Conservation
   Restriction on grazing cattle near the Ash ponds
   Regular check-up of Cattles

6. Policy-Level
   Strict Regulatory Frameworks
   Proper Packing and Monitoring of Fly Ash during Transportation
   Increase the Utilization of Ash in replacement of Concreate cement
   Promotion of Circular Economy
   Research and Innovation support

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7. Community-Level
   Awareness among the local communities
   Public Participation
   Maintaining Rules and Line of thermal Power Plant for their safety
   Eco-restoration Initiatives at Individual level
   Youth Involvement for better understanding and participation
   Focus on Alternatives not on Arguments

6. CONCLUSION

Fly Ash pollution creates Environmental risks and Hazards

The Fly Ash and River sand is found to be 4.73 x 10-5 mm/sec and 2.38 x 10-4 mm/sec, respectively. The Ambient Air Quality of Thermal Power Plant has a mix pattern which exceeds than the prescribed limits. Increasing number of Major oxides and Trace elements causing effect on Environment, polluting Groundwater which breaks the irrigation practices, Bioaccumulation of Trace elements and Heavy Metals in Aquatic ecosystem and Food Chains.

Image: Fly Ash analysis in water by Gravimetric method

The Farmers are facing major issue due to the poor quality of product and that leads to increasing the use of Fertilizers and Pesticides. The High risk of Diseases, syndromes and Deformities in new

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born. After thorough study of different fly ashes, Pathan et al. (2003) suggested that the moderate rates (5 to 10% w/w) of fly ash may be the most appropriate for use in fields. Application of fly ash up to 10% in soil had significant improvement in the growth and yield performance of sunflower crop over control but at 15% level there was downward effect (Kene et al, 1991a). Singh and Singh (1986b) found the good results in rice plants at 10 and 20% fly ash levels, but 30% led to a decrease in yield of rice. Similarly in the present study, onwards 25% level; there was gradual reduction in plant growth, yield and plant biomass.

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