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Assessment of Coal Fly Ash and it's Applications in Bioremediation Technology

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Abstract

Fly ash is a by product of coal based thermal power plant. Management of this huge amount of fly ash is a great concern of environmental issues. Indian government mandated 100% utilization of ash in eco-friendly way. In this concern Kota Super Thermal Power Stations coal fly ash and soil from commercial agricultural land were collected. Physico-chemical analysis for various parameter were planned for both fly ash and soil samples. The comparative investigation revealed that fly ash of Kota Thermal Power Station possess good amount of Nitrogen (N), Sulfur (S), Silicon (Si), Aluminum (Al), Cobalt (Co), Molybdenum (Mo) etc. These elements play a dual role in plant growth and development. These components are essential at their optimum level but become toxic beyond a particular level. Hence fly ash can be used with commercial agricultural field's soil in order to overcome its nutrient deficiency. Thus this paper aims to comprehensively understand the composition, toxicity and potential application of this industrial waste ash and emphasizes on sustainable utilization of this in bioremediation technology in order to immobilized toxic heavy metals and restores natural habitats and improve biodiversity.

Key words : Coal Fly Ash, Bioremediation, Heavy Metals, Electrical Conductivity, Commercial Agricultural Land, Black Soil.

Energy is a fundamental requirement in our day today's life for some basic human needs such as lighting, food preparation, access to clean water, waste water management, transportation and communication. The power plant is a facility which is used to generate electricity. In all over the world there are different types of power plants including coal

fired thermal power, nuclear fission power, hydroelectric power, solar radiation power, geothermic power, wind power, tidal power, gas fired power and many more.[3] Among all of these the most common power generation source is coal fired thermal power plant. In context to Rajasthan Kota Super Thermal Power Station (KSTPS) is Rajasthan's major coal-based electricity generating power plant. KSTPS has total installed power generation capacity of 1240 MW. KSTPS is located on the left bank of the Chambal river. In which coal is burned to generate energy[1]. Coal is used due to it's easy availability & cost effectiveness. This combustion results in generation of Coal Fly Ash (CFA). Management of this huge amount of CFA is a great concern of environmental issues. Improper management by conventional method can lead to environmental pollution, resource depletion *etc*. So there is a need for eco-friendly way of disposal. In order to achieve this the centre government of India under the Environment protection Act (1986) has issued Fly Ash Notification 2021. The Ministry of Environment, forest and climate change (MOEF & CC) is actively formulating required guidelines and rules in order to achieve 100% utilization of FA in an eco-friendly manner. For shift from disposal centric to utilization centric model, CFA can be utilized in cement & concrete production, in building manufacturing materials *i.e*. bricks, blocks, tiles, in road construction *i.e* embankments, road bases, in mine filling, in agriculture[6,12].

CFA can be used as a soil conditioner in sustainable agriculture activity. The use of CFA in agricultural fields is not a "just plug and play solution" (apply and improve solution) due to different composition of CFA and soil. In many studies, it was observed that low to moderate rate application of CFA can enhance and increase crop growth and yield in rice, wheat, legumes, tomato, pumpkin, egg-plant, carrot and cucumber etc.[2,7,17,18,22,23]. Excessive application can introduce a toxic level of heavy metals causing a negative impact on plant growth. In this concern this paper emphasises on understanding the composition of CFA and soil and impact of its micro and macro nutrients on plant growth in combination with suitable microbes.

Sample Collection of CFA :

Research material CFA was collected from Kota Super thermal power plant, Rajasthan. The CFA sample was directly collected from a funnel shaped container, hopper which is found at the bottom of an electrostatic precipitator (ESP) as CFA is a by-product of the coal combustion process so it's composition directly depends on the quality of coal material and it's combustion conditions like temperature, boiler design, operating chemical conditions etc[25,26].

Sample Collection of soil :

In Rajasthan, Hadoti region which includes Kota, Bundi, Baran, Jhalawar districts. This area is predominantly characterized by black soil. Soil sample was collected from commercial agricultural land of Kota by quartering method. It is most suitable for some Kharif crops *i.e.* soya, paddy, black gram and for some Rabi crops *i.e*. wheat, mustard etc. It consists of clayey texture and has high moisture retention capacity. With these advantages some drawbacks are also associated in using black soil for agricultural use. Due to it's clayey

texture and high water retention capacity it is causes waterlogging and black soil lack some nutrients like Phosphorus(P), Nitrogen(N), Zinc(Zn), Carbon(C) which are necessary for plants health and overall growth and development. To overcome these disadvantages farmers uses synthetic fertilizers and heavy machinery. The soil from traditional agricultural land and commercial or conventional agricultural land is same. But the commercial agricultural land emphasizes generally on gaining maximum yield in short term duration. Such farming practices are heavily reliance on input of synthetic fertilizers, pesticides and herbicides. Over the long term simultaneously this lead to alteration of the soil's physical, chemical and biological characteristics[13,14,16,20].

Physico-chemical analysis of CFA and soil samples :

CFA and soil both possess a composite and variable chemical composition. These are consist of some major and micro components. In this concern the soil sample from commercial agricultural land and CFA from KSTPP were analyzed for Electrical Conductivity, pH and their chemical Composition. These samples were analyzed at National Test House, Jaipur and National Test House, Kolkata.

CFA and soil samples were air-dried and analyzed for different parameters. EC and pH were determined by using Electrical Conductivity meter and pH meter respectively. Electrical Conductivity meter calibrated with KCl solution pH meter calibrated with standard buffer solutions[21,22,23]. CFA primarily contains oxides of Silicon (Si), Aluminum (Al), Iron (Fe), Calcium (Ca). It is also enriched with Nitrogen(N), Magnesium(Mg), Potassium (K), Sodium(Na), Sulfur(S), Phosphorus(P), Boron(B), Barium(Ba) and some heavy metals like Cobalt(Co), Silver(Ag), Chromium(Cr), Arsenic(As), Molybdenum(Mo), Cadmium (Cd), Zinc(Zn), Nickel(Ni), Copper(Cu), Lead(Pb), Manganese(Mn) etc also present.

Total Nitrogen(N) content determined by Kjeldahl method[9,21]. Total Carbon(C) and Sulfur(S) content were estimated by titrimetric method with CS analyzer. Phosphorus(P) and of Silicon (Si) SiO_2 content determined by gravimetric method[4,24]. For remaining metallic ion analysis USEPA 3050B digestion method was followed by Atomic Absorption Spectroscopy (AAS). Sample prepared by this method may be analyzed by Inductively coupled Plasma - Atomic Emission Spectroscopy (ICP - AES) or Inductively coupled Plasma - Atomic Mass Spectroscopy (ICP - MS)[8].

Results :

Table-1. Physico-chemical analysis of FA–

S. N.	Tested Parameter	Observed Value For Fly Ash
1	pH	7.1
2	EC (ds/m)	0.7
3	Nitrogen (N)	0.82
4	Carbon (C)	0.6
5	Phosphorus (P)	0.03
6	Potassium (K)	0.14
7	Sulphur (S)	0.11
8	Magnesium (Mg)	0.24
9	Boron (B)	0.19
10	Silicon (Si)	69.48
11	Aluminum (Al)	10.2

12	Calcium (Ca)	2.65
13	# Iron (Fe)	4.07
14	# Barium (Ba)	0.05
15	# Cobalt (Co)	0.003
16	# Mercury (Hg)	0.001
17	# Chromium (Cr)	0.0059
18	# Arsenic (As)	0.39
19	# Molybdenum (Mo)	0.03
20	# Cadmium (Cd)	0.58
21	# Zinc (Zn)	0.0045
22	# Lead (Pb)	0.061
23	# Manganese (Mn)	0.04

Hg in ppm, other elements in %/Mass, # Heavy Metal

Table-2. Physico-chemical analysis of Soil Sample

S. N.	Tested Parameter	Observed Value For Soil
1	pH	7.5
2	EC (ds/m)	0.9
3	Nitrogen (N)	0.54
4	Carbon (C)	2.51
5	Phosphorus (P)	0.17
6	Potassium (K)	0.53
7	Sulphur (S)	0.0025
8	Magnesium (Mg)	0.87
9	Boron (B)	0.03
10	Silicon (Si)	46.59
11	Aluminum (Al)	4.56
12	Calcium (Ca)	7.18
13	# Iron (Fe)	5.43
14	# Barium (Ba)	0.02
15	# Cobalt (Co)	0.001
16	# Mercury (Hg)	0.001
17	# Chromium (Cr)	0.012
18	# Arsenic (As)	0.07
19	# Molybdenum (Mo)	0.001
20	# Cadmium (Cd)	0.12
21	# Zinc (Zn)	0.011
22	# Lead (Pb)	0.097
23	# Manganese (Mn)	0.06

Hg in ppm, other elements in %/Mass, # Heavy Metal

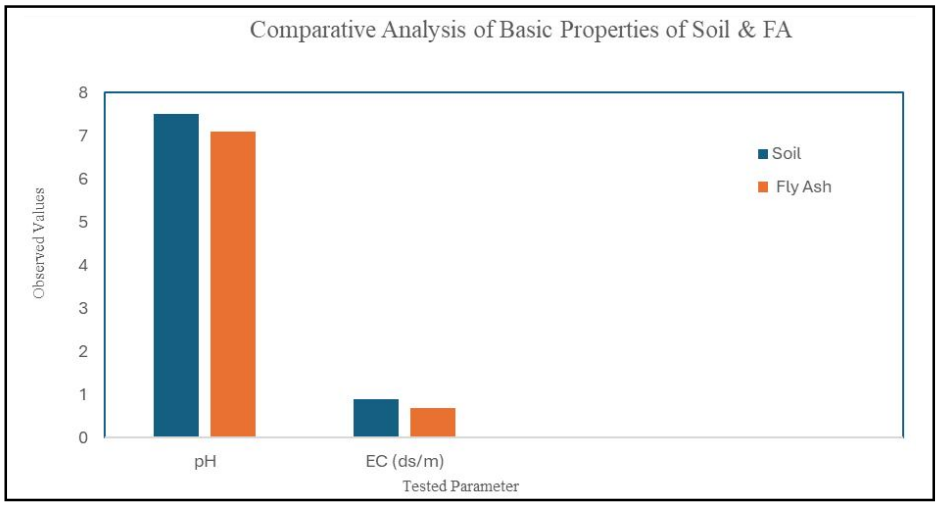

Fig. 1

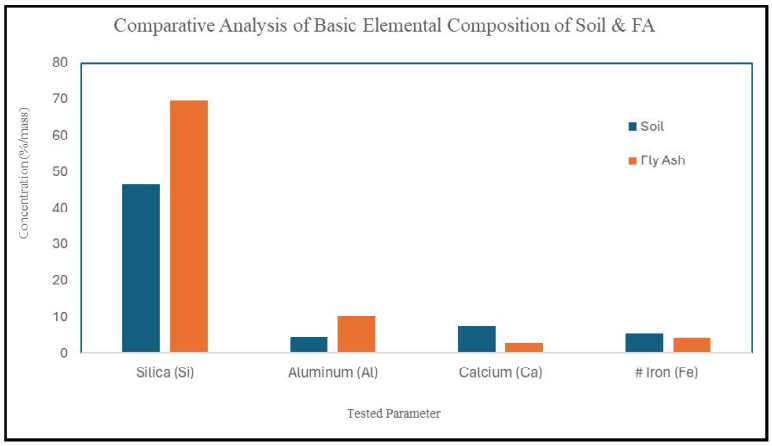

Fig. 2

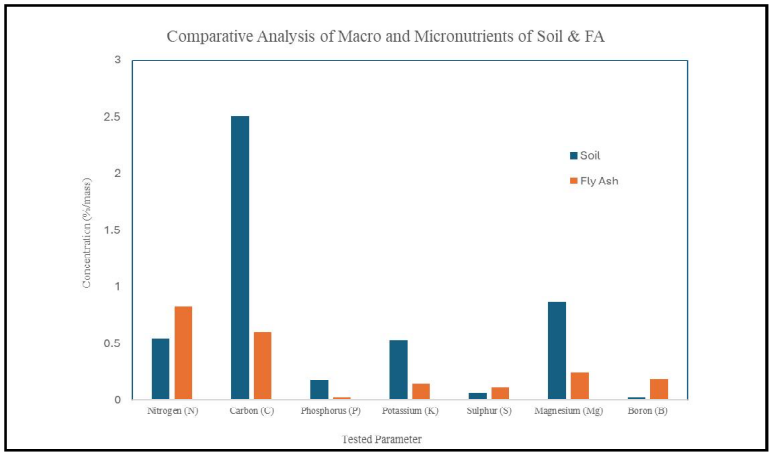

Fig. 3

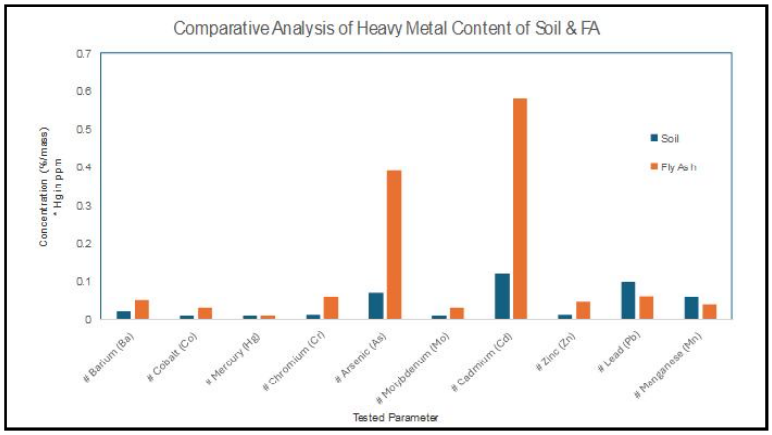

Fig. 4

Various parameters of CFA and soil were examined and provided in table-1 and table-2. The pH of CFA and soil were obtained 7.1 and 7.5 respectively. The EC of CFA and soil were obtained 0.7 and 0.9 ds/m respectively. The Nitrogen(N), Boron(B), Calcium(Ca), Sulphur(S), Boron(B), Silicon(Si), Aluminium(Al) content were noted high in CFA. In addition to these some heavy metals like Barium(Ba), Cobalt(Co), Arsenic(As), Molybdenum(Mo), Cadmium (Cd) were also detected higher in CFA, whereas concentration of Carbon(C), Phosphorus(P), Potassium(K), Boron(B), Magnesium(Mg), Calcium(Ca), Iron(Fe), Chromium(Cr), Zinc(Zn) were found high in commercial agricultural land soil. The Mercury (Hg) concentration were detected in trace amount in both CFA and soil.

The analysis of elemental composition of CFA and soil shows the presence of macro and micronutrients. At their optimal concentrations these macro and micronutrients are pivotal for different physiological and biochemical processes required for plant growth and development. So enrichment of commercial agricultural black soil with KSTPS-CFA mutually complements one another and would show positive outcome on crop plants[11,15]. In this aspect it become important to examine the appropriate quantity of CFA with soil for different crops. Coal source type and combustion conditions govern the physico-chemical composition of CFA. So the optimal application rate of CFA will also determined by the characteristics of soil type. Pre-treatment of CFA and its co-application with living microbes can reduce detrimental effect of heavy metals.

Based on the observations, it can be concluded that physico-chemical composition of CFA varied widely so the mode of use in agriculture is different and it is also depends on the soil type and characteristics. The present study suggests to investigate the optimum ratio of CFA enriched soil for different crops in Hadoti region and the accumulation of heavy metals in the edible parts of plants. Addition of biological agents in these combination transport pollutants into less toxic or non-toxic forms. These CFA enriched soil sample with suitable biological agents can be used as composite fertilizer for organic farming. In such bioremediation techniques CFA and soil samples will serve as a medium. Such farming techniques will be helpful in eliminating environmental pollutants as well as for sustainable agricultural practices.

References :

1. "केटीपीएस विभाग पोर्टल, राजस्थान सरकार." Accessed March 4, 2025. https://department.rajasthan.gov.in/pages/department-page/126.
2. Ajaz S., and S. Tiyagi (2003). *Archives of Agronomy and Soil Science*, *49*: 457-461. https://doi.org/10.1080/03650340310001596428.
3. Asumadu-Sarkodie S. and A.O. Phebe (2016). *Cogent Engineering 3*(1): 1155274. https://doi.org/10.1080/23311916.2016.1155274.
4. Bardsley C.E. and J.D. Lancaster (1960). *Soil Science Society of America Journal*, *24*(4): 265-268. https://doi.org/10.2136/SSSAJ1960.03615995002400040015X
5. Cherie D. (2022). *Asian Soil Research Journal*. *6*(3), 6-10. https://doi.org/10.9734/asrj/2022/v6i330131 https://doi.org/10.14250/CEMENT.74.111.

6. Jaiswal S, M Das, and S.K. Maiti (2006). *Indian Journal of Environmental Protection*, *26*(3): 268–75.
7. Khan, M., and Z.A. Siddiqui, (2017). *Sci. Hortic. 225 :* 177-184.
8. Khandelwal M., N. Grover and N. Srivastava (2014). *J. Phytol. Res. 27(1 & 2)*: 19-23.
9. Mirzakhani H., I. Mani, M. Hasan, A. Nafchi, R. Parray and D. Kumar (2022). *Sensors, 22*(18): 6728. https://doi.org/10.3390/s22186728
10. Mylavarapu R., J. Bergeron, N. Wilkinson and E. Hanlon (2020). EDIS 2020(1). https://doi.org/10.32473/EDIS-SS118-2020.
11. Nanda P. (2021). *International Journal for Research in Applied Science and Engineering Technology*, *9*(11): 1699-1703.
12. Nomani M. Z. M., O. Shaquib and M. Sharma (2025). *Nature Environment and Pollution Technology*, *24:* 305–14. https://doi.org/10.46488/nept.2024.v24is1.023.
13. Rui Li. *et al*., (2025). *Pedosphere 35*(1): 264–279. https://doi.org/10.1016/j.pedsph.2024.06.011.
14. Rui Li., Wenyou Hu., and Zhongjun Jia. *et al*. (2025). *Pedosphere 35*(1): 264–79. https://doi.org/10.1016/j.pedsph.2024.06.011.
15. Sharma M. and R. Varma, (2021). *IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT)* Volume *15*(1): 31-39.
16. Shuai Ma., L. Wang, H. Wang, Y. Zhao, and J. Jiang (2022). *Journal of environmental management 328:* 117024. https://doi.org/10.1016/j.jenvman.2022.117024.
17. Siddiqui Z.A., and L.P. Singh (2005). *J. Plant. Dis. Protect 112:* 146 155.
18. Singh A., and S.B. Agrawal (2010). *Ecotoxicol. Environ. Saf. 73:* 1950 - 1958.
19. Smith J. and Doran J. (1996). *Environmental Science, Agricultural and Food Sciences*. DOI:10.2136/SSSASPECPUB49.C10
20. Sulaeman Y., S. Sukarman, R. Neswati, N. Nurdin and T. Basuki (2023). *SAINS TANAH - Journal of Soil Science and Agroclimatology, 20*(1): 114-123. https://doi.org/10.20961/stjssa.v20i1.70343.
21. Tp P.K. and T.M. Krishna (2023). *Journal Of Advanced Zoology*. Volume *44*(5): 3275-3284. https://doi.org/10.53555/jaz.v44is5.3147
22. Verma H. and A. Dubey, (2017). *J. Phytol. Res. 30* (1 & 2) : 83-88.
23. Verma H., L. Choubisa and A. Dubey (2016). *J. Phytol. Res. 29*(1 & 2) : 85-91.
24. Wright R. and T. Stuczynski, (2018). Atomic Absorption and Flame Emission Spectrometry. *SSSA Book Series*. https://doi.org/10.2136/SSSABOOKSER5.3.C4.
25. Wu J., and Y. Yang *et al*. (2022). *Journal of hazardous materials 445:* 130482. https://doi.org/10.1016/j.jhazmat.2022.130482.
26. Yoda Y., S. Kiyomura, M. Hotta and R. Kawasaki (2021). *Cement Science and Concrete Technology*, *74*(1): 111-117.