# Remediation of Heavy Metals from Fly-Ash with Aid of Ecosystem Engineers: Earthworms – A Review

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***Abstract. The importance of earthworms to ecosystem functioning has led to many studies on the impacts of metals on earthworms. Organic farming is need of the hour to get rid of chemical fertilizers, pesticides and growth regulators. Fly-ash is a useful organic amendment. Huge amounts of fly-ash originate from different coal fired power station throughout the world, presenting several problems, the most important ones being environment pollution. Fly-ash has great potentiality in agriculture due to its efficacy in modification of soil health and crop performance. Vermicomposting is an excellent technique for reducing the toxic heavy metals in fly-ash using earthworm. Earthworms convert organic matter both physically and chemically to increase the soil porosity and therefore, they are also called as 'ecosystem engineers'. Earthworm species have shown their potential in increasing bioavailability of major nutrient elements such as phosphorous and nitrogen in fly-ash and also minimizing the solubility of heavy metals. Keeping the above environnemental concern, an exhaustive review was carried out to determine the efficiency of earthworms to accumulate the heavy metals and increase the plant nutrients availability in fly-ash during vermicomposting processes. This study will demonstrate the efficiency of different species of earthworms to accumulate the heavy metals and increase the plant nutrients availability in fly-ash during vermicomposting processes. Adopting the vermicomposting technology promises more effective fly-ash utilization for agricultural benefits by taking the advantage of increased microbial activities provided by earthworms.***

***Keywords: bioaccumulation, fly-ash, heavy metals, nutrients, vermicomposting***

## 1. INTRODUCTION

Coal based thermal power plants are a major source of power generation in developing countries. Coal has high ash content. About more than 85 percent of ash produced is fly-ash [1]. Fly-ash is a powdery material, produced as a by-product during coal based power generation process. Fly-ash contains silica, aluminium, oxides of iron, calcium, magnesium, arsenic, chromium, lead, zinc and other toxic metals. Fly-ash has a low bulk density, high surface area and light texture [2, 3]. Fly-ash leads to air pollution due to its persistance over a long period of time and also causes health

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hazards [4]. It degrades the environment by clogging natural drainage, reducing pH and potability of water, interfering with the photosynthesis of aquatic plants and disturbing the food chain. Fly-ash has huge problem of its disposal. It is important to overcome these problems not only by safe disposal but also through conversion of these materials to value-added products.

Inspite of being a solid waste, fly-ash can be utilized for various constructive purposes such as (i) wasteland reclamation (ii) waste stabilization (iii) bricks (iv) roads and embankments. (v) agriculture- by correcting pH, better aeration, providing nutrients, enhancing growth and yield of crops. [5] illustrated the possible agronomic uses of fly-ash as a fertilizer. Fly-ash, being a useful ameliorant improves the physical, chemical and biological properties of problem soils and is a reservoir of essential micronutrients. Fly-ash is deficient in nitrogen and phosphorous so by amending it with soil or various organic materials (sewage sludge, bioprocess materials) as well as microbial inoculants like mycorrhizae, enhanced plant growth can be realized. Major constraint associated with the use fly-ash in agricultural ecosystem is the low availability of most of the nutrient elements and low rate of degradation of fly-ash after application in soils. Heavy metals are the most recurrent contaminants preventing fly ash reuse and may be found in problematic concentrations, depending on the type of fly-ash [6].

Vermicomposting is one of the best ways to dispose this waste and also remediate and amend the soil [7]. The active organisms in conventional vermicomposting are earthworms. Earthworms ingest the heavy metals from fly-ash, while converting them into vermicompost. Earthworms can survive in heavy metal contaminated soils and can accumulate metals, such as Cd, Cu, Zn and Pb in their tissues [8, 9] Earthworms may enhance the fertility of soil treated with coal fly-ash by increasing solubilisation of mineral nutrients such as Phosphorous and potassium in the ash. The greatest advantage of the vermiremediation technology is that it is ‘on-site’ treatment and there is no additional problem of ‘earth-cutting’, excavation’ and ‘transportation’ of contaminated soils to the landfills or to the treatment sites incurring additional economic and environmental cost. Remediation of fly-ash using earthworms will become an important component of substantial agriculture, which has a multidirectional impact in terms of safe disposal of fly-ash preventing environmental pollution besides providing nutrient rich materials.

## 2. FLY-ASH

The present outlets as per Fly-ash utilization programme (FAUP), Department of Science and technology, New Delhi, India during 2011-2012, 220 million tonne of fly-ash were generated. Only 50% of the total fly-ash generated was utilized in different sectors.

Fly-ash being a coal combustion residue shows a large variation in their physico-chemical and mineralogical properties based on the nature of parent coal, conditions of combustion, type of emission control devices storage and handling methods [3]. Fly-ash is a mixture of fine, spherical particles with size ranging from 0 - 100 microns. Fly-ash contains heavy metals like As, Cd, Ca, Cr, Co, Cu, Pb, Mn, Hg, Ni, F, Zn Al, B, Ba, Be, Mo (Table 1) and trace elements with $SiO_2$, $Al_2O_3$, $Fe_2O_3$, CaO, MgO in its basic composition.

**Table 1. Heavy metals in Indian Fly-ash**

| Parameters | Total | Available [mg/kg] |
|---|---|---|
| Cu | 40-80 | 0.5- 1.6 |
| Zn | 50-150 | 0.4-1.8 |
| Mn | 500-750 | 0.9-1.5 |
| Fe | 3.3-6.4 | 10-15 |
| B | 17-38 | 0.5-0.8 |
| Mo | 2.2-6.7 | 0.1-0.6 |
| Se | 0.6-2.6 | 0.1-0.4 |
| Cr | 50-150 | 0.3-0.6 |
| Pb | 10-7 | BDL |
| Co | 10-50 | 0.05-0.15 |
| Ni | 50-150 | 0.15-0.25 |
| Cd | 5-10 | 0.03-0.07 |
| As | 1.0-4.0 | BDL |
| Hg | BDL | BDL |

*Source: [10, 11, 12]*

Depending upon the percentage of the basic constituent, fly-ash is divided into two categories as class C and class F. Fly-ash also has several biological properties. The soil fly-ash environment is most suitable for proliferation of the bacteria, thereby contributing towards enhanced availability of soil phosphorous.

## 3. EARTHWORMS

Earthworms are '*unheralded soldiers of mankind'* created by mother nature. Earthworms (phylum Annelida, class Oligochaeta) are one of the foremost components of soil communities and have ecological relevance in the formation and maintenance of soil structure. These invertebrates play an important role in key processes such as decomposition of organic matter and nutrient mobilization

[13]. They convert organic matter both physically and chemically to increase the soil porosity, and therefore, they are also called as '*ecosystem engineers'*. Some of the epigeics, e.g. *Eisenia fetida* (Savigny), *Perionyx excavatus* (Perrier), and *Eudrilus eugeniae* .Kinberg, have been appeared as key candidates for organic waste recycling practices [14, 15]. The behavioral characteristics of earthworms such as burrowing and feeding affect their exposure to heavy elements [16]. Earthworms can bio-accumulate and bio-transform many chemical contaminants including heavy metals and organic pollutants in fly-ash and clean-up the contaminated lands for re-development.

## 4. VERMICOMPOSTING OF FLY-ASH

Vermicomposting is derived from the Latin word 'vermis' meaning worms. This process uses earthworms and microorganisms to convert organic matter into nutrient-rich humus. It is an eco-biotechnological process involving consumption of organic material by earthworms. It is an excellent technique for recycling food waste using earthworms. It involves joint action of earthworms and microorganisms.

Earthworm species should have following features: (i) Prolific breeder (ii) Healthy eater (iii) Resistant. Two species of red earthworms (a) *Eisenia fetida* (The red wiggler) (b) *Lumbricus rubellus* (The red worm) have consistently been used for commercial composting or worm farming, due to their relatively high tolerance of environmental variations. This process can be conducted all year-round, providing environmental conditions within acceptable limits.

## 5. NUTRIENTS

Vermicomposting speeds up the process of decomposition and provides a nutrient-rich end product, called vermicompost, in the form of 'worm castings'. Vermicompost has been one of the critical organic agro input in organic farming systems. Vermicompost is a nutritive 'organic fertilizer' rich in NKP( nitrogen, potassium, phosphorous), micronutrients, and beneficial soil microbes like 'nitrogen-fixing bacteria' and 'mycorrhizal fungi' and are scientifically proving as 'miracle growth promoters and protectors'

[17] reported as high as 7.37% nitrogen and 19.58% phosphorus as $P_2O_5$ in worms' vermicast. There are also good amount of calcium (Ca), magnesium (Mg), zinc (Zn) and manganese (Mn). Vermicompost contain enzymes like amylase, lipase, cellulase and chitinase, which continue to break down organic matter in the soil (to release the nutrients and make it available to the plant roots) even after they have been excreted. [18].

## 6. BIOACCUMULATION OF HEAVY METALS BY EARTHWORM SPECIES

This involves the process by which the chemical concentration in tissues of an organism achieves a level that exceeds that in the soil, as a result of chemical uptake through all possible routes of chemical exposure (e.g., dietary absorption, transport across the respiratory surface, dermal absorption, inhalation). Earthworms can remediate heavy elements from fly-ash through two different pathways: by direct dermal contact with the elements dissolved in the fly-ash solution and/or by ingestion and ensuing gut uptake from bulk fly-ash or specific fly-ash components. Earthworms are potential bioaccumulators of heavy metals and therefore they have been successfully demonstrated in mitigating the toxicity of industrial and municipal waste by vermicomposting technology [19] (Table 2).

**Table 2. Remediation of heavy metals from fly-ash by earthworms**

| S. No. | Methodology | Species | Accumulation of heavy metals by earthworms | References |
|---|---|---|---|---|
| 1. | Fly-ash was mixed with cow-dung in 20, 40, 60 and 80%. Heavy metals conc. before and after vermicomposting were determined. | *Eisenia fetida* | Cu, Cr, Pb, Ni, Zn | [20] |
| 2. | Seven different combinations of cow-dung and fly-ash- 1:1, 1:2, 1:3, 2:1, 3:1 were prepared for vermicomposting. | *Eisenia fetida* *Eudrilus eugeniae* | Zn, Mn | [21] |
| 3. | Fly-ash was composted with and without epigeic earthworm along with cow-dung (OM) in ratios - FA alone ($T_1$), FA+OM (1:1) ($T_2$), FA+OM (1:3) ($T_3$) and FA+OM (3:1) ($T_4$). | *Eisenia fetida* | Cr, Pb, Cd | [22] |
| 4. | Remediation of heavy metals by three earthworm species by three different urban wastes –Flower waste (FW), Municipal solid waste (MSW) and Market waste (MW) | *Eudrilus eugeniae, Eisenia fetida, Perionyx excavatus* | Cu, Pb, Zn, Mn, Cd | [23] |
| 5. | Treatment includes factorial combination of 3 rates of fly-ash and two different species of earthworms. | *Megascolecid* sp and exotic *Aporrectodea trapezoides* | Cu, Cr, Zn | [24] |

Earthworms have different capacities to uptake and bioaccumulate both essential and non-essential elements. It has been hypothesized that this behavior is the result of inter-specific differences in the dietary intake of elements and in physiological and morphological characteristics, such as structure of skin, chemical species requirements, excretion and detoxification [25, 26, 27] Earthworms can tolerate and bio-accumulate high concentrations of heavy metals like cadmium (Cd), mercury (Hg), lead (Pb) copper (Cu), manganese (Mn), calcium (Ca), iron (Fe) and zinc (Zn) in their tissues without affecting their physiology and this particularly when the metals are mostly non-bioavailable. The species *Lumbricus terrestris*, *L. rubellus and D. rubidawas* found to bio-accumulate very high levels of lead (Pb) and Cadmium (Cd) in their tissues. Earthworms are capable of reducing possible toxic effects of superfluous heavy metals by utilizing them for physiological metabolism.

## 7. CONCLUSION

This review provides an alternative way for the utilization of fly-ash apart from the conventional brick making, landfilling etc. The final outcome aids in converting the burden of fly-ash disposal into an opportunity to produce high-potential organic fertilizers capable of enhancing soil fertility, bioremediation and improving crop quality, thereby assisting economic growth and protecting the environment. Fly ash is a useful ameliorant that may improve the physical, chemical and biological properties of problem soils and is a source of readily available plant macro and micronutrients. In conjunction with organic manure and microbial inoculants, fly-ash can enhance plant biomass production from degraded soils.

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