CURRICULUM VITAE

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Career Objective

- To work in a challenging and competitive environment and effectively contribute to the goal of the organization.

Profile Summary

- A focused professional with zeal to make a winning career in research and lectureship.
- *Areas of Interest*: Environmental Engineering, Soil Pollution, Wastewater Engineering, Bioremediation, Risk Assessment, Environmental Biotechnology, Environmental Science, Ecological Restoration, and Biological Sciences.

Academic Details

- *Ph.D* (*Environmental Science & Engineering*): Department of Environmental Science & Engineering, Indian Institute of Technology (Indian School of Mines), Dhanbad (India) (2015-2020: Thesis Submitted).

  Title of Ph.D thesis: Assessment of potentially toxic elements in coal, flyash, and soil, and phytoremediation of mercury by *Brassica juncea* (L.) Czern.

- *M.Sc.-Tech.* (*Environmental Science & Technology*): Institute of Environment & Sustainable Development, Banaras Hindu University, Varanasi (India) with CGPA of 8.06 (2011-14).
- *B.E* (*Biotechnology*): VMKV Engineering College, Vinayaka Missions University, Salem (India) with 83% (2007-11).
- *Higher Secondary:* (*Physics, Chemistry, and Biology*): BD Public School, Patna (India) with 61% (2002-04).
- *Matriculation*: May Flower School, Patna (India) with 63% (2001-02).

Teaching & Research Experiences

- *Guest Faculty* (*Environmental Biotechnology*): School of Biotechnology, Gautam Buddha University, Greater Noida (India) (January 2015 – May 2015).

Research Publications in International Journals (SCI-Indexed; Cumulative IF = 20.487)

- **Raj D**, Chowdhury A and Maiti S.K. **(2017)**. Ecological risk assessment of mercury and other heavy metals in soils of coal mining area. A case study from Eastern part of Jharia coal field, India. *Human and Ecological Risk Assessment.* https://doi.org/10.1080/10807039.2016.1278519. (SCIE Impact Factor = 2.3).
- **Raj D. (2019).** Bioaccumulation of toxic metals in plants grown on coal mine soil. *Human and Ecological Risk Assessment.* https://doi.org/10.1080/10807039.2018.1447360. (SCIE Impact Factor = 2.3).
- **Raj D** and Maiti S.K. **(2019)**. Bioaccumulation of potentially toxic elements in tree and vegetable species with associated health and ecological risks: a case study from a thermal power plant, Chandrapura, India.

Rendiconti Lincei. Scienze Fisiche e Naturali. https://doi.org/10.1007/s12210-019-00831-7. (SCIE Impact Factor = 1.603).

- **Raj D** and Maiti S.K. **(2019)**. Sources, toxicity and remediation of mercury: an essence review. *Environmental Monitoring and Assessment*. https://doi.org/10.1007/s10661-019-7743-2. (SCIE Impact Factor = 1.903).
- **Raj D**, Kumar A and Maiti S.K. **(2019)**. Evaluation of toxic metal(loid) concentration in soils around an open-cast coal mine (Eastern India). *Environmental Earth Sciences*. https://doi.org/10.1007/s12665-019-8657-6. (SCIE Impact Factor = 2.18).
- **Raj D**, Kumar A and Maiti S.K. **(2020)**. *Brassica juncea* (L.) Czern. (Indian mustard): a putative plant species to facilitate the phytoremediation of mercury contaminated soils. *International Journal of Phytoremediation*. https://doi.org/10.1080/15226514.2019.1708861 (SCIE Impact Factor = 2.52).
- **Raj D** and Maiti S.K. **(2020)**. Sources, bioaccumulation, health risks and remediation of potentially toxic metal(loid)s (As, Cd, Cr, Pb and Hg): an epitomised review. *Environmental Monitoring and Assessment*. https://doi.org/10.1007/s10661-019-8060-5. (SCIE Impact Factor = 1.903).
- **Raj D**, Kumar A and Maiti S.K. **(2020)**. Mercury remediation potential of *Brassica juncea* (L.) Czern. for clean-up of flyash contaminated sites. *Chemosphere*.

  https://doi.org/10.1016/j.chemosphere.2020.125857. (SCIE Impact Factor = 5.778).

Chapters Published in Books

- **Deep Raj**, PS Paul, SK Maiti **(2017)**. Chapter: Improvements in Fertility of Reclaimed Coalmine Dumps Due to Afforestation –A Case Study from North Karanpura Area, CCL, India in Sustainable Mining Practices (eds AK Gorai & DS Nimaje). Page 45-54, Narora Publishing House, New Delhi.

Major Contributions in Research as Reviewer of the Journals

- Human and Ecological Risk Assessment: An International Journal
- International Journal of Environmental Analytical Chemistry

Industrial Training

- Industrial Training on Alcohol Fermentation at United Spirit Limited, Hathidah (India).
- Industrial Training at Cachet Pharmaceuticals, Baddi (India).
- Training on Cancer Biology at Mahavir Cancer Sansthan, Patna (India).
- Field Training from Aqua Air Environmental Engineers Pvt. Ltd. Surat (India).

Academic Projects

- Mini Project entitled 'Production of Protease Enzyme from Agro Waste' at VMKV Engineering College, Salem (India).
- Major Project entitled 'Molecular characterization of salt tolerant bacteria using 16S rDNA gene sequence analysis' at Central Inland Fisheries Research Institute, Kolkata (India).

- Major Project entitled ‘Design of Effluent treatment plant (ETP)’ at Aqua Air Environmental Engineers Pvt. Ltd. Surat (India).

Workshop

- National Workshop on Significance of ABO Blood Grouping & Issue of Permanent Blood Grouping card (Sponsored by ICMR New Delhi).

International and National Conferences

- Paper presentation on ‘*Brassica juncea* (L.) Czern. (Indian mustard): A potential candidate for the phytoremediation of mercury from soil’ in International Conference on Sustainable Environmental Engineering and Science (SEES-2019) at Dr. Sudhir Chandra Sur Degree Engineering College, Kolkata (India).
- Paper presentation on ‘Improvements in fertility of reclaimed coalmine dumps due to afforestation: A case study from North Karanpura area, CCL, India’ in National Conference on Sustainable Mining Practices (SMP-2016) at National Institute of Technology, Rourkela (India).
- Paper Presentation on ‘Human Genome Project’ in National Seminar on Application of Biotechnology in Human Welfare (Organized by DBT & CSIR New Delhi) at VMKV Engineering College, Salem (India).
- Participation Certificate of National Conference on ‘Challenges in Biotechnology: Bioblooms- 09’ at VMKV Engineering College, Salem (India).
- Participation Certificate of National students Technical Symposium on BIOINNOVATIONS at VMKV Engineering College, Salem (India).

Memberships

- Rendered services as the Member of:
    - Science Club in the year 2009-10
    - Indian Society for Technical Education in the year 2007-11

Personal Details

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References

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Declaration

I hereby declare that all the above information is correct up to my knowledge, and I bear responsibility for the correctness of particulars mentioned above.

Place: Dhanbad, India

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Ecological risk assessment of mercury and other heavy metals in soils of coal mining area: A case study from the eastern part of a Jharia coal field, India

Deep Raj, Abhiroop Chowdhury, and Subodh Kumar Maiti

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ABSTRACT
Mercury (Hg) and other heavy metals, such as arsenic (As), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), lead (Pb), manganese (Mn), and zinc (Zn), were analyzed in coal (bituminous), roadside soil, reclaimed mine soil, core zone soil, and reference soil (agriculture soil) along three soil profiles (0–10, 10–20, and 20–30 cm) in a coal mining area (Jharkhand, India) inhabited by economically marginalized dense population. Higher toxic metal concentrations in coal (0.47 mg Hg/kg, 2.81 mg As/kg, and 13 mg Pb/kg, 2.61 mg Cd/kg) can cause ecological hazard in the area. Roadside soil has the highest Hg (2.32 mg/kg), and core zone soil has the highest Pb (15.7 mg/kg) concentration. Hg concentration in roadside soil indicates high potential ecological risk, while Cd contamination in mining area can be put under moderate ecological risk. Roadside soils shows highest Ecological Risk Index (ERI) value of 339, indicating considerable ecological risk, and Hg alone contributes 64% of ERI value. Higher ERI and E_f^i (Hg) were due to the deposition of coal dust from mining activities and transportation.

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KEYWORDS
ecological risk; Hg pollution; opencast coal mining; heavy metals; soils

Introduction

Heavy metals occur naturally in soil at low concentrations though they are considered as contaminants of soil because of their widespread occurrence, and acute and chronic toxicity (Chowdury and Maiti 2016a). Heavy metals form an important polluting group, and they not only are toxic and carcinogenic but also tend to accumulate in living organisms (Alloway 2013). Toxic metals are stable because they cannot be degraded or destroyed; therefore, they tend to accumulate in soils and affect the biosphere for a long time. Coal is the main source of mercury and other toxic metals in the nearby soil of coal mining areas (Li *et al*. 2009). Soil pollution near coal mining areas with heavy metals has become a critical environmental concern because of its potential adverse ecological effects (Maiti 2007). The various sources of toxic metals in soil of mine environment are: (1) air that contains mine dust, (2) transport activities, and (3) discharge and dispersion of coal mine wastes. As a result of mining

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Color versions of one or more of the figures in this article can be found online at www.tandfonline.com/bher.

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Bioaccumulation of potentially toxic elements in tree and vegetable species with associated health and ecological risks: a case study from a thermal power plant, Chandrapura, India

Deep Raj[1] · **Subodh Kumar Maiti**[1]

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Abstract

The working of thermal power plant (TPP) in an area is the primary source of pollution, because it releases potentially toxic elements (PTEs) laden fly ash (FA), which may lead to serious health and ecological risks. This study assessed the current status of pollution in the nearby areas of TPP by measuring the concentration of PTEs (As, Cd, Cr, Hg, and Pb) in FA, soils (roadside, forest, agricultural, and residential areas), tree leaves (*Albizia lebbeck* and *Madhuca longifolia*), and vegetables (*Raphanus sativus* and *Allium cepa*). Hg concentration in FA was found to be lower (0.449 mg/kg) than global average Hg content (0.62 mg/kg). PTEs content in topsoil (0–15 cm) of the roadside area was comparatively higher (As, 4.56; Cd, 12.68; Cr, 72.53; Hg, 2.77; Pb, 46.05 mg/kg) than other areas. Bioaccumulation coefficient and transfer factor of As in *M. longifolia* and *A. cepa* were 1.03 and 0.30, respectively, which showed high accumulation of PTE. The ecological risk index (1561) was found to be very high in the roadside area, due to high values ecological risk factor of Cd (1268) and Hg (277) in the area. The total hazard quotients (THQs) posed by As, Cd, Cr, and Pb in vegetables were exceeding the safe limits (THQ > 1), suggesting that long-term consumptions of these vegetables may pose serious health risks. Therefore, the remediation measures are needed to minimize the pollution level in soil to reduce the health risk due to the exposure of PTEs.

Keywords Potentially toxic elements · Fly ash · Vegetables · Bioaccumulation coefficient · Hazard quotient · Health risk

1 Introduction

The process of industrialisation in developing countries like India is highly dependent on non-renewable energy sources (Guttikunda and Jawahar 2014). Coal is among the chief energy sources which contribute to the maximum extent in the energy supply (57.3%) in India (CEA 2018). In general, 5–20 wt% of feed coal produced fly ash (FA), which consists of fine FA (85–95%) and coarse bottom ash (5–15%) (Yao et al. 2015). If FA is not correctly disposed, it may cause soil and water pollution, and lead to environmental hazards and disruption of ecological cycles. Data about the consumption of coal for the energy generation in different parts of the world have been reported by various researchers. For instance, Yao et al. (2015) reported that China was the largest consumer of coal in the year 2012, and accounted for 50.2% of the world coal consumption, while other countries like USA, India, Japan, Russian Federation, South Africa, South Korea, and Germany consumed 11.7%, 8%, 3.3%, 2.5%, 2.4%, 2.2%, and 2.1%, respectively. Taking these data into account, Blissett and Rowson (2012) and Izquierdo and Querol (2012) reported that the annual worldwide generation of FA is approximately 780 Million tonnes (Mt). In 2016–2017, FA generation in India was 169 Mt (of which 63% was recycled) from burning 509.5 Mt of coal with an average ash content of 33% (30–40%) (CEA 2018).

Potentially toxic elements (PTEs) are toxic, non-biodegradable, and persistent in nature (Dabrowski et al. 2008). These are highly hazardous to humans and ecosystems,

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Sources, toxicity, and remediation of mercury: an essence review

Deep Raj · **Subodh Kumar Maiti**

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Abstract Mercury (Hg) is a pollutant that poses a global threat, and it was listed as one of the ten leading 'chemicals of concern' by the World Health Organization in 2017. The review aims to summarize the sources of Hg, its combined effects on the ecosystem, and its remediation in the environment. The flow of Hg from coal to fly ash (FA), soil, and plants has become a serious concern. Hg chemically binds to sulphur-containing components in coal during coal formation. Coal combustion in thermal power plants is the major anthropogenic source of Hg in the environment. Hg is taken up by plant roots from contaminated soil and transferred to the stem and aerial parts. Through bioaccumulation in the plant system, Hg moves into the food chain, resulting in potential health and ecological risks. The world average Hg concentrations reported in coal and FA are 0.01–1 and 0.62 mg/kg, respectively. The mass of Hg accumulated globally in the soil is estimated to be 250–1000 Gg. Several techniques have been applied to remove or minimize elevated levels of Hg from FA, soil, and water (soil washing, selective catalytic reduction, wet flue gas desulphurization, stabilization, adsorption, thermal treatment, electro-remediation, and phytoremediation). Adsorbents such as activated carbon and carbon nanotubes have been used for Hg removal. The application of phytoremediation techniques has been proven as a promising approach in the removal of Hg from contaminated soil. Plant species such as *Brassica juncea* are potential candidates for Hg removal from soil.

Keywords Mercury · Coal combustion · Bioaccumulation · Adsorbents · Phytoremediation

Introduction

Mercury (Hg, hydrargyrum) is a potentially toxic element that has aroused global public health concern due to its toxicity (Alloway 2013; Raju et al. 2019). Hg in coal has been found in the form of cinnabar ore (HgS) and in association with pyrite (Hower et al. 2010). The melting point of Hg is − 38.8 °C, while the boiling point is 356.7 °C (Wang et al. 2012).

Once Hg is liberated into the atmosphere from ores, fossil fuels, and mineral deposits, it can be highly mobile and is deposited on surface soils, water bodies, and bottom sediments (Xu et al. 2015). The natural sources of Hg include degassing of the earth's crust and evaporation from water bodies (oceans) (Rahman and Singh 2019), whereas emission from coal-burning thermal power plants (TPPs) is the main anthropogenic source. The most hazardous compound of Hg in the environment is methylmercury (MeHg) (Liang et al. 2009; Jagtap and

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ORIGINAL ARTICLE

Evaluation of toxic metal(loid)s concentration in soils around an open-cast coal mine (Eastern India)

Deep Raj[1] · Adarsh Kumar[2] · Subodh Kumar Maiti[1]

Received: 5 March 2018 / Accepted: 28 October 2019

Abstract

Open-cast coal-mining activities release a substantial amount of potentially toxic metal(loid)s or metals which contaminates soil in its vicinity. A total of 75 soil samples were collected from an open-cast coal-mining area (North Karanpura area, India), representatives of five land-use sites, namely roadside soil (RSS), reclaimed mine soil (RMS), forest soil (FS), residential land soil (RS), and agricultural soil (AS) from three profiles (0–10, 10–20, and 20–30 cm). The samples were analyzed for five USEPA recognized potentially toxic metals, mercury (Hg), arsenic (As), cadmium (Cd), chromium (Cr), and lead (Pb). Ecological and health risks were assessed to study the impact of metals pollution on ecological ecosystem and children. Hg concentrations were found above the maximum permissible limit and highest in RSS (0.90 mg kg^{-1}) which was 13-, 12-, and 4-fold higher than AS, RS, and FS, respectively. Among all soil samples, a high concentration of Hg was found in topsoil profile (0–10 cm) which indicates anthropogenic sources of Hg due to coal dust deposition and transport activities in the mining region. In addition, the increased concentration of Cd was also observed for most of the sites (RSS: 1.35 mg kg^{-1}; RMS: 1.25 mg kg^{-1}). For all the metals in all the sites, the concentration decreased along the depth. Contamination factor and ecological risk index suggested that roadside and reclaimed area had very high ecological risk due to major contribution of Hg and As contamination in soil. The pollution load index was also found to be very high from the threshold limit, which suggests the possibility of transfer of contaminant from soil to children in coming future, and causes severe health risk.

Keywords Coal mining · Metals · Mercury · Cadmium · Ecological risk · Health risk

Introduction

Coal is the major source of energy which contributes 57.3% of the total energy supply in India (CEA 2018), and consumes about 8% of the total coal in the world (Yao et al. 2015). The rapid expansion of coal mining to meet the energy demand leads to severe vegetation loss, land degradation, and finally results in the release of toxic metals to the environment (Maiti 2013; Muszynska et al. 2017). Toxic metal (As, Cd, Hg, Cr, and Pb) laden fine coal dust easily carried away with the winds, settles down on the soil surface, and contaminates a wider region around the coal-mining sites. Significant concentration of these potentially toxic metals and their continuous exposure for the long time causes severe health effects on human beings (Prasad 1995; Loska et al. 2003; Roba et al. 2016). Among the toxic metals, mercury (Hg) has been recognized as a very serious global pollutant and has a significant impact on coal-mining ecosystem (Yu et al. 2015; Li et al. 2015a). It is highly mobile and non-biodegradable toxic metal which undergoes biomagnifications in the atmospheric environment (Wang et al. 2012). In India, burning of fossil fuels (coal) in coal-fired thermal power plant and coal mine fire are also the major sources of Hg in the environment (Alloway 2013; Rai et al. 2013; Podolsky et al. 2015), and recently, there has been growing interest to study the occurrence of Hg in coal

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Brassica juncea (L.) *Czern.* (Indian mustard): a putative plant species to facilitate the phytoremediation of mercury contaminated soils

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ABSTRACT

A Phytoremediation experimental set up was established by spiking the soil with varying concentrations of mercury (Hg) (Treatment: T1:10; T2:50; T3:100; T4:500 and T5:1,000 mg Hg/kg soil). Hg removal ability of the Indian mustard plant was determined after 30, 60 and 90 days of exposure. Hg accumulation trend in second and third month of exposure was root > leaf > stem, while for the 1st month it was root > stem > leaf. The highest percentage of Hg accumulation (81%) and glutathione (14 mg/kg) was observed in the plants of T4 and T5 treatment, respectively at 90 days of exposure indicating a high level of Hg stress tolerance. At 90 days of exposure the chlorophyll a content in leaves grown on Hg-free soil (control soil) was 1.8, 2.4, 2.8, 3.6 and 4.4 fold higher than T1, T2, T3, T4 and T5 treatment respectively. With increase in exposure duration, translocation factor decreased whereas bioconcentration factor increased signifying Hg is mainly accumulated in the roots. The study suggests that *Brassica juncea* can withstand under high Hg contamination and can show great potential to phytostabilize Hg when grown under 100 mg/kg of soil Hg without showing any significant detrimental effect on the plant.

KEYWORDS
Mercury accumulation; bioremediation; glutathione

Introduction

Mercury (Hg) is a non-essential potentially toxic element which is extremely harmful for the environment and human health. It has been introduced to the environment through anthropogenic activities and natural sources (Hussein *et al.* 2007). Several research studies have reported coal mining as a potential source of Hg contamination for the nearby soils (Yao *et al.* 2010; Fan *et al.* 2011; Raj et *al.* 2017). Thus, Hg accumulation in soil is a matter of huge concern because it may lead to the decreased crop production in the agricultural land area and several health problems among human beings through bioaccumulation (Feng *et al.* 2008; de Abreu *et al.* 2012; Liu *et al.* 2019). Hence, the remediation of Hg is necessarily required to combat these expanding problems.

In recent years, the interest in soil remediation through phytoremediation has increased. Phytoremediation is an alternative approach for soil decontamination, and can be used for minimizing the contamination level of Hg in soil. This technique has a lower cost and is more environmentally friendly for the clean-up of Hg-contaminated soils (de Abreu *et al.* 2012; Wang *et al.* 2012). So, it is considered as one of the most efficient remediation technique of Hg removal (Cassina *et al.* 2012). Although, phytoremediation is a suitable technique for the efficient removal of Hg from soil, however its toxicity put adverse effects on plant morphology and physiology (growth inhibition of root and stem) (Liu *et al.* 2017). The uptake of essential elements also decreases, and the synthesis of photosynthesis pigment gets inhibited due to the presence of high level of Hg in the plant (Marrugo-Negrete *et al.* 2016). Apart from phytoremediation, the other remediation techniques like soil washing, electro-remediation and immobilization are also used for soil remediation (Wang *et al.* 2012, 2019). Diammonium phosphate and clay minerals enriched with calcium carbonate showed their excellence in immobilization of Hg. Wang *et al.* (2019) reported that the application of above two immobilizing agents at the ratio of 1:50 (w/w) removed 90% of Hg from the solutions. Since, Hg is not easy to be washed out from soil particles due to its strong ability to form complexes with organic matter, and thus the soil washing method is not considered to be feasible for Hg removal (Alloway 2013; Xu *et al.* 2015). Similarly, the electro-remediation technique for Hg removal from soil is affected by the soil pH and requires acidic environment for the treatment (Virkutyte *et al.* 2002).

Research has been carried out on phytoremediation techniques for Hg removal from soil. Marrugo-Negrete *et al.* (2015) used *Jatropha curcas* to evaluate their phytoremediation potential for Hg removal, and found that the maximum Hg concentration was observed in the roots followed by stems and leaves. Their research study showed that Hg translocation from soil to root was high during the second

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Sources, bioaccumulation, health risks and remediation of potentially toxic metal(loid)s (As, Cd, Cr, Pb and Hg): an epitomised review

Deep Raj · Subodh Kumar Maiti

Received: 10 September 2019 / Accepted: 25 December 2019

Abstract The release of potentially toxic metal(loid)s (PTMs) such as As, Cd, Cr, Pb and Hg has become a serious threat to the environment. The anthropogenic contribution of these PTMs, especially Hg, is increasing continuously, and coal combustion in thermal power plants (TPPs) is considered to be the highest contributor of PTMs. Once entered into the environment, PTMs get deposited on the soil, which is the most important sink of these PTMs. This review centred on the sources of PTMs from coal and flyash and their enrichment in soil, chemical behaviour in soil and plant, bioaccumulation in trees and vegetables, health risk and remediation. Several remediation techniques (physical and chemical) have been used to minimise the PTMs level in soil and water, but the phytoremediation technique is the most commonly used technique for the effective removal of PTMs from contaminated soil and water. Several plant species like *Brassica juncea*, *Pteris vittata* and *Helianthus annuus* are proved to be the most potential candidate for the PTMs removal. Among all the PTMs, the occurrence of Hg in coal is a global concern due to the significant release of Hg into the atmosphere from coal-fired thermal power plants. Therefore, the Hg removal from pre-combustion (coal washing and demercuration techniques) coal is very essential to reduce the possibility of Hg release to the atmosphere.

Keywords Potentially toxic metal(loid)s · Mercury · Coal and flyash · Plants and vegetables · Phytoremediation

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Introduction

The increasing level of pollution is a serious threat to the environment and mankind (Fayiga et al. 2018). Fundamentally, the natural and anthropogenic sources are two sources of pollution in the natural environment. Among the two, the anthropogenic sources play the major role in elevating the pollution level. Coal mining and thermal power plants (TPPs) are the major anthropogenic contributors of pollutant to the environment (Li et al. 2018). These anthropogenic sources release potentially toxic metal(loid)s (PTMs) into the environment. The five PTMs, namely arsenic (As), cadmium (Cd), chromium (Cr), mercury (Hg) and lead (Pb), have been recognised as the most hazardous and persistent element (Lee et al. 2006; Ozden et al. 2018). These PTMs have the bioaccumulation capacity in the food chain and may cause serious risk to human health (Modabberi et al. 2018; Raj and Maiti 2019a). Direct inhalation, dermal contact and consumption of PTMs-contaminated water and soil are the main exposure routes of PTMs in humans.

The reported global anthropogenic release of As was 82,000 metric tonnes/year (Jang et al. 2016). In a case

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Mercury remediation potential of *Brassica juncea* (L.) Czern. for clean-up of flyash contaminated sites

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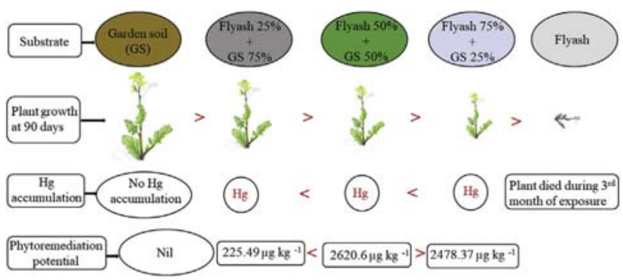
HIGHLIGHTS

- *Brassica juncea* was used for Hg removal from flyash (FA) by pot experiment.
- Enhanced Hg accumulation was found in plant with the increase in exposure time.
- Luxuriant biomass was observed for FA(50%) + GS(50%) with high Hg accumulation.
- Bioconcentration factor suggests *B. juncea* as a moderate Hg accumulator.
- *B. juncea* showed significant phytoremediation potential of 2.62 mg Hg kg^{-1} $plant^{-1}$.

GRAPHICAL ABSTRACT



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ABSTRACT

Apart from Hg mining, coal and its by-products were also recognised as one of the major sources of Hg contamination for the environment causing severe health hazard for human and wildlife. Present study investigates phytoremediation potential (PRP) of Hg from flyash (FA) using *Brassica juncea*. The plants were grown under five different combinations: garden soil (GS) (0% FA + 100% GS), FA25 (25% FA + 75% GS), FA50 (50% FA + 50% GS), FA75 (75% FA + 25% GS) and FA100 (100% FA + 0% GS), and their biometric growth and Hg accumulation in different tissues were observed every month upto 90 days of exposure duration. With increase in time duration, Hg accumulation also increased and mainly accumulated in root followed by stem > leaf however, for FA50 it was root > leaf > stem. Among FA treated combinations, the relative elongation ratio of root and shoot, and their dry biomass increased with increase in time and were significantly higher for FA25 and FA50 combinations. With increase in percentage of FA and exposure duration, the Hg accumulation also increased ($R^2 > 0.964$) and thus Hg content in substrate decreased ($R^2 > 0.852$). The bioconcentration factor of root was enhanced with exposure duration however no changes were observed for TF suggesting maximum phytostabilization potential (0.58 mg Hg kg^{-1} $plant^{-1}$). Non-detrimental effect of Hg and higher PRP of 2.62 mg Hg kg^{-1} $plant^{-1}$ suggests Indian mustard as a promising accumulator species for phytoremediation of FA-contaminated sites when grown on equal proportion of FA and GS, and can show higher PRP if exposed for longer duration.

Abbreviations: Hg, mercury; TPP, thermal power plant; FA, flyash; GS, garden soil; BCF, bioconcentration factor; TF, translocation factor; OC, organic carbon; OM, organic matter; IIT(ISM), Indian Institute of Technology (Indian School of Mines); CV-AAS, cold vapour-atomic absorption spectrophotometer; RER, relative elongation ratio; VI, vigor index; ANOVA, analysis of variance; CRM, certified reference material; SD, standard deviation; DW, dry weight.

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Bioaccumulation of mercury, arsenic, cadmium, and lead in plants grown on coal mine soil

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ABSTRACT

Mercury (Hg), arsenic (As), cadmium (Cd), and lead (Pb) are the major toxic metals released by coal mining activities in the surrounding environment. These metals get accumulated in the soils. The plants grown on the contaminated soil uptake these toxic metals in their roots and aerial parts. This study monitored the bioaccumulation of Hg and other three toxic metals in coal mine soil. The pot study of Hg accumulation in *Brassica juncea* showed that the extent of Hg uptake by roots and shoots of the plants grown on was high in the mature plant and Hg content in root was higher than the shoot. In the soil of unreclaimed overburden (OB) dump, the toxic metal content was higher than that of reclaimed OB dump which posed high ecological risk in the soil of unreclaimed OB dump. Bioaccumulation coefficient (BAC) value showed that Hg was not accumulated in the leaves of *Dalbergia sissoo* L., *Gmelina arborea*, *Peltaphorum inerme* L., *Cassia seamea* L, and *Acacia mangium* L grown on coal mine soil.

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mercury; toxic metals; soils; bioaccumulation coefficient; ecological risk

Introduction

Mining activities lead to toxicological problems in the surrounding environment and imbalance the coal mining ecosystem (Ledin and Pedersen 1996).The toxicological problems in mining areas are caused by contamination with toxic metals which often leach and accumulate in both surface soil and plant (Alloway 2013). Coal mining activities release spoils and dumped at specific place, known as overburden (OB) dump. These spoils are metal-rich solid waste generated during opencast mining of coal. In this process, the waste rocks are exposed to the outer environment and they undergo pedogenesis process for soil formation (Nawab *et al.* 2015). The chemically bound toxic metals are released in soil and become available to the plants (Alloway 2013). Almost all plant species uptake toxic metals present in polluted soil and are transferred to various parts of the plant body through their roots (Kumar *et al.* 1995). Trace metals, especially mercury (Hg), arsenic (As), cadmium (Cd), and lead (Pb) are toxic to the plant system and imbalance the ecosystem of coal mining area (Alloway 2013). Out of all toxic metals, Hg accumulation in soils and its uptake in plant

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