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A review on impact of coal mining on soil properties and reclamation by organic amendments

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ABSTRACT

Coal is one of the most abundant fossil fuel on earth which is involved in the production of power and energy all over the world. Coal mining process generates abundance of mined spoils and waste rocks which oxidizes under atmospheric conditions and releases metal-loaded effluents to the water bodies and soil. These effluents degrade physical, chemical and microbiological quality of soil and, in turn, create threat to human being and ecosystem. New cost effective and environment friendly strategies are needed to restore the disturbed coal mine soil. Therefore, using the organic amendments for the soil restoration may provide such opportunity to reclaim the degraded soil. Organic amendments such as manures, biosolids, pulp, paper, mill sludges, agriculture/crop residues, food processing waste etc. improve the fertility status and biological activity of degraded soil and decrease restoration cost in eco-friendly manner. The objective of this paper is to review the impact of coal mining on soil physico-chemical and biological properties of mined degraded land. This paper also reviews the role of organic amendments in soil reclamation of mine spoils.

***Key words**: Coal mining, Organic amendments, Mine spoils, Reclamation*

Introduction

Coal is the most abundant fossil fuel resource in the country. India ranks as the third largest coal producer of the World, next only to China and USA. It is important constituent of the present Indian economy. Coal Mining is done in two major ways: underground mining and opencast mining. In India more than 85% of the coal production is currently from opencast mines. Opencast mining is a type of surface mining, which entails removing the vegetation, top soil and rock (called overburden materials) above the mineral deposits (Mukherjee and Pahari, 2019), and thus affects the fertility of the surrounding lands (Banerjee and Mistri, 2019).

Coal mining process generates abundance of mined spoils and waste rocks which oxidizes under atmospheric conditions and releases metal-loaded effluents to the surrounding environment. These effluents affect the quality of surface waters and shallow groundwater near the mines.Also, several changes take place in the physical, chemical, and micro-biological characteristics of soil. Masto *et al.* (2015) have assessed that soil quality as one of the key parameters for the evaluation of environmental contamination in the coal mining area. Coal mining activities effect the radical alternations in their geochemical cycles and often lead to land degradation. It changes the soil textural and structural characteristics (Silburn and Crow, 1984). Fine dust particles around coal mining have an adverse impact over a large area. Sometimes these dust particles may be enriched with toxic trace materials including arsenic, cadmium, lead, zinc, chromium, magnesiumand their compounds. Such type of dust, when deposited on land, harms the soil quality and its agricultural production, and health of grazing animals is also affected (Miller *et al*., 2019).

Management of such degraded soil by reclamation strategies should involve soil structure, soil fertility, microbial populations, top soil management and nutrient cycling in order to reclaim the land as closely as possible to its original condition and then continue as a self-sustaining ecosystem. Mine reclamation is one of the important parts of the sustainable development strategy in manydeveloping countries. Good planning and environmental management will minimize the impacts of coal mining on the environment and will help in preserving ecodiversity (Sheoran *et al*., 2010).

Most of the conventional technology are either extremely costly or entails isolation of the waste sites (Sheoran *et al*., 2008a, b). New cost effective and environment friendly strategies are needed to reclaim the disturbed coal mine soil. Therefore, number of organic waste products were used to manufacture soil-forming material may provide such opportunity to reclaim the degraded soil. Adding organic amendments such as manures, biosolids, pulp, paper, mill sludges, agriculture/crop residues, food processing waste etc. to soil improves its quality and functionality. The process has long been recognised as beneficial to the soil's fertility, structure, water retention and buffering capacity (the ability to resist rapid changes in pH)in eco-friendly manner (Schoenholtz *et al*., 1992; Arshi, 2017; Haigh *et al*., 2019).

Effect of Coal Mining on Soil

Opencast coal mining has a series of consequences on land resources and places enormous pressure on the ecological environment. Stripping, excavation, transportation and dumping have different effects on soil physical, chemical and biological properties (Feng *et al*., 2019), inevitably deforests the land, reduces carbon pool and generates different land covers (Ahirwal and Maiti, 2018).

Ghose (2004) assessed the deterioration of soil properties at large opencast coal project of Eastern Coalfields Ltd. (ECL), Godda District Jharkhand. The NPK values were found to decrease with increasing age of soil dumps in compare with unmined soil: N- 151.7-112.5, P-6.5-5.5, K-162.0-121.2kg/ha. The microbial population in soil dumps decreased sharply in compare to unmined soil. The soil porosity was found less due to compaction during excavation. Same was also reported by Javed and Khan (2012). Deteriorated soils of Ledo Colliery reported with less moisture content (9.85%) compared to undisturbed forest soil (23.95%). At disturbed site they also observed the reduced plant cover, less organic matter, poor soil quality and decreased soil water holding capacity. Mohapatra and Goswami (2012) also reported decline in moisture content, porosity, organic carbon, nitrogen, phosphorus level with increasing depth of the soil at Ib river coal field, Orissa.

Kumar and Patel (2013) found low concentration of Nitrogen and Phosphorus in the coal mine dump soils at Basundhara. Makdoh and Kayang (2015) studiedthe physical and chemical properties of the soil at coal mining area of Khliehriat, East Jaintia Hills District, Meghalaya. They observed low moisture, decreased bulk density, low pH of soil, and high concentration of metals (Cu, Zn, Fe, and Mn). Also observed low organic carbon content, low rate of humification, lack of microbes in top soil. Tapadar and Jha (2015) reported high organic carbon at both the disturbed and undisturbed soil at Ledo colliery open cast mine at Tinsukia district of Assam, India. They also observedlow concentration of N, P and K in mine spoils. Calcium concentration of disturbed soil was also found low (160.72 ppm) compared to undisturbed forest soil (424.81 ppm) might be due to excavation and weathering of calcium rich rocks.

Microbial and bacterial population has been found declined at coal mined degraded land. Majumder and Palit (2016) conducted the study to determine the microbial diversity of soil in some coal mine generated wasteland of Raniganj Coalfield area West Bengal. Seven different soil samples were collected from seven different sites namely Nagrakunda, Topsi colliery, Sidhuli, Sankerpurkenda, Bankola, Parascul, Sonepur Bazari of Raniganj Coalfield. They found heterotrophic, gram negative, phosphate solubilizing bacterial population was quite high in Sankerpur Kenda area whereas gram positive bacterial population was low in this area. Nagrakunda showed much higher gram negative bacterial population whereas Bankola showed lower gram negative, nitrate reducing and phosphate solubilizing bacterial population with low organic carbon, potassium content. Gram positive bacterial population was high in Topsi colliery and Sidhuli showed high nitrate reducing bacterial population. Different area of Raniganj coalfield showed different picture of bacterial population with low nitrogen (except Bankola site), potassium (except Nagrakunda site), organic carbon (except Sonepur Bazari site) and medium phosphorus content (except Sidhuli site). Likewise Saini *et al.* (2016) studied the Jharia coal-field and reported that soil has poor texture, low organic matter, and exhibits change in nutrient content due to heavy metal toxicity, change in pH and electrical conductivity. The soil friendly organisms (bacteria, nematodes, earthworms, etc.) die under such harsh conditions, thus limiting the ability of the soil to support vegetation. The existing vegetation also dries up and ultimately dies due to the lack of water and other nutrients.

Coal mining is also associated with high concentration of salinity such as dissolved salts Ca, Cl, No_3^- and So_4^{2-} (Daniels and Zipper, 1997). Salinity has been found to be responsible for delay of germination of seed and inhibition of plant growth (Almansouri *et al*., 2001).

High concentration of heavy metals in the soil at coal mined land has been reported by various researchers. Nessa and Azad (2008) reported the increased concentrations of heavy metal in the mine spoils of Makum Coal field, Assam. Bhuiyan *et al.* (2010) determined the heavy metal concentration in coal-mined affected agricultural soil in northern Bangladesh. The average concentration of Ti, Mn, Zn, Pb, As Fe, Rb, Sr, Zr exceeded the world normal averages and in some cases Mn, Zn, As and Pb exceeded the toxic limit of the respective metals. Cr and Ni concentration was determined high in Bhowra open cast Jharia Coal mine Jharkhand by Masto *et al.* (2011). Ladwani *et al.* (2012) assessed heavy metal contaminationin the soil near coal mining area in Gujarat.The available levels of Cd, Cr, Co, Cu, Mn, Ni, Pb and Zn were found 0.41-0.77, 3-8.0,5.6-19.0, 9.1-57.0, 47-121, 7.1-16.0, 3.4-9.0 and 13-60 mg/kg, respectively, while the international standards were 0.06, 100, 8, 30, 600, 40, 10 and 50 mg/kg, respectively. Soils around the mine were also polluted with Cd, Cr, Co, Cu, Mn, and Ni followed by Pb and Zn. Biswas *et al.* (2013) also reported high acidity of the coal mine soil dumps. Tapadar and Jha (2015) studied the soil properties of Ledo Colliery of Tinsukia district of Assam. Thecoal mine soil dumps were found highly acidic as compared undisturbed forest soil. The average pH of the disturbed soil was reported 4.53 as compared to 5.83 ofundisturbed forest soil. High level of potential acidity (low pH) severely restricts the productivity of mine soils. Boruvka *et al.* (2010) reported altered soil characteristics of coal mine dumps. The average sulphur content of the coal in the Gondwanawas determined below 1%, which was found increased to 8% in the Jharia Coalfield; the average being within 3.5%. The sulphur content of the semi-anthracite deposits of Raniganjwas reported higher up to 9% (Ghose, 2004).

Masto *et al.* (2015) studied SonepurBazari mine of Raniganj coalfield and stated that coal dust comprises Fe, Cu, Zn, Mn, Pb, Cd, Cr, Ni etc and organic pollutants. Pandey *et al.* (2016) analysed 25 samples from 25 different sites from Jharia coal field and reported that Cu and Zn overstepped their respective critical limit in the soil. High concentration of heavy metals in the soil at mine site Gevra coal mine, Korba district, Chhattisgarh has been reported by Priyanka and Singh (2017). The accumulation pattern showed that zinc had higher accumulation (0.998) mg/L followed by copper (0.45) mg/L and lead (0.236) mg/L at contaminated site than control site zinc (0.194, copper 0.08 and lead 0.099) mg/L respectively. Similar observation of metal contamination was observed by Manna and Maiti (2018) in mine affected soil of Raniganj Coal field.

Acid Mine Drainage (AMD) are the main effluent generated from active as well as abandoned mines. The exposure of rocks consisting of ferrous or ferric sulphide minerals to water and oxygen results in generation of AMD (Saha and Sinha, 2018). Goswami (2015) reported acid mine drainage (AMD) as main problem of the North Eastern Coalfields of Assam, Arunachal Pradesh and Jammu and Kashmir and in the Raniganj and Jharia coalfields also. The high acidity of the dumping soil may be due to acid mine drainage (AMD) as was reviewed by Johnson and Hallberg (2005). Ghose (2004) reported that increased acidity in the soil makes it nutrient deficient, while increased availability of heavy metals in the soils results to the toxic effects on microbial populations and thus reduced the plant growth. Acid Mine Drainage (AMD) is formed by breaking of coal and leaching pyrite of sulphur content from the coal and surrounding. AMD is characterised as yellow sludge with the smell of H_2S and an increased pH value. Overburden and acid drainage from coal mining is convertingfertile and productive agricultural lands to unproductive wasteland in some parts of North-east India. Dutta *et al.* (2018) reported that Ledo coalfield of Northeast India produces considerable amounts of AMD. The leachates generated from overburden dump were found rich in heavy metals specially Fe, Cu, Mn and Ni.

Management of Mine Degraded Soils by Organic Amendments

Mine spoils and stored topsoil are usually deficient in nitrogen, carbon and phosphorus. Disturbance of the soils during removal for mining disturbs plant and microbial growth and this disturbs the normal nitrogen cycle of the soil. In warmer climates, as in India, the lack of moisture in the relocated soil will also reduce growth of plants and soil bacteria. In order for these soils to become reusable, they must undergo some form of restoration (Tripathi and Singh, 2008).

Management of coal mine degraded soil primarily includes soil-building process. Topsoil management plays an important role in reclamation plan to prevent nutrient losses (Paramasivam and Anbazhagan, 2019). In natural systems, drastically disturbed lands undergo a succession of living organisms that may take decades or even centuries for successful colonization to occur (Nikhil, 2007). Typically, the degraded soil has a naturally low fertility level and poor water-holding capacity. Soil microbial populations and beneficial mycorrihizal fungi are low or not present (Carlson *et al.*, 2015).

For the rapid reclamation of such soil it is essential to restore the soil productivity by the application of certain amendments. Organic matter in the form of dead leaves, stems and roots in a soil forms protective mulch which reduces soil erosion and water evaporation. In the process of composting, decomposed organic matter (humus) binds soil nutrients to its surface. Humus slowly releases soil nutrients, which can be used by plants. Without humus, soil nutrients added by fertilizing are quickly leached out of the rooting zone before the plants have the opportunity to use them. Soil organic matter also feeds beneficial soil organisms that break down humus and release soil nutrients, especially nitrogen and phosphorus. Once organic matter and soil organisms are present in the mine soil, nutrients can by cycled from dead plants to humus,then from humus to living plants to begin the process again. This process is called nutrient cycling. The more organic matter that is produced, the more nutrients are stored by the humus and clay particles until an equilibrium is reached. Productivity on reclaimed mine soils is directly related to the amount of organic matter present and the amount of nutrients being cycled in the soil (Larney and Angers, 2012; Ahirwal *et al.*, 2018).

The composting is currently viewed primarily as a bio-waste management method tostabilize organic waste, such as manure, yard trimmings, municipal biosolids, and organicurban wastes. The stabilized end-product (compost) plays a crucial role in enhancing the physical, chemical, and biological properties of degraded lands, thereby improving soil health. These bio-wastes are extensively used as an ideal soil amendment for land reclamation of eroded soil (Tian *et al.*, 2006). These are a good source of organic matter and essential nutrients in soils. Large quantities of bio-wastes such as biosolids, municipal solid waste, animal and poultry manure, papermill sludge, and plant residues are generated as the consequences of human population increment and, subsequently, expansion of livestock or poultry industries. Haigh *et al.* (2019) applied composted Municipal Green Waste at Opencast Coal Land in Wales and reported increased soil loadings of total N, P, soluble K, Ca, and Mg. They also observed significant increase in forest canopy cover, tree density and size.

Top soil can be amended with organic materials, mulches, pH adjustments, fertilisers and their soil amendments. In some cases, deeper soil from the mine workings can be mixed with top soil. The amount and type of fertiliser needed to ameliorate top soils will depend on the state of the soil on the mining land and the projected future use of the site-whether the land will be returned to forestry or to agricultural use. Commercial fertilisers can be used. Some sites have tried remediation with sewage sludge, which can provide a longer-lasting nitrogen dose to the topsoil. Other organic residues obtained from agricultural practices can also help with soil structure and water-holding capacity. Such organic additives can be very effective for returning and enhancing microbial activity to soils (Tripathi and Singh, 2008; Sheoran *et al*., 2010; Carlson *et al*., 2015).

The acidity of the soils is of major importance for ensuring return of plant growth. If the soil is alkaline then organic matter can be combined with the top soil and alkaline tolerant plant species can be seeded. If the soil is acidic (low pH) then lime and fly ash can be applied. If the heavy metal content of the soil is too high then organic matter can be applied along with the growing of metal tolerant plant species. In the case of high salinity, gypsum can be applied or the irrigation of the site can be altered (Bian *et al*., 2010). Nitrogen is usually the limiting nutrient in the rehabilitation of mine soils as soil nitrogen is commonly restored by microbial and plant activity which is disturbed during soil relocation. Planting appropriate plants into the mine soil will help restore the nitrogen balance within five to ten years of reclamation (Tripathi and Singh, 2008).

Improving the fertility and health of the eroded soils through amendment is critical for reclamation of disturbed coal mine spoils. Stark *et al.* (1994) applied spent mushroom compost to treat synthetic coal mine drainage. Redox potential (Eh) was lowered and pH was elevated by the compost. The capacity of the compost to retain iron was also found increased. Spargo and Doley (2016) reported increased total N, P, Cu and Zn, soluble K, Ca and Mg, and significantly reduced soluble Na and pH when applied compost to both topsoil and overburden, at a coal mine in the Hunter Valley, New South Wales. Vermi-composting has been practiced by many researchers at coal mined degraded soil. Duraiand Murugan (2013) incorporated coal mine spoil with Vermi-compost and Vermi-leachate for the reclamation. Four dozes of vermi-compost and vermin-leachate and three dozes of vermin-leachate were applied 150/kg of coal mine dumps. To each treatment, sand was incorporated at the rate of 7.5kg, 15kg, 22.5kg, and 30 kg to enhance spoil porosity. The results indicated that pH of the treated soil was decreased. Hence amendment of organic fertilizer leads to enhance spoil porosity, organic carbon for the better environment for the plantation of forest species in coal mine dumps. Similarly Arshi (2017) reclaimed the overburden dump of ECL, Coal field, Lalmatia, Jharkhand with the vermicompost soil. The vermicompost component of the treatments helpful in amending overburden dumps soil texture as well as also provides nutrients for rapid growth of Vesicular Arbuscular Mycorrhizal fungi and multiplication of Rhizobial cells for the development of nodulation in plants. Role of vermicompost in reclamation of coal mined land was also studied by the Emmerling and Paulsch (2001).

After the establishment of the Surface Mine Reclamation Act of 1977 biosolids composts are commonly used for mine land reclamation (Sopper, 1992; Haering *et al*., 2000). Biosolids can be improves mine soil deficiencies such as low organic matter, CEC, pH, and nutrients (Forsberg and Ledin, 2006; Ojeda *et al*., 2010). Biosolidsusually contain 1% to 6% nitogen, depending on the source and processing (Center for Urban Horticulture, 2002). Biosolids and sewage sludge also can be used to reconstruct and manufactured topsoil and even incorporated into degraded soils to increase vegetation growth (Brown *et al*., 2003).Branzini and Zubillaga (2011) reported biosolid compost and phosphate fertilizer for their effective ability in reducing mobility of Cu, Cr, Zn.

Emmerling *et al.* (2001) studied the impact of application of organic waste materials (sewage sludge, coal sludge, composted sewage sludge and compost) on microbial and enzyme activities of mine soils in the Lusatian Coal mining region. In this study they found that with increasing application rates of these organic wastes microbial respiration, substrate induced respiration and enzyme activities (invertase and alkaline phosphatase) also increased. Grobelak and Napora (2015) observed the immobilization of the heavy metals (Cd, Pb and Zn) when applied the organic amendments (after aerobic sewage sludge digestion in the food industry) and inorganic amendments (lime, superphosphate, and potassium phosphate) on the soils contaminated with heavy metals.

Wood chips are another frequently used surface-applied amendment on mine sites. Wood chips add few soil nutrients, but they promote biological activity during decomposition, thereby having the potential to increase soil organic matter content and increasing soil water holding capacity by changing soil structure (Edwards *et al*., 1992; Walsh and Redente, 2011). Organic C can also change water retention because it forms polysaccharides that bind soil particles together, causing aggregation and allowing infiltration. Wood chips also reduce surface evapotranspiration. In a reclamation project on mine land in North Idaho, Walsh and Redente

(2011) found increased organic matter, ammonium-N and nitrate-N after 4 years by adding wood chips. Wood chips on the soil surface also block direct sunlight, keeping the soil cool and reducing evaporation (Schoenholtz *et al*., 1992). Nada *et al.* (2012) studied the effect of wood compost on extreme soil characteristics in the Lusatian Lignite Region. They reported improvement in physical properties such as water holding capacity and bulk density in soil ameliorated with compost. Chemical properties of degraded soil were found increased significantly with the increase of compost application rates, particularly organic matter content, total nitrogen and cation exchange capacity. Treated soil also showed a significant increase in grass biomass (fresh and dry matter yield). They revealed that addition of wood compost had significant positive effects on the soil physical and chemical properties, which affected the response of plant growth and can facilitate the revegetation of substrates contaminated with coal spoil.

Ashrafi *et al.* (2013) studied the effect of two low-cost amendments, inorganic eggshell and organic banana stem for the purpose of in situ immobilization of Pb, Cd, and Zn. They observed eggshell amendment notably decreased mobility of Pb, Cd, and Zn in the soil by transforming their readily available forms to less accessible fractions. Banana stem amendment also reduced exchangeable form of Cd and increased its residual form in the soil. Similarly, Soares *et al.* (2015) evaluate the capacity of compost obtained by co-composting of industrial eggshell to immobilise lead and zinc in an acidic soil contaminated by mining activities. This raised the soil pH and reduced the soil mobile fraction for both Pb and Zn, in more than 95%.

Various organic and inorganic amendments such as manures, sludge, litter, fertilizers, lime are important amendments that develop the soil biological system and create the correct soil conditions to allow the plants to stand in such soil and complete their life cycles. Ashlee *et al.* (2008) treated surface coal mine in Schuylkill County, Pennsylvania for field reclamation with various amendments includes a lime and fertilizer, composted poultry layer manure and fresh poultry manure mixed with paper mill sludge. They reported that composted poultry layer manure or fresh manure mixed with paper mill sludge are effective strategies to facilitate establishment of sustained vegetative cover on mined lands. Composted poultry manure was reported superior at controlling N and P loss. Likewise, Mushia *et al.* (2016) also observed higher growth rate of selected plants when the soil at coal mine near Witbank in the Mpumalanga province of South Africa amended with poultry manure and lime. Mukhopadhyay and Masto (2019) added farmyard manure (FYM), chicken litter (CL), plant litter (PL), and biochar (BC) to mine spoil in the presence and absence of fly ash (FA) at Jharia Coalfields (JCF), Dhanbad, India. They reported highest cumulative CO_2 emission for plant litter-added mine spoil and lowered for the fly ash amendment. They also observed higher substrate-induced respiration, microbial biomass carbon and dissolved organic carbon (DOC) with the amendment PL, CL, and FYM. Contrary result was obtained for Fly ash that although it increased microbial biomass carbon but decreased DOC. Fly ash decreased CO_2 emission from mine spoil is attributed on the interaction of organic matter with the surfaces on fly ash and the resultant physical protection against microbial decomposition.

Read *et al.* (2019) reported higher pH, organic matter, and extractable P with poultry litter than NPK fertilizer when applied poultry litter (22.4 Mg/ha), swine mortality compost (22.4 Mg/ha), and NPK fertilizer (896 kg/ha), with and without co-application of 11.2 Mg/ha flue gas desulfurization (FGD) gypsum at a surface lignite mine in northeast Mississippi. The poultry litter, swine compost, and NPK fertilizer along with FGD gypsum decreased organic matter of surface soil by approximately 33, 6, and 12%, respectively. Poultry litter application also improved soil fertility; growth of Bermuda grass and canopy height in mine degraded soil.

Conclusion

Mining industry held second position after the agriculture as the World's oldest and most prominent industry. Mineral and mineral based products are integral parts of the economic and social development of the society. Coal is a valuable resource. It provides a significant amount of the world's energy supply and it is the basis for many industries. Mining activities lead to significant degradation of the ecosystem ascause's damage to land, soil, water, flora, fauna as mining land gets disturbed. Long-term and large-scale measures are required in order to build greater resilience in a coal-mine degraded soil. The management of overburden dumps

(OBDs) and degraded soil through the application of organic composts is low cost environmental friendly technique for significant improvement in fertility status and biological activities of the overburden dumps and contaminated soil. Reclamation activities should also focus on decreasing the degree of metal mobility in the soil profile and metal bioavailability to levels that are not phytotoxic. Extensive and elaborate studies and research need to be done at laboratory scale and at field to assess the impact of coal mining on soil, air, surface water, ground water and biodiversity in India. In India, more effort should be made toperform research on effective, low cost and environmental friendly organic material and composts and to generate some effective combinations and then should be practiced at field. Further, it is necessary to encourage and focus on alternative clean sources of energy to meet future energy demands. Proper implementation of regulatory rules and policies is as important as other management strategies to deal with environmental issues.

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