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Assessment of soil characteristics in the vicinity of open cast coal mine and its suitability for vegetative reclamation in Charhi and Kuju of Jharkhand, India

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Abstract

Coal mining is inevitable for economic growth of a country, but at the same time deteriorates the quality of the environment. Open cast mine, especially affects the top soil most negatively. In the present study, soil samples from three representative areas of mining *viz* proposed, operational and abandoned sites from Charhi and Kuju of Jharkhand were collected and analysed for physico-chemical parameters and metals with an objective to determine their suitability for vegetative reclamation. Soil samples appeared to be slightly acidic (5.97 ± 0.66) with low EC values (101± 76 μScm^{-1}) , total organic carbon (0.71 ± 0.35 %), organic matter (1.34 ± 0.66 %) and overall nutrient, especially nitrogen (167± 64 kg ha^{-1}) contents than required for reclamation by revegetation. However, bulk density was found conducive for reclamation. Total Cr (317 ± 287 to 417 ± 393 mg kg^{-1}), Cu (121 ± 72 to 344 ± 143 mg kg^{-1}), Ni (171 ± 46 to 373 ± 134 mg kg^{-1}) and Pb (114 ± 115 to 182 ± 145 mg kg^{-1}) content were found to be higher in soil. Sitewise variation was also significant for Cu and Ni. Pearson's correlation suggested significant ($p \leq 0.05$) positive inter elemental correlation between Cr-Fe, Cr-Mn, Cu-Ni, Fe-Mn and Mn-Ni. Positive geoaccumulation index (Igeo) values for all the metals except Fe, overall contamination degree of 31.10 and significant enrichment factor indicated considerable contamination. This baseline data could be utilized for vegetative reclamation planning of the study area in future.

Key words

Correlation, Geostatistical calculations, Heavy metals, Open cast coal mine, Reclamation.

Introduction

Coal mining operations damage the environment and ecosystem to an unacceptable degree. Sustained utilization of land resources after mine closure therefore, requires concurrent conservation and reclamation initiatives. Reclamation by various physical and biological processes converts degraded land to productive land with sustained benefits. This also helps to preserve and maintain eco-diversity similar to pre-mining conditions. Till date several researchers have reported various effects of mining on the environment (Ekka *et al*., 2011). Generally physical, chemical and microbiological properties of soil are affected in the process of opencast mining, spoiling the top soil layer and making it unfit for growth of vegetation (Ghosh, 2004; Biswas *et al*., 2014). Growth of vegetation or plantation on overburden dumps for post mining land reclamation is usually difficult due to deficiency of nutreints (Rai *et al*., 2011). Coal mining also causes enrichment of a number of heavy metals into the surroundings waste dumps and tailings, which due to their persistent nature is a subject of concern for the environment and human health (Anh *et al*., 2011). These heavy metals find their way to nearby water bodies and agricultural crops grown in the vicinity of mining areas and lead to bioconcentration and biomagnification in food chain (Roy *et al*., 2010; Dutta and Ghosh, 2013). Regular

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monitoring of heavy metal pollution and concurrent mitigation is required for their management to reduce their detrimental effects on local people. Several reports on deleterious environmental and social impacts of coal mining in Jharkhand including groundwater contamination, forest clearing, biodiversity loss, subsidence and threat to local communities (Priyadarshi, 2010) are available. In the present study, a comparative analysis of the physico chemical quality of soil, including total metal concentration, was conducted and their geostatistical characteristics was calculated to ascertain the degree of contamination in three phases, namely proposed, operational and abandoned mining sites in Charhi and Kuju. The purpose of the present study was to find out the impact of coal mining activities, and asses the suitability of mining areas for vegetative reclamation after mine closure to restore land use and ecosystem services.

Materials and Methods

Study site, soil sampling and analyses : The present study area, Kuju and Chari Coal Mining areas were divided into 3 representative areas of mining (operational, abandoned and proposed) (Fig. 1) and adjacent to each type, 10 mine soil samples were collected randomly from 0-15 cm soil depth by digging pits (15×15×15 cm^3 size). Soil samples were collected in polythene air tight bags, brought to the laboratory and were stored at 4°C for further analyses.

Soil moisture (%) was calculated according to the gravimetric method by the following formula :
MC = (Wet mass - Dry mass/ Dry mass) x 100.

Texture of soil was analysed using sieves and gravatory shaker. Soil collected in different sieves was weighed again and the percentage of sand silt and clay was calculated. Soil bulk density was determined according to the method of Black (1965). Soil pH and EC was measured by electronic digital pH meter (Make: YSI Professional PlusQuatro cable 6050000). Total organic carbon of soil samples were determined by Walkley- Black chromic acid

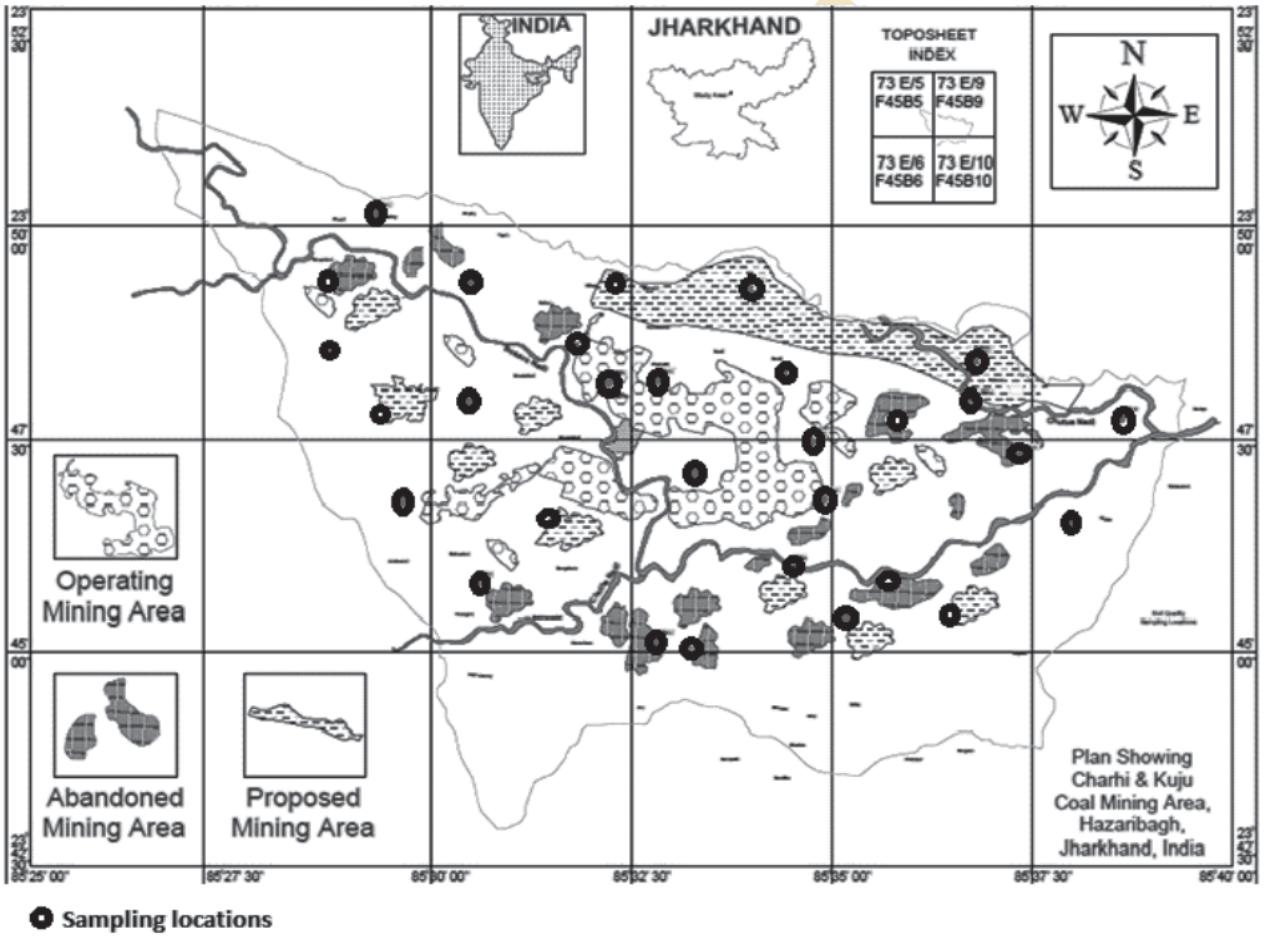

Fig. 1 : The study area of Charhi and Kuju coal mining areas of Jharkhand

wet oxidation method (Bartlett *et al*., 1994). Organic matter was calculated by using the values of organic carbon, and by the formula (Organic matter (%) = Organic carbon (%) x 1.9) given by Maity (2003). Total nitrogen content was determined by steam distillation technique (Bremner and Keeney, 1966). Available phosphorus was estimated by the method of Olsen *et al*. (1954). Potassium was estimated with the help of flame photometer (Toth and Prince, 1949).

Elemental extraction and estimation of soil samples: Dried and powdered soil (0.25 g) was microwave digested using EPA method '3051 A' (US Environmental Protection Agency, 1998) followed by cold digestion for 10 min with freshly prepared aqua regia (10 ml). Digested samples after cooling for 15 min were diluted up to 50 ml with 1% (v/v) HNO_3 and allowed to stand overnight. Diluted samples were filtered through 0.45 µm cellulose acetate disposable filters and elements were estimated by ICP OES 2100DV.

Statistical analysis: Correlation statistics and level of statistical significance were analyzed using Microsoft Excel and SPSS 19.0 (statistical software). The *p* value ≤ 0.05 was considered to indicate statistical significance.

Contamination factor (CF), Enrichment factor (EF) and geo-accumulation index (Igeo): Contamination factor (CF) was calculated according to the formulae $CF=C_N/B_N$ given by Turekian and Wedepohl (1961). According to Hakanson's classification in 1980 there are four categories of CF. $C_f < 1$- Low contamination factor indicating low contamination. $1 \leq C_f < 3$-moderate contamination factor, $3 \leq C_f < 6$ considerable contamination factor and $6 \leq C_f$ very high contamination factor.

Enrichment factor (EF) was based on standardization of tested element against a reference element (Fe) by the formula: $EF=(M/Fe)_{Sediments}/(M/Fe)_{Shale.}$. Five contamination categories were recognized on the basis of enrichment factor (Sutherland, 2000) The values were interpreted as: *EF < 2:* Deficiency to mineral enrichment; *EF = 2-5:* Moderate enrichment; *EF = 5-20:* Significant enrichment; *EF = 20-40:* Very high enrichment: *EF > 40:* Extremely high enrichment.

Geoaccumulation index (I_{geo}) was calculated by the following formula:, $I_{geo} = Log_2 C_N/1.5 B_{N.}$ Where, C_N is the measured content of element and B_N is the average shale content. The seven proposed descriptive classes by Muller (1981) for *I*geo values are: a) value > 5, class 6 meaning extremely contaminated; value 4-5, class 5 meaning strongly to extremely contaminated; value 3-4, class 4 meaning strongly contaminated; value 2-3, class 3 meaning moderately to strongly contaminated; value 1-2, class 2 meaning moderately contaminated; value 0-1, class 1 meaning uncontaminated to moderately contaminated and value 0, class 0 meaning uncontaminated (Chakraborty *et al*., 2014). The world average concentration of these elements reported for shale was considered as the background values (Turkian and Wedepohl, 1961).

Results and Discussion

Physico-chemical parameters of soil samples are summarised in Table 1. Texture analysis revealed dominance of sand fraction in all the three phases of soil samples (Fig. 2). Sand, silt and clay content varied from 74 to 82.9 %, 9.6 to 18.4% and 7.5 and 7.7%, respectively. Soil appeared to be loamy sand type (USDA classification). Therefore, commonly used soil amendments like straw, mulch cover would be required to conserve soil moisture and ameliorate optimal condition for revegetation and reclamation.

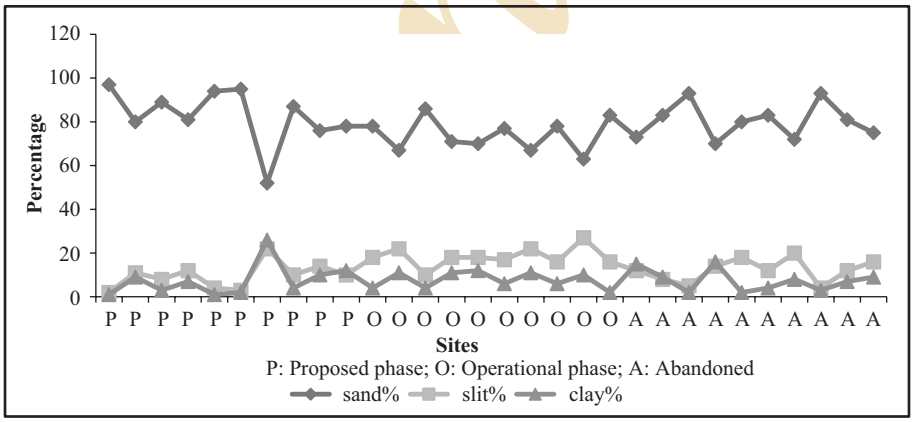

Fig. 2 : Sand, silt and clay composition of soil samples at three phases of mining

Table 1 : Average values of physico-chemical parameters of soil at different phases of mining

Parameters	Mean ± SD (Minimum to Maximum)
MC (%)	4.31 ± 2.14 (1.00 – 8.77)
BD (gcc^{-1})	1.42 ± 0.05 (1.32 – 1.52)
pH	5.97 ± 0.66 (4.8 – 7.65)
EC ((μ scm^{-1})	101± 76 (37.5 – 473)
TOC (%)	0.71 ± 0.35 (0.24 – 1.77)
OM (%)	1.34 ± 0.66 (0.54 – 3.35)
N ($kg\ ha^{-1}$)	167± 64 (71– 314)
P ($kg\ ha^{-1}$)	5.79 ± 6.07 (0.38 – 23.31)
K ($kg\ ha^{-1}$)	110 ± 56 (42 – 296)

Moisture content varied between 1.0 to 8.77% with a mean value of 4.31 ± 2.14%. Minimum average field moisture required for growth of plants was 5% and thus, the MC content of majority of the samplings sites were not suitable for plantation. Bulk density was found to be varying between 1.32 to 1.52 gcc^{-1}, indicating good soil according to the classification of Bradshaw (1980). Low bulk density is generally linked to high organic matter content in soil (Leelavathi *et al*., 2009). The mean pH values of soil samples was found to be 6.09 (in proposed), 6.06 (in operational) and 5.79 (in abandoned). Growth of plants are affected negatively both in very low, as well as high pH (Rai *et al*., 2009). pH range of 6.5 – 7.5 has been said to be optimal for plant nutrient avaialability (Rai *et al*., 2011). Data showed slightly low pH, which might be due to oxidation of pyrite present in coal.

Mean value of EC was found to be 101 ± 76 μScm^{-1} ranging between 37.5 to 473 μScm^{-1}, lower than other reports of Jharkhand's coal mining areas (Rai *et al*., 2009; 2011). Among the different phases, EC was found to be slightly higher in the abandoned mining areas. TOC ranged between 0.29 to 1.04% in the operational phase, 0.32 to 1.77% in proposed area and 0.3 to 1.28% in abandoned area with an average value of 0.71 ± 0.35 %. Data showed higher values in the proposed area which might be due to more natural vegetation in the proposed sites. Organic carbon levels above 0.8% are good for plant growth, and less than 0.4% is unfit for plantation (Rai *et al*., 2011). Organic matter in the present study ranged from 0.46 to 3.35% with higher values in proposed areas as compared to other phases.

Nitrogen content varied between 71to 314 $kg\ ha^{-1}$ with few sites containing less than the normal values irrespective, of type of sites. According to (Gupta *et al*. 2006), normal soil contains 272 – 544 $kg\ ha^{-1}$ of available nitrogen. Mined soil generally show less nitrogen due to lack of organic nitrogen and consequently, less mineralized inorganic nitrogen (Gairola *et al*. 2014).

Phosphorus was found to be higher in proposed and abandoned areas. Overall range of phosphorus ranged between 0.38 to 23.31 $kg\ ha^{-1}$. Some of the earlier reports of phosphorus content in soil of coal mining areas of India were 3.42 to 5.51 $kg\ ha^{-1}$ in Jharia coalfield (Rai *et al*., 2009), 1.11 $kg\ ha^{-1}$ around the Ib river coalfield, Orissa (Mohapatra and Goswami, 2012).

Potassium was found ranging between 42 $kg\ ha^{-1}$ to 296 $kg\ ha^{-1}$ indicating slightly higher concentration in the abandoned and proposed mining site's soil, though statistically insignificant.

Analysis of heavy metals in soil samples from different phases of mining revealed all the elements Cr, Cu, Ni and Pb to be higher than the normal concentration, generally found in soil, indicating the study area to be contaminated with these heavy metals up to considerable level.

I_{geo} value of the metals in all the three phases indicated all the metals, except Fe, to be positive suggesting moderate to considerable enrichment (Fig. 3). EF values, however, indicated minimal enrichment of Cr (0 – 1.86; mean 0.75 ± 0.43), Cu (0.28 – 8.70; mean 1.62 ± 1.87), and Ni (0.26 – 4.47; mean 1.08 ± 0.86) and moderate enrichment for Pb (0 – 13.71; mean 2.81 ± 3.27). Overall contamination degree (C_{deg} = 31.10) was found to be notable.

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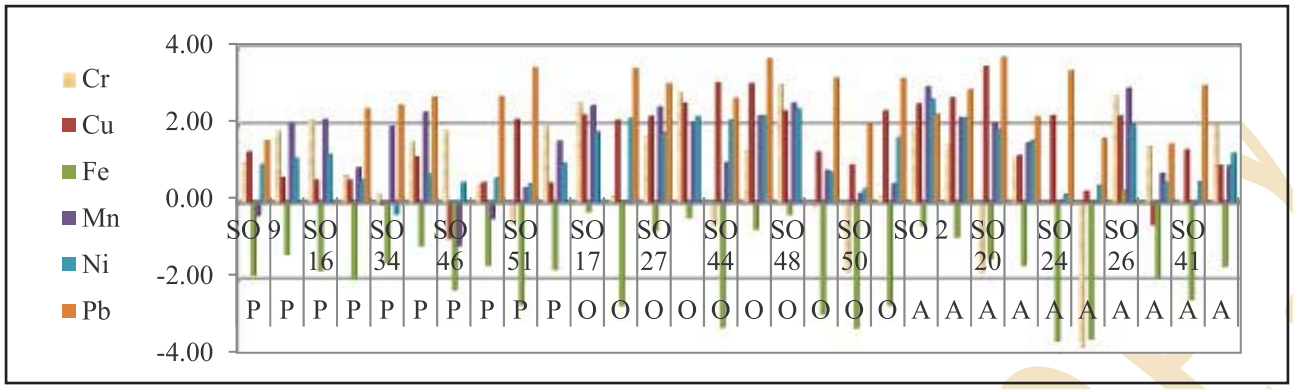

Fig. 3 : I_{geo} values of metals in soil samples of three phases of mining (P-Proposed; O- Operational; A – Abandoned)

Chromium in the environment is important for its mobility and adsorption characteristics (Srinivasa *et al*., 2010). Chromium content ranged below detectable limit to 1100 mg kg^{-1} with an average value of 337 ± 175 mg kg^{-1} in the proposed area, 417 ± 393 mg kg^{-1} in the operational area and 317 ± 287 mg kg^{-1} in the abandoned area. Cr content indicated that most of the samples to be moderately polluted with few sites in the operational area to be highly polluted (Omotoso and Ojo, 2015). However, mean enrichment factor for Cr was 0.75 representing deficiency to minimal enrichment (Sutherland, 2000). Mean contamination factor was 3.97, representing considerable contamination (Chakraborty *et al*., 2014). Copper concentration in soil samples ranged from 35 to 762 mg kg^{-1} with an average concentration of 121 ± 72 mg kg^{-1} in the proposed area, 344 ± 143 mg kg^{-1} in the operational area and 281 ± 215 mg kg^{-1} in the abandoned area (Table 2), respectively. Average concentration (344 mg kg^{-1}) was found to be higher in soil samples of operational phase as compared to other samples showing significant site wise variation (F= 7.38 and F_{crit} = 3.35). I_{geo} for Cu was 2.22 in the operational phase of mining soil samples indicating moderate pollution (Ololade, 2014). EF-Cu varied from 0.28 to 8.70, suggesting significant enrichment in certain areas. Contamination factor was 5.53 indicating considerable contamination. Fe concentration in soil samples, in the present study area, ranged between 0.55 to 8.00 % with a mean value of 1.93 ± 0.55 % in proposed area, 2.75 ± 2.05 % in the operational area and 2.60 ± 2.22 % in the abandoned area, respectively. Contamination factor suggested high contamination in the operational (5.84%) and abandoned sites (5.51%).

The mean Mn concentration in soil samples ranged between 580 mg kg^{-1} and 10060 mg kg^{-1}. Ni content ranged between 82 and 642 mg kg^{-1}. Sitewise variation of Ni was significant in three phases (F = 6.196; F_{crit} = 3.354). Mean values were 171 ± 46 mg kg^{-1} in the proposed, 373 ± 134 mg kg^{-1} the operational and 299 ± 174 mg kg^{-1} in the abandoned phases, respectively. Though I_{geo} values suggested least contamination (range = 0.70 to 1.75), while contamination factor (range = 2.53 to 5.49) indicated considerable contamination. Lead occurs as a trace element in coal, and typical pleconcentration in bituminous coal ranges between 3-111 ppm on burning one ton of coal lead to 4.2 x 10-4 pounds of lead (EPA, 2001a). As high as 400 mg kg^{-1}Pb was recorded in soil samples collected from the abandoned mining areas (Table 2). Highest average Pb concentration in the operational area was found to be 182 ± 145 mg kg^{-1} while I_{geo} values of Pb in three phases indicated moderate to high pollution intensity (Chakraborty *et al*., 2014). Mean contamination factor was 7.69 reflecting very high contamination of Pb in the surface sample soils of the study area.

Analysis of inter-element Pearson correlation in soil samples showed positive correlation with significant probability ($P < 0.05$) between Mn/Cr (0.66), Mn/Fe (0.86) and Mn/Ni (0.64). Fe/Cr (0.81) and Ni/Cu (0.71). Mn was also positively correlated at $P < 0.05$. However, Cr was found to be negatively correlated with Pb. Relationship between Cr and Fe and Mn might be probably because they originated from identical source. It was same for Cu and Pb, which also indicates possible common pollution sources, as well as, common sink. A positive correlation between the metals might be due to geogenic sources in the study area.

The study indicates that the study area in its present condition is contaminated with heavy metals which though presently does not pose risk, but in acidic environment will lead to leaching and subsequent passage to groundwater.

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