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Influence of open cast mining on the soil properties of Ledo Colliery of Tinsukia district of Assam, India

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Abstract- Open cast coal mining cause severe alteration of soil characteristics that leads to instability and functional irregularity of ecosystem. The present investigation, therefore, was carried out to evaluate the role of open cast coal mining in alteration of native soil characteristics. Soil samples are collected from disturbed soils of Ledo colliery and undisturbed forest soil. Soil characteristics of Ledo colliery deviated from forest soil. The pH of the disturbed soil was 4.53 compared to 5.83of undisturbed forest soil. Open cast mining significantly ($P<0.05$) altered the soil pH from normal forest soil. Statistically insignificant deviation of soil Temperature, MC, OC, N and Mg in disturbed soil was observed. However, pH, P, K and Ca of disturbed soil varied from forest soil significantly ($P<0.05$). The concentration of all the heavy metals studied viz. Cr, Ni, Cu, Zn, As, Cd and Pb was high in disturbed soil compared to forest soil. However, site has significant influence on the variation of Ni ($P<0.01$), Zn ($P<0.01$) and Cu ($P<0.05$) concentration. Thus, open cast mining altered the soil properties, making nutrient deficient, highly acidic and increased heavy metal toxicity.

Index Terms- Open cast coal mining, acid mine drainage (AMD), soil nutrient deficiency and heavy metal.

I. Introduction

Soil is an important and vitalizing component of ecosystem and its properties are influenced by continuous interactions of its abiotic and biotic constituents (Machulla et al., 2005). Due to rapid pace of development and industrialization there is a gradual increase in the demand of mineral resources of earth crust. The development of our society and human civilization rely heavily upon the mining of mineral resources resulting in alteration of pristine land forms and release of toxic mineral wastes (Sheoran et al. 2010). Mining activities, specifically unscientific open cast coal mining cause drastic alteration of the landscape, topography and land use pattern of the soil (Nessa and Azad, 2008; Sheoran et al., 2011; Maharana and Patel, 2013). Additionally, it leads to acid mine drainage (AMD) and heavy metal contamination. Heavy metals are elements with metallic properties and specific weights higher than 5gm cm^{-3}, which do not degrade (Gorhe et al., 2006) but enter the food chain consequently forming complex toxic compounds leading to detrimental effect on biological functions (Jarup, 2003; Lenart and Wolny-Koladka, 2013). Open cast coal mine overburden dumps contain mixture of coal seam, parent rock and subsoil (Jha and Singh, 1991; Mummey et al., 2002). The mine spoils are deficient in plant nutrient due to lack of biologically rich top soil and represents a disequilibriated geomorphic system (Soulliere and Toy, 1986; Keefer and Sajwan, 1993), consequently causing problem for pedogenesis, revegetation, and restoration (Maharana and Patel, 2013).

North-eastern region of India is rich in floral and faunal diversity. Coal mines of Assam are mainly located in the Indo-Burma biodiversity hot spot. Open cast mining and improper and insufficient post-mining practices are being practiced in all the coal mines of Assam (Nessa and Azad, 2008). In view of the increased unscientific open cast coal mining activities, decreasing soil fertility and adverse effects on soil flora and fauna, it is of utmost concern to monitor the physico-chemical characteristics of coal mine overburden spoil, which pave the way for better understanding the directions of improving soil fertility, reclamation and leading to vegetation development. The present study, therefore, was designed to assess the impact of unscientific open cast coal mining on different physico-chemical properties of soil.

II. MATERIALS AND METHODS

Study site and sampling

The study area for the present investigation was located in Tinsukia district of Assam, India. The Ledo colliery as open cast mining disturbed site and one undisturbed forest site were considered for the study. The geographical locations are $27^{0}17.272'$ N & $95^{0}45.012'$ E (Ledo colliery) and $27^{0}16.748'$ N & $95^{0}44.175'$ E (Forest). The area under investigation has subtropical and high humid climate. The coal mine overburden soil was disorganized, poor in supportive and nutritive capacity. The area experienced annual average rainfall of 194.87 mm, average relative humidity of 78.58 % and 12.9 ^{0}C & 25.6 ^{0}C were mean minimum and maximum temperature respectively. A total of 51 rhizospheric soil samples (< 20 cm depth) were collected from both disturbed and undisturbed sites in year 2010-2011 during February and August. The individual samples of each site of a sampling were mixed in equal proportions separately to make a total of 4 composite samples. Samples were stored at 4 ^{0}C prior to analysis.

Soil physical and chemical characteristics

Soil pH of the composite samples was determined using digital pH meter in 1:5 (w/v) soils: water suspension. During sampling, soil thermometer was used to measure soil temperature (^{0}C). To maintain uniform depth of measurement in dumping spoil soils, pilot hole of 10 cm was drilled using nail of same diameter as the thermometer through wooden block. Soil temperature was recorded after 2 minutes of insertion into the pilot hole.

Soil moisture content (%) of sub-samples was determined by drying 10 g of fresh soil in hot air oven at 105 ±5 ^{0}C until constant weight was observed. The formula used for calculating the soil moisture content (%) is as follows:

$$\text{Soil moisture content (\%)} = \frac{W_2 - W_3}{W_3 - W_1} X100$$

Where, W1= Weight of foil (g); W2= Weight of moist soil + foil (g); W3= Weight of dried soil + foil (g).

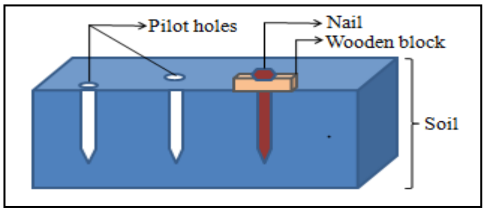

Figure 1: Design of wooden block to measure soil temperature

Soil organic carbon (%) was determined by titrimetric chromic acid wet oxidation method of Walkley and Black (1934). The soil organic carbon < 0.50% was interpreted as low, between 0.50-0.75% as medium and > 0.75% as high. Subbiah and Asija's (1956) alkaline potassium permanganate method was used to determine available nitrogen (Kg/ha). The available nitrogen < 250 Kg/ha was interpreted as low, between 272-544 Kg/ha as medium and > 500 Kg/ha as high. Available phosphorus (Kg/ha) was determined by Brays method (Bray and Kurtz, 1945) while, flame photometric method of Toth and Prince (1949) was followed for determination of potassium (Kg/ha) concentration. Ammonium saturation method followed by complexometric titration method was used for concentration (ppm) determination of Ca and Mg (Schwartzenbach et al., 1946).

Soil heavy metal analysis

The concentration of soil heavy metals viz. chromium (Cr), nickel (Ni), copper (Cu), zinc (Zn), arsenic (As), cadmium (Cd) and lead (Pb) was determined spectrophotometrically (AAS, Shimadzu, AA-7000) according to Jackson (1967). For this, 1 g soil was mixed with 20 ml triple acid mixture of HNO_3: HCl: H_2SO_4 (1:2:4) in a digestion flask and digested by heating. 10 ml of HCl: H_2O (1:1) mixture added and whole digested content was filtered through Whatman filter paper no. 42. Total volume of the filtrate adjusted to 50 ml with distilled water and analyzed for different heavy metal concentrations (mg/ml) using AAS. The following calculation was used to estimate the heavy metal concentrations. $\text{Heavy metal (ppm)} = A \times 50^{*} \times 1000^{**}$.
Where, A= concentration of heavy metal (mg/ml); * = volume of the filtrate (50 ml = 1 g soil); **= conversion factor to ppm (mg/Kg).

Statistical analysis

One-way Analysis of Variance (ANOVA) was performed to evaluate the significance of variation influenced by open cast mining disturbance using SPSS 16.0 version.

III. RESULTS AND DISCUSSION

Soil physico-chemical properties

The physico-chemical properties of the disturbed coal mine dump soil and undisturbed forest soil is presented in Table I. The comparative analysis indicated that the open cast coal mining altered native soil characteristics. The heterogeneous and altered soil characteristics of coal mine dumps were also reported by Boruvka et al. (2010). The disturbed coal mine soil dumps were highly acidic as compared to slightly acidic undisturbed forest soil. The average pH of the disturbed soil was 4.53 as compared to 5.83 of forest soil. High acidity of the coal mine soil dumps is consistent with the reports of Biswas et al. (2013). The high acidity of the dumping soil may be due to acid mine drainage (AMD) as was reviewed by Johnson and Hallberg (2005). AMD is mainly due to exposure of iron pyrite (FeS_2) and other sulphide minerals to both oxygen and water, subsequently their oxidation resulting in low pH (Johnson and Hallberg, 2005). Ghose (2004) reported that high acidic conditions of soil make it nutrient deficient, while, increased the availability of heavy metals resulting into toxic effects on the plant growth and also on the microbial populations which is a key component of the soil ecosystem.

Table I: Physico-chemical characteristics of disturbed coal mine dump spoils and undisturbed forest soil. (Temp.: temperature; Av.: available).

Site	pH	Temp. (^{0}C)	MC (%)	OC (%)	Av. N_2 (Kg/ha)	Av. P_2O_5 (Kg/ha)	Av. K_2O (Kg/ha)	Av. Ca (ppm)	Av. Mg (ppm)
Disturbed soil	4.53	24.39	9.85	2.01	468.29	47.04	37.19	160.72	109.44
Forest soil	5.83	21.5	23.95	1.612	623.34	178.75	296.16	424.82	92.12

The average temperature of disturbed soil was high as compared to forest soil Table I. This may be due to lack of plant cover on the disturbed mine dump soil as was also reported by Javed and Khan (2012). Disturbed soils of Ledo colliery contain less moisture content (9.85 %) compared to undisturbed forest soil (23.95 %). The lack of plant cover, less organic matter and poor soil quality of disturbed site decreased soil water holding capacity and is consistent with the reports of Kumar and Patel (2013).

Soil organic carbon was high (> 0.75 %) in both the disturbed and undisturbed soil. Disturbed soil harbored less concentration of N, P and K compared to Forest soil (Table I). This finding is consistent with the reports of Ghose (2004). Similarly, Maharana and Patel (2013) also found low concentration of N and P in the Basundhara open cast coal mine dump soils as compared to undisturbed forest soil. The anionic phosphate forms strong bonds with particles that generate anion exchange capacity. In highly acidic coal mine dump soil, P react with heavy metals and consequently might reduced its bioavailability (Vetterlein et al. 1999). Similarly, nitrification is also slow and simultaneously, low pH plays key role in loss through volatilization. Additionally, reduction of soil microbial population might have some role in reduction of soil N concentration (McKenzie, 2003).

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 subsequent weathering of Calcium rich rocks. However, concentration of Magnesium was higher in disturbed soil.

Table II: One-way analysis of variance (ANOVA) showing the influence of site /open cast coal mining on the physico-chemical and heavy metal properties the soil.

P-value																
	pH	**Tem**	**MC**	**OC**	**N**	**P**	**K**	**Ca**	**Mg**	**Cr**	**Ni**	**Zn**	**Pb**	**Cu**	**Cd**	**As**
Site Ledo Forest	0.033	0.718NS	0.311NS	0.567NS	0.115NS	0.035	0.025	0.030	0.789NS	0.423NS	0.018	0.005	0.781NS	0.055	0.544NS	0.183NS

NS: not significant ($P > 0.05$)
P values without NS are significant either at $P < 0.05$ or < 0.01

One-way ANOVA results (Table II) showed that site has highly significant effect on pH, P, K, Ca and also indicates that open cast mining significantly altered key soil properties. Kumar and Patel (2013) reported similar findings from Ib valley coalfields in Odisha.

The results of heavy metal concentrations of two different categories of soils are presented in Figure 2. The concentrations of seven heavy metals (Cr, Ni, Cu, Zn, As, Cd and Pb) studied were found higher in disturbed soil compared to undisturbed forest soil.

Heavy metal concentrations

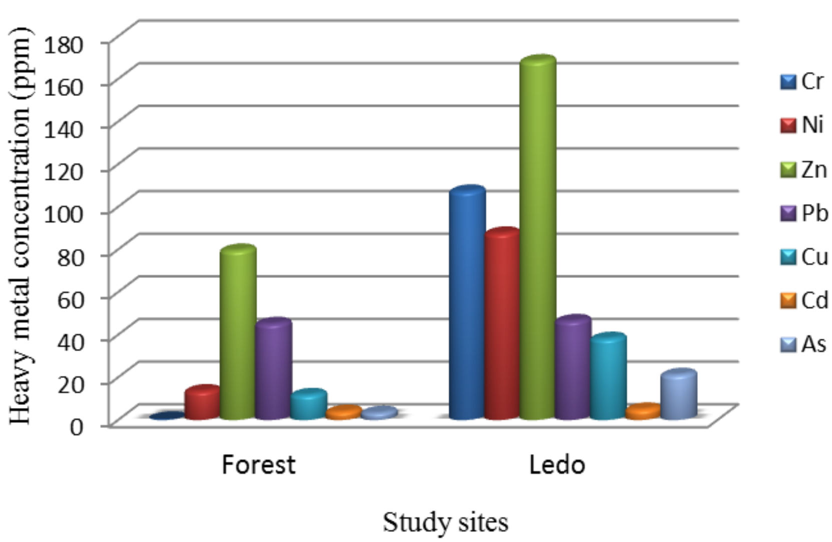

Figure 2: Heavy metal concentrations (ppm) of undisturbed forest soil and disturbed Ledo colliery dump soil.

Nessa and Azad (2008) reported the increased heavy metal concentrations in spoil soils of Makum coal field. Increased concentration of Cr and Ni were detected in Bhowra open cast coal mine as reported by Masto et al. (2011). One-way ANOVA results (Table 2) showed that Ni, Zn and Cu were significantly influenced by the open cast coal mining. However, statistically no significant variation of Cr, Pb, Cd and As among disturbed and undisturbed sites was observed both at $P < 0.05$ and $P < 0.01$.

IV. CONCLUSION

From the above discussion, it can be concluded that unscientific open cast coal mining and poor post mining practices severely altered the native soil properties. The spoil soil became highly acidic and nutrient deficient which is detrimental to the growth and establishments of the plants. Highly acidic condition of the spoil soil increased the bioavailability of the heavy metals. Consequently, soil became toxic and cause mainly oxidative stresses in plants. Simultaneously, it affected negatively the growth and activity of microorganisms which play key role in soil dynamics. Thus open cast mining destroyed the soil structure, increased the soil acidity, made the soil nutrient deficient and increased the heavy metal toxicity.

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