Carpathian Journal of Earth and Environmental Sciences, February 2015, Vol. 10, No. 1, p. 241 - 248

THE SEASONAL CHANGES IN SOIL PROPERTIES DUE TO COAL MINE IMPACTS

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Abstract: Mining activities results in extensive soil damages, altering microbial communities and affecting vegetation leading to destruction of vast amounts of land. The entire mining process, starting from unloading the raw coal to the loading of processed coal, liberates particulate matter, which would ultimately settle on the soil at varying distances. This is likely to affect soil quality and possibly the health of the inhabitants. Soil samples were collected from the nearby areas of an opencast coal mine (OCM) located in Jharia coalfield of Dhanbad, India. The control site was an abandoned land approximately 18 km away from the sources of contamination. These samples were analyzed for physico-chemical and biological properties during three different seasons. The results showed that the soils of OCM impacted soil quality in terms of nutrient contents and microbial population, this is attributed to the mining activities in view of the absence of other sources of pollutants. However, the concentrations of other heavy metals were well below the threshold levels for human health risk assessment. There were slight variations observed in the concentration of heavy metals, assessed during different seasons in soil samples. Microbial population count was also observed very less than that of the native soil.

Key words: Coal mining, impact, soil properties, soil nutrients, soil microbial population

1. INTRODUCTION

Mining activity, wherein the land is used temporarily for the exploitation of mineral wealth, is one of the major causes for the degradation of environment, and it becomes more serious if it is open cast mining. Open cast mining, have resulted in drastic alternations in their geochemical cycles and often lead to land degradation, with adverse changes in soil textural and structural attributes. Being deficient in plant nutrients due to lack of biologically rich top soil, mine spoil represents a dis-equilibriated geomorphic system and poses problem for the process of pedogenesis, re-vegetation and restoration (ELAW, 2010).

Dump materials are left over the land in the form of over burden dumps (mine spoils). These occupy large amount of land, which loses its original use and generally gets soil qualities degraded. Soil contamination from heavy metals released from mining activities is a worldwide environmental problem (Tack et al., 1996). These elements become mobile with the exploitation of coal and on combustion contaminate farms, forests, and soil, and affect the quality of surface and ground water, and finally, human health (Gupta, 1999). Due to lack of vegetation cover of the large areas of open cast mines the quantum of evaporation considerably affecting the water balance of the area and as a consequence of which permanent lowering of water table may take place.

Mine wastes are generated in huge quantities, on the order of tens of millions of tons per year. These wastes include the solid waste from the mine, called “gob,” refuse from coal washing and coal preparation, and the sludge from treating acid mine drainage. There are a number of environmental impacts from this waste generation. First, the land where these wastes are dumped is no longer useable for other purposes.

Opencast mining damages the top soil layer and affects several changes of the physical, chemical and microbiological properties of soil (Kundu & Ghose, 1998). Mining operations degrade significant areas of land and replace existing ecosystem with undesirable waste materials in form of mine spoil dumps (Singh et al., 2007). Dumping of solid waste on land can invariably introduce a wide range of pollutants to the soil. On the other hand, there are compounds that do not occur naturally and their presence in soil and sediments are entirely due to anthropogenic activities (Jung & Thornton, 1997).

The nutrient status of over burden soil is also a major factor limiting plant growth (Pederson et al., 1988). Open cast excavation of coal deposits involves the removal of overlying soil and rock debris and their storage in over burden dumps change the natural land topography, affect the drainage system and prevent natural succession of plant growth (Bradshaw & Chadwick, 1980; Wali, 1987; De & Mitra, 2002).

Microbial activity is a key factor affecting the functioning of all terrestrial systems. It has an important role in decomposition and nutrient cycling. Soil microbes are an essential component of most terrestrial ecosystems. Indeed, as decomposers they regulate nutrient dynamics, and they also act as a highly labile nutrient pool, so that soil microbes are also considered as a sensitive indicator of soil fertility (Wardle et al., 2004; Joergensen & Emmerling, 2006). Dehydrogenase (DHA) is one of the most important enzymes in the soil environment, and is used as an indicator of overall soil microbial activity because it occurs intracellular in all living microbial cells. DHA play a significant role in the biological oxidation of soil organic matter by transferring hydrogen from organic substrates to inorganic acceptors (Zhang et al., 2001).

2. MATERIALS AND METHODS

2.1 Study area

The Ghanudih open cast mine of Jharia coal field were selected. It is one of the most important coalfields in India, located in Dhanbad district of Jharkhand, India between latitude 23°39’ to 23°48’ N and longitude 86°11’ to 86°27’ E (Fig. 1). This is the most exploited coalfield because of available metallurgical grade coal reserves. Mining in this coalfield was initially in the hands of private entrepreneurs, who had limited resources and lack of desire for scientific mining. The mining method comprised of both opencast as well as underground. The opencast mining areas were not properly backfilled, so large voids are present in the form of abandoned mining.

2.2. Sample collection

Soil samples were collected from the nearby areas of an opencast coal mine (OCM) located in Jharia coalfield of Dhanbad, India during winter (December, 2011), summer (May, 2012) and monsoon (August, 2012) season from different locations of the study area (Fig. 1).

2.2.1. Mine spoils collection

Mine spoils were collected from different locations of five un-reclaimed over burden by a manually operated split tube coring tool (depth 20 cm). From each site 5 samples were collected, after collection, the samples were mixed thoroughly to prepare the composite sample. About 5 kg of composite samples were collected from each sampling location. The composite sample was divided into two parts, one for the physico-chemical studies and one for the microbiological study. The samples were properly packed and brought carefully to the laboratory.

2.2.2. Soil samples collection

Soil samples were collected from un-mined soil, adjacent of the open cast mines in three different seasons, where local vegetation was already established. The control site was an abandoned land approximately 18 km away from the sources of contamination. Using Garmin GPS (etrex VISTA HCx), the longitude and latitude of each sampling location was recorded on the field.

2.3. Analytical studies

2.3.1. Characterization of mine spoils and soil samples

The collected samples were analyzed for texture, moisture content (MC), water holding capacity (WHC), bulk density (BD), porosity, pH, electrical conductivity (EC), organic carbon (OC), available nitrogen (N), available phosphorus (P) and available potassium (K), cation exchange capacity (CEC). Heavy metals determined were Co, Cu, Ni, Fe, Mn, Zn and Pb. Moisture content and water holding capacity were determined by gravimetric method. Bulk density was determined by soil core method, and the porosity was calculated from the bulk density. pH and EC were determined by using pH meter and EC meter respectively in suspension of soil (spoil sample) in water in the ratio of soil: water = 1:2.5. Organic carbon was determined by oxidation with potassium dichromate in acid medium (Walkey & Black, 1934).

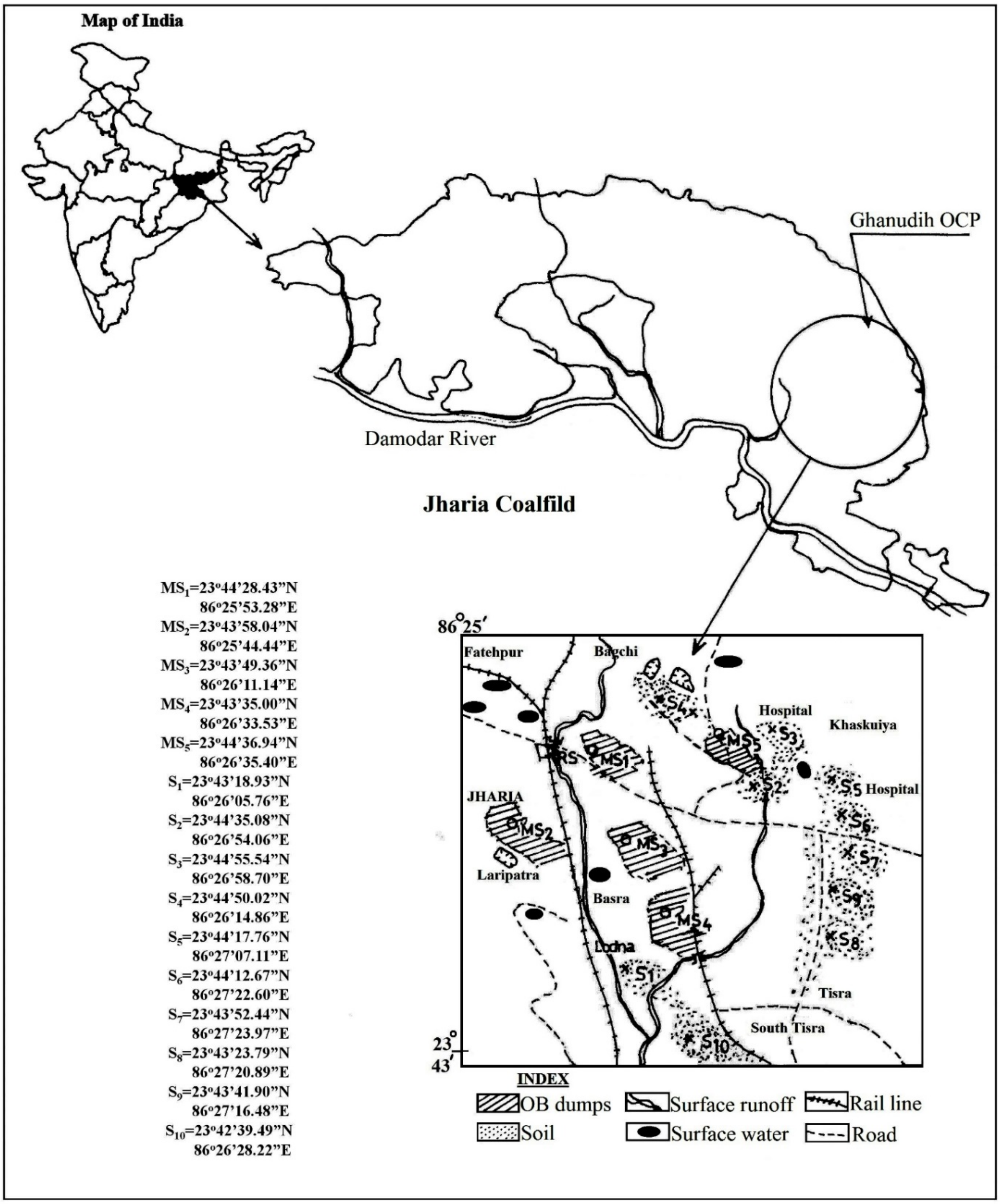

Figure 1. Study area map showing sampling locations site (MS = mine spoils and S = soil samples).

Available N was determined by alkaline permanganate method (Subbaiah & Asija, 1996). Available P was determined by Olsen method (Sparling et al., 1985). Available K was extracted by neutral 1(N) ammonium acetate solution (soil to extractant ratio of 1:10) and determined by Flame photometer (Jackson, 1973). Trace metals were analyzed by atomic absorption spectrophotometer (GBC, Avanta, Australia). Dehydrogenase activity was assayed using 2, 3, 5-triphenlytetrazolium chloride as substrate (Casida, 1977).

2.3.2. Isolation and enumeration of microorganisms from the soil

Nutrient agar medium (containing per liter of peptone - 5.0 g, beef extract - 3.0 g, NaCl - 5.0 g, agar - 15.0 g, pH - 7.0±0.2) was used for isolation of bacteria while Actinomycetes isolation agar - M490 medium (containing per liter of sodium caseinate - 2 g, L-asparagine - 0.1 g, sodium propionate - 4 g, dipotassium phosphate - 0.5 g, magnesium sulphate - 0.1 g, ferrous sulphate - 0.001 g, agar - 15 g, pH - 8.1±0.2) and Rose Bengal agar medium (containing per liter of peptone - 5 g, monopotassium phosphate - 1 g, rose bengal - 0.05 g, dextrose - 10 g, magnesium sulfate - 0.5 g, agar - 15 g, pH - 6.5±0.2.) was used for fungi and actinomycetes respectively, the petri plates were incubated at 35°C for 48 hr for bacteria, 30°C for 120 hr for actinomycetes and 25°C for 72 hr for fungi. The microbial populations were enumerated as colony forming units (CFU) from a serial dilution of sample suspension.

2.3.3. Microbial population count

Microbial population such as bacteria, actinomycetes and fungi were counted following standard dilution plate technique. 10 g sample was taken and dissolved in sterile water and volume made up 100 mL, which was further serially diluted to get 10^{-4} dilution. From these diluted samples, 1 mL solution was dispensed over each of three replicates and then media for growth of different microorganisms were added. The populations of microorganisms were considered from the number of microbes multiplied by the dilution factor for each sample (Aneja, 2010).

3. RESULTS AND DISCUSSION

3.1 Characterization of mine spoils

The studied mine spoil sample was of high bulk density, low moisture content, low water holding capacity and deficient in nitrogen, phosphorus, and potassium (Table 1). The texture of over burden dump materials was drastically disturbed due to mining activity, the texture was found as sandy type. Several researchers are of opinion that lesser amount of clay materials has many microspores through which water passes very slowly into the dump materials. Hu et al., (1992) are of opinion that soil with more than 50% stoniness should be rated as poor quality. Mine spoils with sandy texture cannot hold as much water or nutrients as finer textured soil like loams and silts.

The Low moisture content in the mine spoil maybe attributed due to lack of organic matter, higher stone content and sandy texture. Minimum average field moisture required 5% sufficient growth for the plant. The lower value of water holding capacity may be due to higher percentage of sand particle present in over burden dump materials. Bulk density was varied between 1.80-1.92 $g.cm^{-3}$ with an average value of 1.85 $g.cm^{-3}$, which is comparatively higher as compared to the native soil. High bulk density limits rooting depth in mine soil. Severely compacted (bulk density > 1.7 g/cc) mine soil, particularly those with less than two feet of effective rooting depth, shallow intact bedrock and the presence of large boulders in the soil simply can-not hold enough plant available water to sustain vigorous plant communities through protracted drought.

The acidic pH in mine spoil might be due to leaching of basic ions. This acidic nature arose due to the geology of the rock presented in the area. The results are also suggested by Campbell et al., (2001). A mine soil pH ranged between in the 6.0 to 7.5 is ideal for forages and other agronomic or horticultural uses (Gitt & Dollhopf, 1991; Gould et al., 1996). Brady & Weil (2002) found that a pH range of 6.5 to 7.5 is optimal for plant nutrient availability. Cation exchange capacity was varied between 2.87-5.15 Meq/100 g with an average value of 3.91 Meq/100 g. This result also suggests that low cation exchange capacity has reduced water holding capacity, soil organic carbon and nutrient properties of the soil (Bahrami et al., 2010).

Overall mine spoils were found poor in nutrient contents and microbial population. The lower level of organic carbon, available nitrogen, available phosphorous and available potassium in mine spoils, as compared to native soil, might be due to the disruption of ecosystem functioning, depletion of soil organic pool, and also due to the loss of litter layer during mining, which is an integral storage and exchange site for nutrients. Several researchers also reported lower clay fraction, high soil bulk density, and low water holding capacity and poor physical conditions of over burden dump materials (Russell & La, 1986; Srivastava, 1999; Banerjee et al., 2000; Dutta & Agarwal, 2002). Acidification in the mine spoil due to different mineral deposits in the over burden dump materials (Johnson & Skousen, 1995; Suzuki et al., 1999).

3.2 Correlation analysis

Correlation analysis measures the closeness of the relationship between chosen variables. If the correlation coefficient is nearer to +1 or –1, it shows the perfect linear relationship between the two variables. This way analysis attempts to establish the nature of the relationship between the water quality parameters. The degree of a linear association between any two of the water quality parameters, as measured by the Pearson correlation matrix. The correlation matrix of physico-chemicals parameters of the mine spoils was calculated and relations between them were studied. The correlation of data between physico-chemical parameters showed both significant ($p<0.05$) positive and negative $p<0.01$) responses.

Table 1. Physico-chemical and biological properties of coal mine spoils

Parameters	Unit	Range (min-max)	Mean±SD
Sand	%	84.56-86.70	85.42±0.76
Silt	%	10.10-12.04	11.17±0.59
Clay	%	3.20-3.70	3.41±0.25
Moisture content	%	4.10-5.60	4.62±0.60
Water holding capacity	%	19.25-21.50	20.55±0.85
Electrical conductivity	$\mu S.cm^{-1}$	155.25-184.50	208.40±13.13
Bulk density	$g.cm^{-3}$	1.80-1.92	1.85±0.05
Cation exchange capacity	Meq/100 g	2.87-5.15	3.91±0.85
Organic carbon	%	0.60-0.75	0.66±0.07
pH	--	6.24-6.55	6.39±0.14
Available nitrogen	$kg.ha^{-1}$	26.25-28.30	26.98±0.87
Available phosphorous	$kg.ha^{-1}$	1.35-2.05	1.57±0.30
Available potassium	$kg.ha^{-1}$	39.50-46.30	43.16±2.85
Cu	$mg.kg^{-1}$	12.65-17.65	14.78±1.93
Zn	$mg.kg^{-1}$	98.58-125.25	114.99±10.24
Mn	$mg.kg^{-1}$	278.56-351.80	317.74±35.38
Fe	$mg.kg^{-1}$	12457.32-14522.80	13336.03±807.16
Ni	$mg.kg^{-1}$	18.69-25.44	22.18±2.89
Cr	$mg.kg^{-1}$	24.56-36.21	30.78±4.62
Pb	mg.kg	5.84-8.20	7.02±0.84
Co	mg.kg	8.25-11.45	9.82±1.18
Cd	mg.kg	1.09-1.54	1.28±0.17
Dehydrogenase activity	$\mu g.g^{-1}$ dry soil h^{-1}	2.05-4.52	3.36±0.95
Bacteria	$cfu.g^{-1}$ (-- x 10^3)	2.00-4.00	3.05±0.80
Actinomycetes	$cfu.g^{-1}$	6.60-10.40	8.20±1.56
Fungi	$cfu.g^{-1}$	1.50-5.20	2.56±1.53

Table 2. Physico-chemical properties of soil samples during different season

Para-meters	Unit	Monsoon		Winter		Summer	
		Range (Min-max)	Mean±SD	Range (Min-max)	Mean±SD	Range (Min-max)	Mean±SD
Sand	%	61-68.4	65.28±2.1b	58.12-65.5	61.77±1.88c	65.2-73.2	68.40±2.97a
Silt	%	22-27.78	24.07±1.8b	23- 28.3	26.36±1.62a	20.4-25.2	23.19±1.66b
Clay	%	9.2-12.7	10.65±1.15b	10.4- 13.6	11.87±1.05a	6.4-11	8.81±1.44c
MC	%	5.34-9.9	8.13±1.51a	5.3-8.7	7.43±1.11ab	5.3-7.8	6.66±0.76a
WHC	%	31.62-41.83	36.32±3.34a	31.14-41.67	37.58±4.08a	26.19-35.34	31.29±3.17b
EC	$\mu S.cm^{-1}$	159.45-201.56	176.68±15.24b	148.88-195.75	182.99±14.45b	193.97-239.28	221.84±17.08a
BD	$g.cm^{-3}$	1.05-1.45	1.19±0.13b	1.04-1.54	1.23±0.13b	1.23-1.5	1.34±0.09a
pH	--	6.12-7.02	6.31±0.25c	6.25-7.05	6.64±0.21b	6.28-7.21	6.91±0.33a
CEC	Meq/100 g	5.66-8.2	6.76±0.71ab	5.15-7.17	6.36±0.61b	6.2-8.1	7.12±0.66a
OC	%	0.86-1.06	0.95±0.06c	1.13-1.35	1.25±0.08b	1.14-1.6	1.37±0.14a
AN	$kg.ha^{-1}$	101.07-122.2	109.05±7.35b	99.23-27.83	112.74±7.7b	118.8-149.4	134.61±10.58a
AP	$kg.ha^{-1}$	3.74-5.34	4.64±0.54b	4.32-6.39	5.24±0.63a	4.86-7.02	5.74±0.71a
AK	$kg.ha^{-1}$	150.32-180.23	167.96±9.9c	186.83-219.47	204.31±10.86b	203.07-251.26	223.32±15.86a

MC (moisture content), WHC (water holding capacity), EC (electrical conductivity), BD (bulk density), CEC (cation exchange capacity), OC (organic carbon), AN (available nitrogen), AP (available phosphorous), AK (available potassium), Different alphabetical letters in the same row are significantly, different (p<0.05) according to Duncan's multiple range test.

3.3 Analysis of soil samples

The physico-chemical and biological properties of soil samples from mining area during different seasons were analyzed and compared with standard guidelines and control (non-mining area) soil. The soil quality changed from silty loam to sandy loam, which not only affects vegetation but also plays a vital role in changing the local climate (Table 2). Others physical properties of soil such as water holding capacity, soil moisture etc. in mining areas were lower than that of non-mining area. Soil nutrients like available nitrogen, available phosphorus and available potassium were also lower in mining areas with respect to control soil. Cation exchange capacity was also disturbed by mining activities, suggesting that the mining activities have definitely damaged the quality of adjacent soil.

3.4. Seasonal variation in concentration of heavy metals in soil samples

There were slight variations observed in concentration of heavy metals assessed during different seasons in soil samples (Table 3). The concentrations of Cd, Zn, Cr, Co, Fe and Mn were found higher during summer, whereas Cu, Pb, and Ni were noticed higher during winter season. The calculated value was exceeding that of control soil. A heavy metal contamination is known to have adverse effect on soil biological functions, including the size, activity and diversity of soil microbial community (Kandeler et al., 1996; Kelly et al., 1999; Chander et al., 2001).

3.5. Seasonal variation in soil microbial count

Microbial population was observed almost 10 times lesser in soil samples from mining area as compared to non-mining area soil (Table 4). The bacterial population was dominated over actinomycetes and fungi. Higher microbial population was counted in monsoon season.There is strong evidence that soil microbes are more sensitive to heavy metals contamination than crop plants and animals (Giller et al., 1999). However, most studies that have evaluated seasonal soil microbial dynamics in the dry tropics have been based on forest and savanna ecosystems, and little information has been acquired for cropland (Kushwaha et al., 2000). In addition, most of these studies were conducted with only few samplings, and hence the effect of short term soil microbial variations is still unclear in mining area. These results suggest that soil organic matter decomposition mainly occurred in the rainy season, and this is consistent with other studies done in dry tropical ecosystems (Chen et al., 2002; Garcıa-Oliva et al., 2003; Cookson et al., 2006).

Spedding et al., (2004) also found that the seasonal effect on soil microbial dynamics was larger than the effect of land management, i.e., tillage and residue application in Canada. Zaman et al., (1999) showed that both sufficient carbon substrate and favorable soil moisture conditions are necessary to increase microbial biomass. Hence, we presume that, due to reduced soil moisture during the dry season, soil microbial population will be reduced.

There was a statistically significant (p<0.05) difference between metal concentrations in the mining area and non-mining area control soil. This might be due to surface runoff and strong wind action which caused the movement of mine waste material.

Table 3. Seasonal variation in concentration of heavy metals in soil samples during different season

Heavy metals	Unit	Monsoon		Winter		Summer	
		Range (Min-max)	Mean±SD	Range (Min-max)	Mean±SD	Range (Min-max)	Mean±SD
Cu	$mg.kg^{-1}$	9.55-18.78	14.17±3.27b	15.81-22.25	18.48±2.23a	10.34-16.88	13.2±1.86a
Zn	$mg.kg^{-1}$	93.44-104.34	100.72±3.43c	98.56-112.89	108.22±4.69b	136.4-155.45	147.1±6.03a
Mn	$mg.kg^{-1}$	354.23-512.2	403.39±44.73b	343.77-432.89	388.25±31.13b	390.76-509.22	439.67±33.95a
Fe	$g.kg^{-1}$	11.54-15.48	14.13±1.40b	11.22-14.45	12.76±0.93c	14.43-16.55	15.42±0.87a
Ni	$mg.kg^{-1}$	9.87-18.24	14.08±2.65b	15.32-22.43	19±2.06a	10.2-16.78	13.02±2.17b
Cr	$mg.kg^{-1}$	12.44-25.54	21.37±3.95ab	13.5-26.78	19.4±4.57b	17.89-31.56	23.9±4.68a
Pb	$mg.kg^{-1}$	5.87-9.24	7±1.24ab	5.9-10.45	8.09±1.45a	5.21-8.23	6.56±1.06b
Co	$mg.kg^{-1}$	6.87-10.58	8.78±1.24b	7.12-9.67	8.38±0.86b	9.18-12.26	10.18±1.08a
Cd	$mg.kg^{-1}$	0.59-1.12	0.81±0.16b	0.62-0.96	0.77±0.13b	0.78-1.17	0.94±0.13a

Different alphabetical letters in the same row are significantly different (p<0.05) according to Duncan's multiple range test.

Table 4. Biological properties of soil samples during different season

Properties	Unit	Monsoon		Winter		Summer	
		Range (Min-max)	Mean±SD	Range (Min-max)	Mean±SD	Range (Min-max)	Mean±SD
Dehydrogenase activity	$\mu g.g^{-1}$ dry soil h^{-1}	5.7-10.55	8.845±1.91a	4.56-8.44	7.076±1.53b	4.58-8.75	6.25±1.56b
Bacteria	$cfu.g^{-1}$ = -- $x10^4$	85-600	355.2±183.94a	18-245	113±67.95b	5-102	46.3±33.17b
Actinomycetes	$cfu.g^{-1}$ = -- $x10^4$	47-254	137.6±78.06a	12-180	87.7±49.43a	5-83	31.1±26.12b
Fungi	$cfu.g^{-1}$ = -- $x10^4$	5-124	57.1±40.75a	0.8-100	34.38±34.53a	0.6-80	24.86±29.01a

Different alphabetical letters in the same row are significantly different (p<0.05) according to Duncan's multiple range test.

These concentrations may be derived from interaction of rain with over burden dumps containing elevated levels of these metals. It is generally agreed that most of the heavy metals contamination in surface environment is associated with a cocktail of contaminants rather than one metal. Thus, many workers have used a pollution index (PI) of soil to identify multi-element contamination resulting in increased overall metal toxicity (Nimick & Moor, 1991; Chon et al., 1998).

The soil quality change from silty loam to sandy loam not only affects vegetation but also plays a vital role in changing the local climate. Cation exchange capacity was also disturbed by mining activities, suggesting that the mining activities have definitely damaged the quality of adjacent soil.

4. CONCLUSIONS

Coal mining activities has significant adverse impact on soil quality adjacent the mining areas. The studied mine spoil sample was of high bulk density, low moisture content, low water holding capacity and deficient in nitrogen, phosphorus, and potassium. The soil nutrient and number of microbial population has greatly reduced due to mining activities. These conditions may be caused due to leaching of heavy metals and ions from the mine spoil materials by infiltrating recharge water. These spoils are not suitable for both plant and microbial growth. The study not only helps to compare the quality of the mine spoil and native soil but also helps in understanding the future scope of growth of vegetation in the region. An appropriate management plan is suggested in the study area to have a better soil and water quality for proper plant growth as well as for maintaining human health for sustainable development.

Acknowledgments

The authors would like to thank Bharat Coking Coal Limited (BCCL) for providing necessary help for collection of samples and other field studies. Authors also thank the Department of Environmental Science and Engineering, Indian School of Mines, Dhanbad, India for providing necessary supports for conducting the research.

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Received at: 09. 06. 2014
Revised at: 16. 01. 2014
Accepted for publication at: 21. 01. 2015
Published online at: 13.02. 2015