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Assessment of Soil Physico-Chemical Properties and Heavy Metals Bioaccumulation on Plants at a Coal Mining Affected Forest of Changki, Nagaland

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ABSTRACT

Alteration in soil characteristics is a trend that coincides with coal mining due to its negative impacts on the terrestrial ecosystem. The present study aims to determine the seasonal variation on soil physico-chemical properties and detect the heavy metals Zn, Cd, Cu, Ni and Pb on the soil and plants from the forest affected by coal mining activities. Significant changes in soil parameters were observed with each season. Nutrient element such as available nitrogen, potassium and available phosphorus was recorded lowest in winter followed by spring, summer and autumn. The heavy metal analysis shows Zn and Cd were above the standard limits in coal mining affected forest (CMAF) soil while in all the plant samples the element Zn, Cd and Cu were beyond the permissible limits given by WHO (1996). Transfer Factor (TF) of Zn and Cd was highest in *Thysanolaena latifolia*. Maximum Cu TF was detected in *Melastoma malabathricum* and *Chromolaena odorata* while Ni TF was highest in *Chromolaena odorata*. However, Pb was not detected in any of the plants and soil samples. The result suggests tailing and dumping of mine waste into the forest could have altered the soil properties and elevated heavy metal contamination. Therefore, proper soil management policy and conservation efforts needs be adopted in the coal mining affected forest of Changki.

Keywords: Changki coal mines, Physico-chemical properties, Heavy metals, Transfer factor.

INTRODUCTION

Coal mining is one of man's earliest sources of resource exploration for fuel. Due to its abundance, coal has been excavated excessively to meet the demands of rapid industrialization and urbanization. Economically it stands out among the other resources and is the main source of primary energy in the developing countries. However, the process of mining has various environmental consequences, starting from excavation to loading and unloading; coal produces dust and radiation which have a direct negative impact on the ecology, biodiversity and health of the surrounding communities (Chaulya *et al.* 2011). The composition of coal includes diverse trace elements which when released in abundance causes toxicity and can be fatal for the environment. The overburden dumps during coal excavation when deposited in un-mined forest build mine spoils, this affects the landscape and its impact can be felt over a vast area of land and hence has an environmental repercussion. Soil becomes deteriorated in coal mining affected area with relatively low pH, low nutrients content and organic carbon (Rai *et al.* 2011, Talukdar *et al.* 2016). Naturally occurring

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heavy metals in soil are generally very less and tend to remain in low concentration but anthropogenic activities have prompt large quantities of metal being emitted into the environment, which has dramatically increased its concentrations (Gowd *et al.* 2010). Currently, soil pollution by heavy metals represents one of the foremost necessary environmental issues (Weissmannova and Pavlovsky 2017) since they are extremely persistent pollutants and their lethality is a problem associated with biological to ecological reasons. Metals cannot be completely broken down, when concentrations within the plant exceed optimal levels and their systems are adversely affected. Therefore, a wide range of symptoms from physiological to metabolic alterations in plants is triggered by the increase of heavy metals concentration (Dubey 2011). Disturbed mined areas are mostly deprived of vegetation and very few adaptable selected species flourished in the area and dominate the community.

Changki, a mining village of Mokokchung district, Nagaland is popularly known for the Merayim coal fields producing tertiary coals. Due to the traditional landholding system, the village coal mines are owned by small-scale private local ventures and intervention from the government is restricted to a certain limit. During the last few decades, there have been major changes in the landscape affecting the water bodies and soil productivity of the forest. The mining practices caused large scale deforestation, destruction, denudation and deterioration of the forest along the vicinity of the village. Therefore, the present investigation is taken up with a view to check the soil physico-chemical properties and assess the concentration of some selected heavy metals on the soil and its accumulation on dominant plant species from coal mining affected forest. The findings will reiterate measures with regulations that will provide necessities in tackling soil-related issues and its management.

MATERIALS AND METHODS

Study area

The designated study area i.e Coal mining affected forest (CMAF) is located adjacent to the Merayim coal fields at Changki, Mokokchung district of Nagaland with geographical coordinates; latitude - 26◦27′40″ N, longitude - 94◦20′58″E and altitude - 248 m. The coal mines stretch over an area of 52,000 m^2 and annually on average 250 tons of overburden mine spoils and tailing waste are dumped at the borderline of the CMAF. Fig.1 represents the landuse/landcover (LULC) map of the study area.

Collection and analysis of soil and plant samples

Coal mining affected forest (CMAF) soil samples was collected from September, 2018 to August, 2019

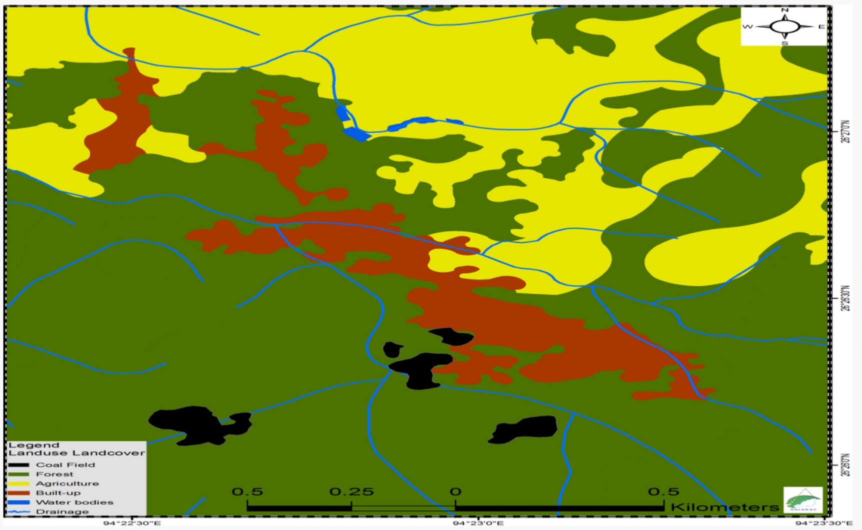

Fig. 1. Landuse and landcover map of the study area at Changki.

covering the four seasons of winter, spring, summer and autumn. The soil from the depth of 0-10cm was sampled and stored in labeled ziplock bags. Latter unwanted debris, forest litters, stones and gravels were removed from the sample, thereafter air-dried and grounded into fine particles that could pass through a 0.5mm sieve. Parameters like soil moisture and bulk density were analyzed before the samples were air-dried. In this study, 15 soil parameters such as pH and electrical conductivity (Jackson 1973), soil temperature (Soil thermometer), soil moisture (Gravimetric method Misra 1968), soil texture (Pipette method Piper 1942), particle density, porosity and bulk density (core method Allen 1989), soil organic carbon (Walkley and Black's method 1934), available nitrogen (Johan Kjeldahl method, 1883 - Kelplus nitrogen estimation system), available phosphorus (Bray's no. 1 extract method, 1945) using spectrophotometer, potassium using flame photometer (Photometric method) following Trivedy and Goel (1986) and cation exchange capacity (Bower *et al*. 1952) were determined. For detection of heavy metals, five plant species viz., *Melastoma malabathricum, Dicranopteris linearis, Chromolaena odorata, Pteridium esculentum* and *Thysanolaena latifolia* were selected based on their dominance and the soils from the four seasons were aggregated as one sample. The shoots (stem, leaves) of each selected plant species were taken to the laboratory, rinsed with distilled water and air-dried in a dust free room. The samples were grinded and digested following Nitric-hydrochloric acid digestion method (Ang and Lee 2005). The selected plant's samples and the soil were analyzed for the detection of five heavy metals viz., Zinc (Zn), Cadmium (Cd), Copper (Cu), Nickel (Ni) and Lead (Pb) which were determined quantitatively using Perkin Elmer, Atomic Absorption Spectrometer (AAS) AAnalyst – 700. Triplicates readings were taken for all the parameters and elements analyzed.

Digestion of heavy metals

The Nitric-hydrochloric acid digestion (1:3) method formulated by Ang and Lee (2005) was used for the digestion. Samples were weighed (0.5g) and placed in a 100 ml Poly tetrafluoroethylene (PTFE) beaker. 9 ml of the freshly prepared acid mixture of 65% HNO_3 and 37% HCl were added to the samples. Then, the mixture was boiled gently over a hot water bath at 95°C for a time period of 4–5 h (or until the sample had completely dissolved).

Transfer factor (TF)

Determination of Transfer factor (TF) was calculated to ascertain the amount of heavy metals accumulated in plants as a fraction of the soil totals formulated by Olanescu *et al.* (2007).

$$TF = \frac{M_P}{M_S}$$

Where: TF– transfer factor, Mp– Metal content in plant (mg kg $^{-1}$) and Ms – Metal content in soil (mg kg $^{-1}$).

RESULTS AND DISCUSSION

Physico-chemical parameters

The seasonal mean variations of the physico-chemical characteristics of CMAF soil are presented in Table 1. Physico-chemical properties are an important indicator of soil quality as each soil parameters possess distinct interactions and close associations which jointly determine the quality characteristics of the soil (Garcia-Ruiz *et al*. 2009). Soil temperature is considered as a function of heat flux in the soil and heat exchanges between the soil and its atmosphere (Elias *et al.* 2004). The highest soil temperature was recorded during summer (35^0C ± 2.05) and lowest in winter (24.7^0C ± 2.09). The differences in soil temperature can be due to variations of seasons which may result from changes in radiant energy taking place through soil surface (Chiemeka 2010). Soil texture plays a major role in determining the soil quality and influences other soil properties as well. The present study recorded summer having the maximum mean value of sand (60.96% ± 0.85) and silt (21.96% ± 0.6) while clay in autumn (20.86% ± 1.02) was higher than spring (19.6% ± 3.3), winter (19.46% ± 1.65) and summer (17.06% ± 1.34). The alteration and reduction of the volume of macropores can have a direct negative impact on soil infiltration capacity and its moisture content which is reflected in coal mining affected soils. Maximum soil porosity with a mean value of 0.46% ± 0.01 was observed in

Table 1. Seasonal variation in soil physico-chemical properties at coal mining affected forest (CMAF).

Soil parameters	Winter	Spring	Summer	Autumn
Soil temperature (^{0}C)	24.7±2.09	25.7±3.34	35±2.05	34.6±3.36
Sand (%)	59.63±5.4	59.26±2.7	60.96±0.85	59.16±1.61
Silt (%)	20.9±0.36	21.13±0.97	21.96±0.6	19.96±0.89
Clay (%)	19.46±1.65	19.6±3.3	17.06±1.34	20.86±1.02
Soil porosity (%)	0.41±0.01	0.416±0.03	0.42±0.01	0.46±0.01
Bulk density (gcm^{-3})	1.45±0.06	1.44±0.1	1.39±0.03	1.32±0.02
Particle density (gcm^{-3})	2.47±0.05	2.49±0.12	2.44±0.07	2.49±0.1
pH	2.96±0.2	3.2±0.26	3.86±0.3	3.9±0.34
Moisture (%)	20.9±5.4	23.1±6.02	35.9±2.35	32.07±3.49
Electrical Conductivity (μ Scm^{-1})	272.8±5.94	328.1±16.6	334.7±6.7	295±12.9
Cation Exchange Capacity (meq100 g^{-1})	20.06±2.65	24.56±2.7	25.36±3.6	32.38±2.7
Organic Carbon (%)	1.24±0.32	1.32±0.23	0.95±0.13	1.46±0.39
Potassium (kg ha^{-1})	159.8±7.5	162.4±3.2	172.±44.4	178.4±8.2
Available Nitrogen (kg ha^{-1})	74.23±10.6	79.4±4.3	105.9±12.9	105.63±6.4
Phosphorus (kg ha^{-1})	5.9±0.3	6.83±0.85	8.3±1.27	7.86±0.41

autumn with the lowest in winter (0.41% ± 0.01). Decrease of soil macropore volume in winter can be a result of soil compaction due to trampling by humans coupled with a decline of soil organic carbon content in the mine spoil (Yimer *et al.* 2008) while the increase in soil porosity in summer can be attributed to organic matter from forest litters. Bulk density is an important property for gaseous exchange, as such soil with high BD would pose root growth restriction and may cause cessation of plant growth (Ghose 2004). Observed mean bulk density (BD) ranges from 1.32 g cm^{-3} ± 0.02 (autumn) to 1.45 g cm^{-3} ± 0.06 (winter) which is unlikely to have adverse effects on plants (Amacher and Perry 2007, Brzezinska *et al*. 2011). Particle density (PD) governs successful vegetation which also influences water holding capacity, bulk density, soil moisture availability and nutrient content. Season wise highest mean value of PD was recorded in spring (2.49 g cm^{-3} ± 0.12) and autumn (2.49 g cm^{-3} ± 0.1) while the lowest was observed in summer (2.44 g cm^{-3} ± 0.07). The pH value of 5.5-7.2 which is slightly acid to neutral is optimum for plant growth (Amacher and Perry 2007). However, in CMAF the soil have relatively low pH with the minimum mean value in winter (2.96 ± 0.2) and maximum in autumn (3.9 ± 0.34). Coal mining activities exposes sulfur-containing pyrites that oxidize to sulfuric acid on exposure to oxygen, water and certain aerobic bacteria, resulting to low soil pH. The leaching rate of forest wastes, soil nature, chemical composition, may also be responsible for it (Goswami and Sarma 2008). The field moisture is a fluctuating parameter that depends on the time of sampling, amount of organic carbon, texture and thickness of litter layers (Maiti 2006, 2013). As such soil moisture was recorded lowest in winter (20.9 % ± 5.4) and highest in summer (35.9 % ± 2.35) when forest litter was abundant. Low moisture content in winter may be attributed due to lack of organic matter, higher stone content and sandy texture (Sadhu *et al.* 2012). Electrical conductivity (EC) < 200 indicates low salt level, 200-500 serves as an optimum salt level for plants and > 500 indicates high salt level, which may have adverse effect on the plants as estimated by Lal (1994). Observed mean EC in summer (334.7μS cm^{-1} ± 6.7), spring (328.1μS cm^{-1} ± 16.6), autumn (295μS cm^{-1} ± 12.9) and winter (272.8 μS cm^{-1} ± 5.94) were all under optimum level. The cation exchange capacity (CEC) is an important indicator of soil fertility as they are not easily leached by water. Autumn was recorded having the highest CEC average value of 32.38 meq 100g^{-1} ± 2.7, while the lowest was observed in winter (20.06 meq100g^{-1} ± 2.65). The findings suggest that low CEC in winter has influenced low water holding capacity, reduce soil organic carbon and nutrient properties of the soil as all these parameters are related directly or indirectly. Soil organic carbon (SOC) is known to accelerate the rejuvenating properties of soil. SOC as categorized by Feiza *et al.* (2011), Lal (1994); 2-3% - moderate limitation, SOC > 3.0% - slight to no limitation. In the CMAF soil all the seasons have low mean value of SOC as recorded in autumn (1.46% ± 0.39), spring

(1.32% ± 0.23), winter (1.24% ± 0.32) and summer (0.95% ± 0.13). The soil nutrient such as available nitrogen, phosphorus and potassium are conducive to the accumulation of the increase in soil organic matter (Six *et al.* 2002). The maximum mean value of potassium was recorded in autumn (178.4 kg ha^{-1} ± 8.2) and minimum in winter (159.8 kg ha^{-1} ± 7.5). Available nitrogen in the soil is the nitrogen element that is used directly by plants for its cellular function, which is mainly derived from the mineralization of soil total nitrogen (Liu *et al*. 2016). The observed mean value of available nitrogen was recorded highest in summer (105.9 kg ha^{-1} ± 12.9) and lowest during winter (74.23 kg ha^{-1} ± 10.6). The low N_2 content in soil during winter may be due to lack of adequate amount of organic nitrogen, lower mineralization and nitrification rates, reduced vegetation cover and lack of microbial activity. Mean value of available phosphorus was highest in summer (8.3 kg ha^{-1} ± 1.27) followed by autumn (7.86 kg ha^{-1} ± 0.41), spring (6.83 kg ha^{-1} ± 0.85) and winter (5.9 kg ha^{-1} ± 0.3). Gahoonia and Nielsen (2003) stated that soils with low temperatures have low availability of phosphorus because the release of phosphorus from organic material is hindered by low temperature which is relevant in the present study. The result reflects that mining activities such as tailing, dumping of overburden spoils and untreated mine drainage into the forest area has lowered the pH and reduced the amount of organic matter content in soil which has indirectly influence other soil properties through its aggregate effect.

Heavy metals concentration in the soil and plant samples

Assessment on the heavy metals at CMAF soil shows that the element Zn was the most abundant while Pb was not detected in any of the samples. In accordance with Denneman and Robberse (1990), Ministry of Housing, Netherland (1994), the target values which are specified to indicate desirable maximum levels of elements in the soils shows Zn (54 ± 0.89 mg kg$^{-1)}$ and Cd (2.4 ± 0.076 mg kg^{-1}) were beyond the desirable limits while Cu (35.4 ± 0.95 mg kg^{-1}) and Ni (18 ± 0.78 mg kg^{-1}) were low in concentration and meets the standardized limits (Table 1). Considering the geochemical background (GB) value, the results indicate that Zn, Cu and Ni were below the average value while Cd exceeded the GB value given by Kabata-Pendias (2011) presented in Table 2.

Table 2. Heavy metal of CMAF soil, desirable limits and Geochemical background (GB). *Target values are specified to indicate desirable maximum levels of elements in unpolluted soils. Source: Denneman and Robberse (1990) and Ministry of Housing, Netherland (1994). ** GB value of heavy metals in surface soils over the world (average, mg kg^{-1}), Kabata-Pendias (2011).

Elements	CMAF soil (mg kg^{-1})	*Desirable limit (mg kg^{-1})	**GB average (mg kg^{-1})
Zn	54 ± 0.89	50	70
Cd	2.4 ± 0.076	0.8	0.41
Cu	35.4 ± 0.95	36	38.9
Ni	18 ± 0.78	85	29
Pb	0	35	27

The concentration of heavy metals varies from one plant to another as shown in Table 3. The value of Zn in *Melastoma malabathricum* (54 ± 0.89 mg kg^{-1}), *Dicranopteris linearis* (46.8 ± 0.57 mg kg $^{-1}$), *Chromolaena odorata* (57.6 ± 0.66 mg kg^{-1}), *Pteridium esculentum* (55.2 ± 0.58 mg kg $^{-1}$) and *Thysanolaena latifolia* (66 ± 0.73 mg kg^{-1}) were beyond the permissible limit (WHO). Highest value of Cd was observed in *Thysanolaena latifolia* (2.4 ± 0.078 mg kg $^{-1}$) followed by *Pteridium esculentum* (1.2 ± 0.073

Table 3. Heavy metal concentration (mg kg^{-1}) in the CMAF plants.

Elements	*Melastoma malabathricum*	*Dicranopteris linearis*	*Chromolaena odorata*	*Pteridium esculentum*	*Thysanolaena latifolia*	Permissible limits WHO (1996)
Zn	24.6±0.47	46.8±0.57	57.6±0.66	55.2±0.58	66±0.73	0.60
Cd	0.6±0.034	0.9±0.069	0.6±0.034	1.2±0.073	2.4±0.078	0.02
Cu	54±0.99	27.6±0.84	54±0.84	27.6±0.46	39.6±0.62	10
Ni	3.6±0.11	5.4±0.17	8.4±0.28	3±0.098	6.6±0.13	10
Pb	0	0	0	0	0	2

Table 4. Transfer factor of heavy metals on the plant samples.

Elements	*Melastoma malabathricum*	*Dicranopteris linearis*	*Chromolaena odorata*	*Pteridium esculentum*	*Thysanolaena latifolia*
Zn	0.45	0.86	1.06	1.02	1.22
Cd	0.25	0.37	0.25	0.5	1
Cu	1.52	0.77	1.52	0.77	1.11
Ni	0.2	0.3	0.46	0.16	0.36
Pb	0	0	0	0	0

mg kg $^{-1}$), *Dicranopteris linearis* (0.9 ± 0.069 mg kg $^{-1}$), *Chromolaena odorata* (0.6 ± 0.03 mg kg $^{-1}$) and *Melastoma malabathricum* (0.6 ± 0.034 mg kg $^{-1}$). Maximum value of Cu was detected in *Melastoma malabathricum* (54 ± 0.99 mg kg^{-1}) and *Chromolaena odorata* (54 ± 0.84 mg kg^{-1}), the minimum value is recorded in *Dicranopteris linearis* (27.6 ±0.84 mg kg $^{-1}$) and *Pteridium esculentum* (27.6 ± 0.46 mg kg $^{-1}$) while *Thysanolaena latifolia* has a concentration of (39.6 ± 0.62 mg kg $^{-1}$). Ni has a value of (3.6 ± 0.11 mg kg $^{-1}$), (5.4 ± 0.17 mg kg $^{-1}$), (8.4 ± 0.28 mg kg $^{-1}$), (3 ± 0.098 mg kg $^{-1}$) and (6.6 ± 0.13 mg kg $^{-1}$) content in *Melastoma malabathricum, Dicranopteris linearis, Chromolaena odorata, Pteridium esculentum* and *Thysanolaena latifolia.* In respect to the permissible limit of heavy metal on plants given by WHO (1996), the concentration of the element Zn, Cd and Cu in the plant samples were above the desirable standard value while Ni content was in the permissible limit in all the samples.

Transfer factor (TF)

TF of heavy metals from the CMAF soil to the plants differs significantly in all the plant samples as shown in Table 4. *Thysanolaena latifolia* (1.22) has the highest TF of Zn, followed by *Chromolaena odorata* (1.06), *Pteridium esculentum* (1.02), *Dicranopteris linearis* (0.86) and *Melastoma malabathricum* (0.45). The TF of Cd was recorded highest in *Thysanolaena latifolia* (1.00) and lowest in *Melastoma malabathricum* and *Chromolaena odorata* with the value of 0.25. *Dicranopteris linearis* and *Pteridium esculentum* have a TF value of 0.37 and 0.5 respectively. Cu has TF value of 0.77, 0.77, 1.11, 1.52 and 1.52 in *Dicranopteris linearis, Pteridium esculentum, Thysanolaena latifolia, Melastoma malabathricum* and *Chromolaena odorata.* Maximum TF of Ni was observed in *Chromolaena odorata* (0.46) and minimum in *Pteridium esculentum* (0.16) while *Melastoma malabathricum, Dicranopteris linearis* and *Thysanolaena latifolia* have a TF value of 0.2, 0.3 and 0.36. The elemental concentrations among various samples reflect the difference in uptake capabilities and their translocation to the shoot of the plants. The results of TF is similar to the findings of Amusan *et al.* (2005) and Agyarko *et al.* (2010) where they demonstrated that the metals uptake by plants differs from one metal to another and from one plant species to another. The TF of Zn in *Chromolaena odorata, Pteridium esculentum* and *Thysanolaena latifolia*, Cd in *Thysanolaena latifolia* and Cu in *Melastoma malabathricum, Chromolaena odorata* and *Thysanolaena latifolia* were relatively high. The result depicts that heavy metal accumulation in the plant tissues at CMAF may cause toxicity and enhance the risk factors of elemental environment pollution. However, in view of hyperaccumulation, the high concentration of Zn, Cd and Cu on the selected plant samples indicates that *Thysanolaenaa latifolia, Chromolaena odorata, Pteridium esculentum* and *Melastoma malabathricum* are dominant accumulator at the CMAF area and can be suggested for phytoremediation. An important characteristic of these plants that makes accumulation possible is their tolerant nature to increasing concentrations of the metals. As explained by Garbisu and Alkorta (2003), this could be a result of exclusion of these metals from the plants or by compartmentalization of the metal ions; since, the metals are retained in the vacuolar compartments or cell walls and hence do not have access to cellular sites where vital functions such as respiration and cell division takes place.

CONCLUSION

As per the observation, climatic conditions along with coal mining activities played a major role in influencing the soil properties and its nutrients composition. The absence of Pb in both the CMAF soil and plant samples implies that the elements present in the soil can be a major factor governing the heavy metal contents in the plants. The study shows Cd exceeded the GB value while the metals Zn, Cd and Cu accumulation on the plants samples were beyond the standard limits of WHO (1996). Comprehensive evaluation from the research suggests that mining activities may have altered the soil physico-chemical properties and increased the degree of heavy metal contamination in the soil. Hence, the utmost necessary step is to control the discharge of coal mining overburden dumps, tailing and effluents into the forest area. These activities, if not enforced by law, could lead to further deterioration of soil quality as well as loss of native plant species and therefore needs to be examined considering perspective views on social, ecological and environmental conditions.

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