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A baseline case study onrat-hole coal mining and its impact on soil and microbial characteristics inKhliehriat, East Jaintia Hills District, Meghalaya

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Abstract:

Coal extraction in Meghalaya is done by 'rat-hole' mining, which has led to notable changes in the surrounding environment, resulting in reduction of forest cover and loss of biodiversity, soil erosion and pollution of water, land and air. Assessment of soil quality plays a key role in evaluation of mining effects as indicator of environmental risks. The physiochemical parameters of soil such as pH, soil moisture content (SMC), soil organic carbon (SOC), soil organic matter (SOM), exchangeable potassium (ex.K), total phosphate (TP), total kjeldahl nitrogen(TKN) and heavy metal contents were analysed along with the bacterial and fungal population dynamics and compared to the un-mined site from nearby area. The pH of the mining site was 2.75 compared to 4.39 of un-mined site. Rat hole mining significantly *($P<0.05$)*altered the soil pH and statistically insignificant deviation of SMC and TP was observed in mine soil. There was significant ($P<0.05$) difference between pH, exchangeable K, TKN, SOC and SOM of mining area soil when compared to unmined location. Concentration of heavy metals such Mn, Cr, Pb, Fe, Zn, Al, Ni, Co and Cu was tested.There is more than 50% increase in the metal concentration such as Mn, Pb, Fe, Al and Co in mined soil samples when compared with unmined soil samples. The microbial population in mined soil decreased sharply in comparison to unmined soil.The baseline findings indicate that rat-hole coal mining altered the soil physicochemical properties leading to nutrient deficiency, acidic condition and increased heavy metal toxicity that affected the indigenousmicrobial population.

Keywords: Rat-hole mining, soil physio-chemical properties, heavy metals, microbial population.

ISSN: 2278-4632
Vol-10 Issue-6 No. 13 June 2020

Introduction:

Meghalaya, one of the eight states of north eastern India, has large reserves of coal, lime, and uranium (Warjri & Syiem, 2018). During the last few decades, there has been phenomenal increase in mining of coal, limestone, sillimanite and clay, causing large-scale destruction and deterioration in the environment(Sarma, 2005). Coal extraction in the state is done using primitive sub-surface mining method i.e., 'rat-hole' mining. These unscientific mining method and absence of any post-mining treatment and management of mined areas makes ecosystems vulnerable to environmental degradation (Tiwari, 1996) as represented in Figure 1. Coal Mining have stopped in Meghalaya since the NGT ban in 2014, however the damage done by previous mining can be seen in the barren areas around the abandoned mines. Though NGT claimed that the ban was imposed for theenvironment protection, the main question arise what about the abandoned mines which is still effecting the environment and the livelihood of those people which are totally dependent on coal mining.

Coal mining contaminated the nearby soils through atmospheric deposition, and is one of the most common sources of pollution in soil (Mondal et al., 2010). Various mining operations like top-soil handling, drilling, blasting, overburden-handling by draglines and conveyors; coal handling, loading, unloading, etc. generate huge amounts of dust which contains metal species like Fe, Cu, Zn, Mn, Pb, Cd, Cr, Ni, Co, V, Ti, Br, Zr, etc and ultimately settle on nearby soils (Masto et al., 2011) and present of excess amounts of heavy metal are generally harmful to plants, animals, and human health (Jarup, 2003). Soil pollution affects the availability of nutrients, soil structure and water quality of that area.The major impact of mining on the environment are changes in soil stratification, declined in biotic diversity, and alteration of basic structural and functional nature of the ecosystems which ultimately effect the nutrient cycles and trophic interactions (Ghose, 2004). Soil is not only an a vital component of ecosystem as its properties are influenced by continuous interactions of its abiotic and biotic constituents but also acts as an indicator of environmental pollution (Machulla et al., 2005, Singh & Singh, 2004). Assessments of soil from rat-hole mining in comparison with unmined site on different physio-chemical properties, heavy metal content and microbial diversity give a better understanding on the soil conditions and the environmental risks associated with mining. This study might lead to the directions of improving soil fertility, reclamation and restoration and vegetation development.

ISSN: 2278-4632
Vol-10 Issue-6 No. 13 June 2020

Method and material:

Study site and sampling:

The study area for the present investigation was located in Khliehriat, East Jaintia Hills District, Meghalaya, which lies between 25°13'N and 92°17'E (Figure 2). For this study, a total of 12 soil samples (< 20 cm depth) were collected from different abandoned rat hole coal minesand 5 soil samples were collected from unmined/undisturbed sites (adjacent to mines) which were taken as control sites. A portion of the fresh soil samples was refrigerated for the analysis of soil biological parameters whereas the rest of the samples were air-dried at room temperature, slightly ground with mortar pastels, and passed through a 2mm sieve for further analysis (Rashid et al., 2014).

Soil physical and chemical characteristics:

Soil pH was determined using a digital pH meter (Professional Meter PP–20, Sartorius) in a 1: 2.5 w/v suspension of soil and deionized water (Anderson & Ingram 1993). Soil moisture content was determined by gravimetric method (Allen et al., 1974). Soil organic carbon (SOC) and soil organic matter (SOM) was determined by colorimetric method (Anderson &Ingram 1993). Total Kjeldahl nitrogen (TKN) and total phosphorus (TP) in soil were determined by Kjeldahl digestion of air–dried soil sample with conc. H_2SO4 using Kjeltabs as catalyst (Allen et al., 1974), TKN was analyzed following ammonia reduction method and total P by the vanado–molybdate method using FIASTAR 5000 auto–analyzer (FOSS, Denmark). Soil exchangeable potassium (ex.K) was analysed using Flame Photometer (Model–1381E, ESICO) after extracting the soil with ammonium acetate (pH 7) solution (Jackson, 1973).

Soil heavy metal analysis:

Estimation of heavy metals like Mn, Cr, Pb, Fe, Zn, Al, Ni, Co and Cu of soil samples were done using ***ICP-OES (Thermo Scientific™ iCAP™ 7600).*** Trace elements were extracted from soil samples using acid digestion method by EPA (3050B). Soil samples (1 gm) were digested by conc HNO_3. The digestate was filtered through Whatman No. 41 filter paper and the final volume was made up to 100 mL with distilled water and used for estimation of metals.

ISSN: 2278-4632
Vol-10 Issue-6 No. 13 June 2020

Microbial population study:

Standard spread plate count method by the surface inoculation were used for enumerated the total viable number of microorganisms (bacteria and fungi) in the soil samples. One-gram of soil samples were serially diluted and plated on nutrient agar medium (HiMedia, India), incubated at 37°C for 24-48 hrs for bacterial colonies count. Potato dextrose agar medium (HiMedia, India) were used for fungal count, the plates were observed for fungal growth after incubation period of 7 days at a temperature of 25 °C (Harley & Prescott, 2002). The total bacterial and fungal count were calculated and expressed in CFU/g (colony-forming units per gram).

Statistical analysis

One-way Analysis of Variance (ANOVA) was performed to evaluate the significance of variation influenced by rat-hole mining disturbances using statistica 7.0version.

Results and discussion:

Soil physical and chemical characteristics: The physio-chemical parameter of the rat-hole coal mine soil samples and the unmined soil samples is presented in Table 1. The average mean for pH of the coal mine soil samples were found to be 2.75 which is highly acidic when compare to the unmined soil samples which have an average mean of 4.39 which is slightly acidic in nature (Figure 3). Decrease in pH of coal mine soil samples have been reported by many researchers (Makdoh & Kayang, 2015; Ko-at et al., 2017), as there are various factors such as acid mine drainage caused by exposure of iron pyrite ((FeS_2) and other sulphide minerals which get oxides both by water and oxygen result in drop down of pH in the soil and water samples (Johnson &Hallberg, 2005). The soil moisture content and total phosphorus(TP) showed not much different between the rat-hole mine and un-mined soil samples. Other soil parameters such as ex. K, TKN, SOC and SOM were high in control samples in comparison with the coal mine soil. The results of the one-way analysis of variance (ANOVA) showed that the rat-hole mining have significant ($P<0.05$) difference between pH, ex. K, TKN, SOC and SOM when compared to un-mined soil, whereas SMC and TP showed to be statistically non-significant.

ISSN: 2278-4632
Vol-10 Issue-6 No. 13 June 2020

Soil heavy metal analysis: The heavy metals concentrations of the metals such as Mn, Cr, Pb, Fe, Zn, Al, Ni, Co and Cu of the 2 different types of soil samples are presented in table 2. The concentration ofMn, Cr, Pb, Fe, Zn, Al and Co were found higher in mined soil compared to unmined soil, except Ni and Cu were its concentration is similar to the control soil. The percentage of heavy metal in mined soil in comparison to unmined soil is shown in figure 4. There is more than 50% increase in the tested metal concentration such as Mn, Pb, Fe, Al and Co in mined soil samples. One-way ANOVA results (Table 2) showed that Mn, Cr, Pb, Fe, Zn, Al and Co was significantly differ in the rat-hole coal mining, whereasNi and Cu are found to be statistically not significant at $P< 0.05$.

Microbial population study: Microorganism in soil plays an important role in the ecosystem and involved in the transformation of soil nutrients and organic matter (Merino et al., 2015). The microbial population study in both the rat-hole mine soil and unmined soil samples are represented in table 3. The present study showed that the mean cfu ($x10^6/g$) for bacteria obtained from the mined soils is 4.35 and 11.14 in unmined soil(Figure 5), whereas the mean cfu ($x10^2/g$) for fungal obtained was 7.9 from mined sample and 15.8 from unmined samples(Figure 6). The microbial population in rat-hole mined soil decreased sharply in comparison to unmined soil. One-way ANOVA results also found to be significant ($P<0.05$) difference between microbial population of mine soil when compared to un-mined soil.

Conclusion: The present comparative study between soil of rat-hole coal mining sites and unmined undisturbed sites revealed that the mining had altered the soil native characteristics and has a negative impact on the soil quality. The mining soil have less nutrients, acidic pH, high metal contents and low bacterial and fungal population which may led to less fertility of the soil. High acidic conditions of soil is one of the main reason that make the soil nutrient deficient, as it increased the availability of heavy metals which is toxic for plant and microbes growth(Tapadar&Jha, 2015). Microorganisms play a major role in soil dynamics such as restoration of the nutrient hence reducing in the number of microbes may result in the broken down of nutrient cycle causes deficiency in nutrients which ultimately make the soil unproductive (Ghose, 2004). From this study we can conclude that the coal mining has negative impacts on the soil, however, coal is an important source of energy and ban on coal mining in Meghalaya seems to be unfair as its touch the livelihood of many people. Instead of completely banning on coal mining there should be an alternative solution to minimize the effect of mining as suggested by Talukdar et al. (2016). There are many fields based Eco-

ISSN: 2278-4632
Vol-10 Issue-6 No. 13 June 2020

restoration studies done around the world (Cunningham &Berti, 1993, Wong, 2003; Gonzalez & Gonzalez-Chavez, 2006; Mendez & Maier 2008) which can be used for reducing the toxic effect of coal mining and these can be apply in Meghalaya coal mine areas.

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Figure Legends:

Figure 1: Diagramatic representation of water and soil pollution caused by coal mines in Meghalaya.

Figure 2: Map showing sampling area with GPS location of Khliehriat located in East Jaintia Hills District, Meghalaya, India.

Figure 3: pH variation between the control and coal mine soil samples.

Figure 4: Graphical representation of coal mine soil sample heavy metal percentage increases against heavy metal concentration of control soil sample.

Figure 5: The mean bacterial cfu (x10^5/g) of mine and control soil samples.

Figure 6: The mean fungal cfu (x 10^2/g) of mine and control soil samples.

Table 1: Physico-chemical characteristics of rat-hole coal mine and unmined soil samples with one-way analysis of variance (ANOVA) analysis showing the influence of rat-hole coal mining over the properties of unmined soil.

Soil parameter	**Control soil samples (n-5)**				**Rat-hole mine soil samples (n-12)**				**Significance (p < 0.05)**
	Max	**Min**	**Mean**	**SD**	**Max**	**Min**	**Mean**	**SD**	
pH	5.2	4.14	4.39	0.04	3.32	1.95	2.75	0.01	Significant
SMC(%)	19.3	16.17	18.48	0.09	28.10	10.3	21.46	1.18	NS
Ex.K(mg/g)	0.061	0.048	0.057	0.01	0.06	0.03	0.026	0.01	Significant
TKN (mg/g)	2.815	1.63	2.62	0.13	1.43	0.11	0.94	0.01	Significant
TP (mg/g)	1.97	0.230	0.22	0.02	0.3	0.01	0.17	0.03	NS
SOC(%)	5.21	4.81	4.93	0.04	0.349	0.019	2.70	0.45	Significant
SOM (%)	8.93	7.12	8.51	0.09	4.81	0.41	5.10	0.68	Significant

ISSN: 2278-4632
Vol-10 Issue-6 No. 13 June 2020

SD, standard deviation; n, number of sample; SMC, Soil moisture content; Ex.K, Exchangeable potassium; TKN, Total Kjeldahl nitrogen; TP,total phosphorus; SOC, Soil organic carbon; SOM, Soil organic matter; and NS, not significant at P < 0.05.

Table 2: Heavy metal concentration (ppm) of rat-hole coal mine and unmined soil samples with one-way analysis of variance (ANOVA) analysis and the percentage increase in heavy metal of mine soil in comparison with the control soil samples

Soil heavy metalconc (ppm)	**Control soil samples (n-5)**				**Rat-hole mine soil samples (n-12)**				**Percentage increase against control (%)**	**Significant (p < 0.05)**
	Max	**Min**	**Mean**	**SD**	**Max**	**Min**	**Mean**	**SD**		
Mn	5.7	3.2	4.4	1.03	82.1	22	50.24	27.1	**91.3**	Significant
Cr	199.6	139.1	176.65	26.4	756.1	184.8	399.88	266.3	**55.8**	Significant
Pb	5.8	3.4	4.75	1.009	56.9	14.8	34.95	22.6	**86.4**	Significant
Fe	29691.2	25001.6	27777.3	4054.6	88230.5	35453.65	54019.7	23459.9	**48.6**	Significant
Zn	50.6	12.7	26.99	16.1	54.1	25.7	39.98	11.87	**32.5**	Significant
Al	2476.6	1186.3	1984.75	572.93	6477.9	3520.2	4737.65	1251.1	**58.2**	Significant
Ni	24.2	10	14.275	6.652	23.6	9.7	16.1	5.73	**11.3**	NS
Co	0.9	0.3	0.65	0.25	6.4	3.7	4.68	1.19	**86.1**	Significant
Cu	5.42	2	3.38	1.64	12.9	0.3	5.58	6.27	**39.4**	NS

SD, standard deviation; n, number of sample; Mn, Manganese; Cr, Chromium; Pb, Lead; Fe, Iron; Zn, Zinc; Al, Aluminium; Ni, Nickel; Co, Cobalt; Cu, Copper; and NS, not significant at P < 0.05.

Table 3: The microbial CFU count of rat-hole coal mine and unmined soil samples with one-way analysis of variance (ANOVA) analysis.

Soil microbial population (CFU/g)	**Control soil samples (n-5)**				**Rat-hole mine soil samples (n-12)**				**Significant (p < 0.05)**
	Max	**Min**	**Mean**	**SD**	**Max**	**Min**	**Mean**	**SD**	

ISSN: 2278-4632
Vol-10 Issue-6 No. 13 June 2020

Bacteria ($X10^5/g$)	122.4	98.6	111.4	10.1	50.1	41.4	43.5	6.34	Significant
Fungi ($X10^2/g$)	20.6	12.9	15.8	3.3	9.1	6.3	7.9	1.18	Significant

SD, standard deviation; n, number of sample; CFU/g,colony-forming units per gram.

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