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ORIGINAL ARTICLE

Impact of slate quarrying on soil properties in semi-arid Mahendragarh in India

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Abstract Slate quarrying in Mahendragarh district of Haryana state has resulted in changes in soil properties. Most of the mining area is devoid of vegetation. The soil in and around the mining area (0–1 km) is alkaline (pH 11.2–11.7) but non-saline (electrical conductivity < 4). The alkaline nature of the soil was attributed to the high concentrations of hydroxyl (OH^-), carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) present in minerals of mined materials. Biotite, limonite, kaolinite, gibbsite, muscovite, geothite, dolomite and so on were the chief minerals added to soil through mining. The physical properties of soil, i.e. porosity, water-holding capacity (WHC), bulk density and particle density represented poor soil health in mining area (34.4, 29.8%, 1.636, 2.496 g/cc, respectively) and they improved with distance away from it (46.4, 38.3%, 1.070, 2.180 g/cc, respectively, at a distance of 1 km). Porosity and WHC were found to be a function of increased organic matter away from the mining area. CO_3^{2-}, HCO_3^-, phosphate (PO_4^{3-}), lead (Pb) and iron (Fe) were more in mining area and decreased with distance. On the other hand, sodium (Na^+), potassium (K^+), chloride (Cl^-), sulphate (SO_4^{2-}), organic carbon, total Kjeldahl's nitrogen, cation exchange capacity, chromium (Cr) and cadmium (Cd) increased with distance from mining area. High concentration of heavy metals in mining area was a cause of concern (0.93 μg/g Cd, 22.35 μg/g Cr, 26.25 μg/g Pb, 1,383.75 μg/g Fe). The change in physico-chemical properties could be because of the addition of chemical constituents that are a part of major minerals present in mined material. The soil away from mining area represented comparatively better properties.

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Introduction

Earth has got vast reserves of minerals and ores concentrated in its depth, which have played a key role in development, economy and prosperity of a country. Mining is second only to agriculture as world's oldest and most important industry. The ever-increasing demand in development has led to blind excavation of minerals and ores without paying any attention to the environment. In recent years, the over-exploitation of mineral resources has left the environment around mining areas in a shattered state. Mining has resulted in air and water pollution, loss of biodiversity, soil pollution and land degradation (Kumar 1996; Bruijnzeel 2004). The disruption of geology and soil–plant stability circuit, increased import from the system and depletion of soil organic pool are some of the results of mining (Harthill and Mckell 1979). As soil acts as an ultimate sink of all the pollutants produced in mining, the impacts on properties of soil become imperative to study. Mining results in clearing of vegetation in the area which reduces the essential nutrients and organic matter content of soil, results in reduced biological activity and decreased productivity of soil (Pandey and Kumar 1996) especially in the areas that are agriculture-dominated. Such soils get concentrated in the chemical constituents present in the parent rock and lack others. A high concentration of trace metals has been observed in soil in and around mining areas (Cappuyns et al. 2006; Riba et al. 2002). The change in physico-chemical properties of soil leads to infertile or barren soil that does not support normal growth of vegetation for years (Jha and Singh 1991) and adversely affects agricultural production too. Mining, in other words, accounts for increase in area under wastelands. Singh et al. (1991) reported that slate quarrying is responsible for the change in soil properties and adversely affects the soil quality. The change in properties of soil is in turn related with the reduced production. The present study is important because, despite being a source of slate reserves mined for many years, the chief minerals present in the area are yet to be studied in detail. Major share of land in Haryana is used for agriculture and the study of effects of mining on soil is still in infancy. It is imperative to identify the mineral resources, addition of heavy metals and their effects on soil to gain an insight into economical and sustainable use of resources. The present study was undertaken to study major minerals, their effects on soil and alterations in physico-chemical properties of soil with distance.

Materials and methods

Description of study area

Haryana, an agriculture-based state of North India, with an area of 44,000 km^2 has about 6% of area under wastelands. Haryana can be divided into two natural areas, sub-Himalayan Terai and Indo-Gangetic plain. The plain is fertile and slopes from north to south with a height above the sea level, averaging between 700 and 900 ft. South-west of Haryana is dry, sandy and barren. Haryana has no perennial river. About 6% ($\approx$2,540.10 km^2) of the total area of Haryana lies under wastelands, out of which approximately an area of 57.08 km^2 is under mining with a share of 35.05 km^2 in Mahendragarh district alone. Mahendragarh is famous for its slate mineral deposits chiefly used in construction of roads and buildings (Thussu 1993). The district lies between North latitude 27°47′ and 28°26′ and East longitude 75°56′ and 76°51′, with an area of 1,683 km^2, a domain of dry land topography throughout. The overall relief is undulatory with a regional north to north-east slope placed at 210–250 m above mean sea level. The rocks exposed in the district belong to Delhi Supergroup and are divided into Alwar and Ajabgarh groups. The Alwar group of rocks comprises predominantly of arenaceous sediments and is represented by massive quartzite, usually felspathic in nature, micaceous quartzite with subordinate bands of mica schist and carbonaceous phyllite. The Ajabgarh group of rocks in the area is characterized predominantly by argillaceous sediments and include shale, slate and siltstone together with few quartzitic and cherty bands, siltstone being more predominant than the other two varieties. Both these groups of rocks are intruded by amphibolite, granite, aplite, pegmatite, calcite and vein quartz. Alkaline earths occur as efflorescence on the surface of the earth and contain predominantly carbonates and bicarbonates of sodium. The climate of the area is characterized by the dryness of air, a hot summer and cold winter. The mean daily maximum and minimum temperature is 41.0 and 27.0 and 22.0 and 6.0°C for summer and winter, respectively.

Sample collection and analysis

The selection of the site was done based on the intensity of mining. Behali, situated on the Nangal-Chaudhari road was selected as the site under study to collect the representative soil samples (Fig. 1). The chief deposits of slate occur near Kund, Behali, Bjar, Rampur, Ganiar and Bas. The entire range is worked for slates, blocks and beams of slate and associated shale and siltstone. Mining area was undulatory and uneven. The atmosphere was dusty with unpaved roads and tailings and heaps of mined material laid at places. Blasting was observed in morning; and drilling, breaking the rocks and loading was done manually for rest of the day. The duration of work was 8 h per day. Five samples (A–E) were collected, each from mining area, a site 50 m away from mining area, 100 m away, 500 m away and 1 km away from the mining area, respectively. The study was concentrated to a distance of 1 km and the distance more than it was not included minimizing the possibility of effect of other sources. From each sampling point, three soil samples were collected removing 1-in layer of topmost soil. They were mixed thoroughly to get a representative sample of the point. All the samples were taken from points at least 100 ft away from road, large tree and civil construction. The samples, so collected, were put in thick quality polythene bags and immediately brought to the laboratory. Sand and silt + clay percentage were estimated by 'pipetting method of soil texture determination' (Gee and Bauder 1979) based on settling velocity of particles in water.

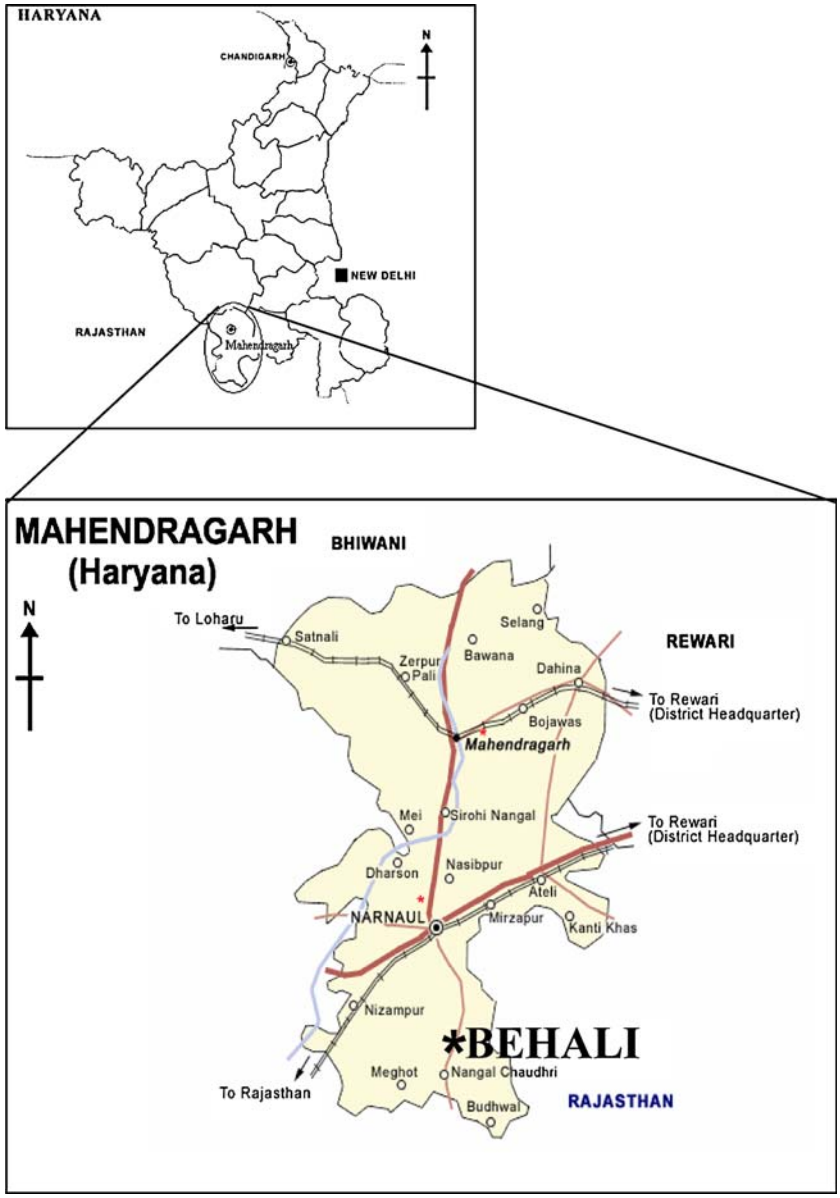

Fig. 1 Location of Mahendragarh district and sampling site (Behali) in Haryana state

$$\text{Percent silt + clay} = [(T_s - 67) \times 0.2 + (H_s - H_b)] \times 1\ \text{L} \times \left(\frac{1}{50}\ \text{g soil}\right) \times 100$$

% sand = 100 – (% silt + clay), where H_s—hydrometer reading of sample (g/L), H_b—hydrometer reading of blank (g/L) and T_s—temperature.

Bulk density was determined by 'core cutter method' (SAA 1977). Particle density and water-holding capacity (WHC) were measured by 'pycnometer bottle method' (ASTM D854 2001). Porosity of the sample was calculated using the following relation (NIOSH 1994).

$$\text{Porosity (\%)} = 1 - \left(\frac{\text{bulk density}}{\text{particle density}}\right)$$

The samples were dried in shade and sieved through 0.3-mm-sized mesh before chemical analysis. The extract preparation and chemical analysis was done as per standard recommended methods (Eaton et al. 1995) using double glass-distilled water and analytical grade (AR) chemicals. Heavy metals (Cd, Cr, Pb and Fe) were analysed by atomic absorption spectrophotometer, GBC 932+ model, in air–acetylene flame. The qualitative estimation of minerals present in the soil was done using Fourier transmission infrared spectroscopy on Shimadzu-8201 PC infrared spectrophotometer model.

Results and discussion

Physical properties of soil

The soil in and around the mining area was found to be alkaline (pH 11.2–11.7). The alkalinity can be attributed to the hydroxyl (OH^-), carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) ions present in the rocks as an important component of minerals associated with the rocks. Electrical conductivity (EC) of the soil varies between 0.14 and 1.21 mmho/cm. The alkaline pH and EC<4 suggest that the soil is alkaline but non-saline with a major share of hydroxides and carbonates of calcium and magnesium. The percentage of sand decreased with distance from the mining area which may be attributed to the large size of soil particles in the mining area as compared with the soil in areas away from it. The soil, based on soil texture, was found to be sandy loam. The high density of particles in mining area was because of the density of the parent rock. The bulk density of soil in the mining area and its proximity was more and it decreased with distance from the mining area as the particle density of mined particles is more. Porosity increased with distance from the mining area. It could be attributed to an increased void space between the particles which are comparatively loosely packed. An increase in organic matter also contributed towards it. Increase in organic matter increases the biochemical activity in soil and results in aggregation of particles, thus increasing the porosity. The addition of foreign particles in the form of leaves, twigs and so on also result in increased porosity with distance. They, alongwith the partially degraded organic matter provide additional space, enhanced porosity and aeration and account for increased WHC as observed in our results. Thus, porosity and WHC are a function of increased organic matter away from the mining area. The physical properties of the soil are presented in Table 1.

Chemical properties of soil

The soil in mining area was found to hold a low concentration of sodium (Na^+) and potassium (K^+) ions. The concentration of these ions increased as we moved away from the mining area. Na^+ and K^+ concentration increased to about 8 and 50 times, respectively, at a distance of 1 km as compared with the concentration in the mining area. The low concentration of these ions, in mining area, could be because of the relatively low concentration of these species in parent rock and their susceptibility to weathering as evident from the alkaline but non-saline nature of the soil. The concentration of chloride ions (Cl^-) followed the similar trend. On the other hand, the CO_3^{2-} and HCO_3^- ions were high in concentration in mining area and below the detection limit at a distance of 100 m and the distance over it. These ions were found to be integral components of minerals like calcite, dolomite and so on present in the mined material. Concentration below the detection limit at a distance of 100 m and over it shows that much of the dispersion was confined to a distance less than 100 m. Another study (Organiscak and Reed 2004) has also shown that the dispersion of dust in limestone quarrying was confined to about 100 ft. The vehicles operating in the mining area were found to be responsible for the dispersion of mined dust to still distant places. Sulphate (SO_4^{2-}) was low in concentration (0.011–0.015%) in the mining area. It was higher (0.419–0.476%) in the non-mining area. It showed an increasing trend with distance with an increase of about 400 times at a distance of 1 km compared with the concentration in the mining area. Phosphate (PO_4^{3-}), on the other hand, was found to be higher in the case of mining area and less at a distance of 1 km, though the difference is quite low. Percentage of organic matter was very low (4.5 g/kg). It increased with distance from the mining area and reached a maximum at a distance of 1 km (41.7 g/kg) with an increase of about ten times. It could be attributed to sparse or no vegetation in mining area as they are cleared of vegetation. The organic carbon content increased with an increase in vegetation. No effect of mining was observed on percentage of organic carbon at a distance of 500 m (Fig. 2a). Percentage of nitrogen [total Kjeldahl's nitrogen (TKN)], too, followed a similar trend. It was minimum in the mining area (0.22 g/kg) and maximum (1.68 g/kg) at a distance of 1 km from the mining area. It could be attributed to the input from vegetation as well as the runoff of fertilizers from agricultural fields nearby. Nitrogen content increased to about eight times at a distance of 1 km from the mining area (Fig. 2b). As the ionic species and organic matter content increased with distance, they led to an increase in cation exchange capacity (CEC) of soil too. It was minimum (16.1 meq/100 g soil) in the mining area and maximum (233.4 meq/100 g soil) with an increase of about 14.5% within a distance of 1 km (Fig. 2c). Improvement in the properties of soil with distance from the mining area leads to improvement of vegetation cover. Good WHC and nutrient level of such areas favours growth of vegetation and it adds organic matter to soil establishing a positive feedback improving the quality of soil further. Heavy metals (Cd, Cr, Pb and Fe) were also present in the soil. Cd and Cr were low in concentration in the mining area (0.93 and 22.35 μg/g,

Table 1 Physical properties of soil samples

Sample	Soil texture	Sand (2–0.05 mm) (%)	Silt + clay (<0.05 mm) (%)	Bulk density (gm/cc)	Particle density (gm/cc)	Porosity (%)	WHC (%)
A	Sandy loam	89.9	10.1	1.636	2.496	34.4	29.8
B	Sandy loam	84.5	15.5	1.932	2.600	25.7	24.8
C	Sandy loam	87.0	13.0	1.789	2.556	30.0	28.9
D	Sandy loam	88.6	11.4	1.210	2.272	46.8	40.7
E	Sandy loam	82.4	17.6	1.070	2.180	46.4	38.3

respectively) and high at a distance of 1 km (2.80 and 25.40 μg/g, respectively). Pb and Fe were high in concentration in the mining area and low in areas away from it. These elements could be attributed to vehicles and machines operating in mining area. The addition of Fe could also be from minerals like ilmenite, chlorite, limonite, biotite, geothite and so on present in the mined material. The chemical properties of soil samples are given in Table 2.

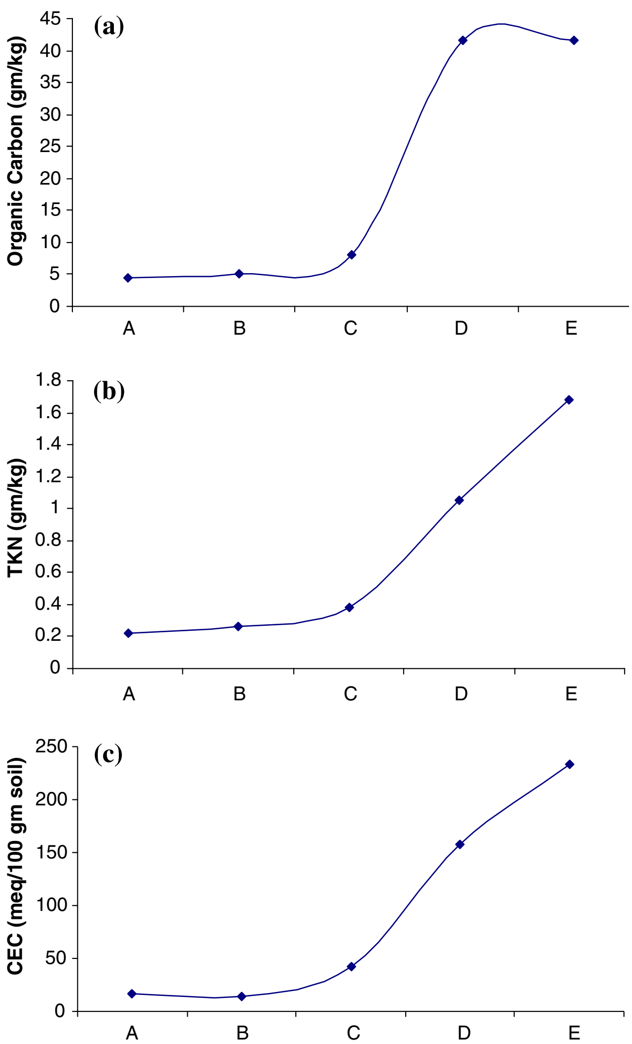

Fig. 2 Status of organic carbon (**a**), TKN (**b**) and CEC (**c**) in different soil samples

Mineralogical investigation

Different minerals present in the soil samples are given in Table 3. It was observed that minerals like plagioclase feldspar, biotite, kaolinite, gibbsite, biotite, muscovite and so on are present which owe to the alkalinity of soil as they bear associated hydroxyl (OH^-) group. The presence of hydroxyl-bearing minerals, at a distance of 500 m and 1 km away from the mining area, chiefly, could be responsible for the slight increase in the pH of the soil. The noticeable amount of carbonates and bicarbonates in the mining area and its proximity (50 m) could be because of the presence of carbonate-bearing minerals like calcite and dolomite. The decreased amount of these minerals in soil away from it could be the reason for a low concentration below the detection limit, of these species. As most of these minerals are prone to intermediate stages of weathering (Jackson et al. 1948), some of the ions like Na^+, K^+, Cl^- and so on can leach out easily from the minerals along with the runoff and reach to places comparatively away from the core of the mining area. Similar results have been observed in our study. The presence of minerals like ilmenite, chlorite, limonite, biotite, geothite and so on was probably responsible for the high concentration of Fe.

Conclusion

Physico-chemical properties of soil reveal that the soil in the mining area has poor health. It is alkaline but non-saline with a high concentration of OH^-, CO_3^{2-} and HCO_3^- ions to account for it. The soil is sandy loam in texture with high particle density, bulk density, particle density and low porosity. Such soils have poor hydraulic conductivity. Water does not percolate easily through the soils and results in runoff that ultimately results in leaching of salts and high erosion rate as

Table 2 Chemical properties of soil samples

Sample	pH	EC (mS/cm)	Na^+	K^+	Cl^-	CO_3^{2-}	HCO_3^-	SO_4^{2-}	PO_4^{3-}	Org. C	TKN	CEC	Cd	Cr	Pb	Fe
A	11.5	0.14	0.004	0.002	0.11	0.153	0.187	0.011	0.11	4.50	0.22	16.1	0.93	22.35	26.25	1,383.75
B	11.4	0.29	0.009	0.003	0.11	0.102	0.124	0.015	0.09	5.10	0.26	14.3	BDL	19.75	23.75	1,337.50
C	11.2	1.29	0.016	0.026	0.24	BDL	BDL	0.461	0.08	8.10	0.38	42.8	BDL	14.25	17.05	1,236.25
D	11.3	1.05	0.024	0.049	0.39	BDL	BDL	0.419	0.07	41.70	1.05	158.1	1.70	25.38	17.45	1,273.00
E	11.7	1.21	0.032	0.104	0.40	BDL	BDL	0.476	0.07	41.70	1.68	233.4	2.80	25.40	17.95	1,204.25

All the parameters are expressed in percent (%) except Org. C and TKN (gm/kg); CEC (meq/100 g soil) and heavy metals (Cd, Cr, Pb and Fe) (in μg/gm)

Table 3 Major minerals present in soil samples

Sample	Chief minerals
A	Biotite, limonite, dolomite, gibbsite, kaolinite, quartz, muscovite, boehmite
B	Biotite, limonite, dolomite, gibbsite, kaolinite, quartz, muscovite, vermiculite
C	Biotite, limonite, gibbsite, kaolinite, muscovite, plagioclase feldspar, geothite
D	Biotite, limonite, gibbsite, montmorillonite, geothite, boehmite, diaspore
E	Biotite, limonite, gibbsite, ilmenite, hydrous chlorite, plagioclase feldspar

observed in various studies (Loredo et al. 2003). The runoff could contaminate the groundwater and surface water bodies (Bzowski and Dawidowski 2002; Babut et al. 2003).

The input of soil and dust from the mining area, beside transportation through runoff and mechanical means, could be responsible for change in chemical properties of soil with the addition of toxic elements (Pb, Cd, Cr and Fe). The effects of heavy metals are well established and they pose problems even in efforts to reclaim the affected area. The sources of trace elements are the minerals present in rocks and the anthropogenic activities at the place. The substances can move to other compartments of the environment and pose a serious threat to population in the neighbouring areas. As major fraction of mined material is carried to a distance of about 100 m, the effects are pronounced within the area. Soil quality improves beyond it with an overall increase in nutrients (Na, K, TKN, organic carbon, sulphate and so on). It becomes important when most of the area around is used for agriculture. Mining can result in expansion of wastelands whereas minimization of mine tailing quantity and reclamation through proper environment management plan (Ghose 2003) can put the land to use, reduce health risks and help in improving agricultural production.

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