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Soil quality index for evaluation of reclaimed coal mine spoil

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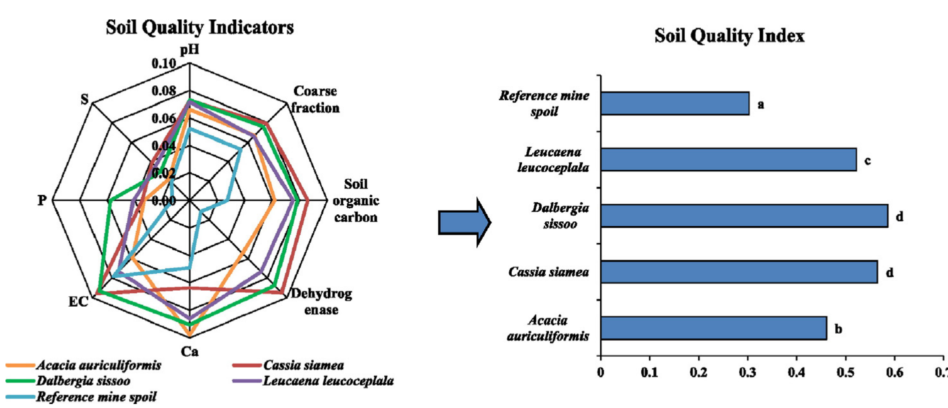
HIGHLIGHTS

- Mine spoil quality index developed from physical, chemical, biological properties.
- Key indicators are coarse fraction, pH, EC, organic carbon, P, Ca, S, dehydrogenase.
- Soil quality index was higher in reclaimed (0.6–0.9) than the bare site (0.4).
- Tree species with high index values are recommended for reclamation of mine spoil.
- *Dalbergia sissoo* and *Cassia siamea* are appropriate for reclamation of mine spoil.

GRAPHICAL ABSTRACT



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ABSTRACT

Success in the remediation of mine spoil depends largely on the selection of appropriate tree species. The impacts of remediation on mine soil quality cannot be sufficiently assessed by individual soil properties. However, combination of soil properties into an integrated soil quality index provides a more holistic status of reclamation potentials of tree species. Remediation potentials of four tree species (*Acacia auriculiformis*, *Cassia siamea*, *Dalbergia sissoo*, and *Leucaena leucocephala*) were studied on reclaimed coal mine overburden dumps of Jharia coalfield, Dhanbad, India. Soil samples were collected under the canopies of the tree species. Comparative studies on the properties of soils in the reclaimed and the reference sites showed improvements in soil quality parameters of the reclaimed site: coarse fraction (−20.4%), bulk density (−12.8%), water holding capacity (+0.92%), pH (+25.4%), EC (+2.9%), cation exchange capacity (+46.6%), organic carbon (+91.5%), N (+60.6%), P (+113%), K (+19.9%), Ca (+49.6%), Mg (+12.2%), Na (+19.6%), S (+46.7%), total polycyclic aromatic hydrocarbons (−71.4%), dehydrogenase activity (+197%), and microbial biomass carbon (+115%). Principal component analysis (PCA) was used to identify key mine soil quality indicators to develop a soil quality index (SQI). Selected indicators include: coarse fraction, pH, EC, soil organic carbon, P, Ca, S, and dehydrogenase activity. The indicator values were converted into a unitless score (0–1.00) and integrated into SQI. The calculated SQI was significantly ($P < 0.001$) correlated with tree biomass and canopy cover. Reclaimed site has 52–93% higher SQI compared to the reference site. Higher SQI values were obtained for sites reclaimed with *D. sissoo* (+93.1%) and *C. siamea* (+86.4%).

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1. Introduction

Despite significant progress on advocacy towards renewable energy, socio-economic activities of our modern society still depend on fossil fuels. Coal is still a very important energy resource for steel, cement, and thermal power plants (Ram and Masto, 2014). Coal mining leads to the removal of vegetation cover and topsoil, dumping of overburden materials, mine fire, etc.; these mining activities bring about dramatic physical changes and disruption of local ecosystems. In addition to severe land degradation, coal mining often had adverse effect on biodiversity (Mukhopadhyay et al., 2014). The disturbances in soil profile and other earth movements due to coal mining reduces land productivity; it can also cause severe soil, air and water pollution (Maiti, 2013).

As mining is a temporary land use, there is scope for the restoration of mine spoil through reclamation after the completion of mining projects (Mukhopadhyay et al., 2013; Ram and Masto, 2010). Establishment of tree species on mine spoil helps in acceleration of soil-forming processes; prevention of soil erosion; augmentation of organic matter, nutrient cycling, microbial communities, and overall aesthetics of the area (Josa et al., 2012; Srivastava et al., 2014; Zhao et al., 2012). Presence of pollutants like polycyclic aromatic hydrocarbons (PAHs) and trace elements, which are inherent to coal, may also affect the establishment of tree species.

Biological reclamation of mine spoils depends on the selection of appropriate tree species and their ameliorative effects (Dutta and Agrawal, 2002; Mukhopadhyay et al., 2013; Sinha et al., 2009). The impact of tree species on the mine soil quality cannot be assessed by individual mine soil parameters, as most of the parameters are interlinked and difficult to interpret. Therefore, an integrated soil quality index based on a combination of soil properties will provide a more meaningful assessment of reclamation status. A number of soil quality and fertility indices have been proposed for agricultural soils (Amacher et al., 2007; Andrews et al., 2002; Bastida et al., 2008; Karlen et al., 2003; Mukherjee and Lal, 2014; Rossi et al., 2009; Velasquez et al., 2007; Viana et al., 2014); but only few are for mine soil (Asensio et al., 2013; Mukhopadhyay et al., 2013; Mukhopadhyay et al., 2014; Sinha et al., 2009; Zhao et al., 2013).

Unlike agricultural soils, coal mine spoil may have pollutants like trace metals and PAHs which need to be considered for mine soil quality assessment. Soil pollution is normally assessed by relating the pollutant levels to the environmental guidelines or by pollution indices like geo-accumulation index, pollution load index, enrichment factor, etc. However, pollutants are not the dominant factor controlling the overall quality of a soil; other parameters such as soil texture, pH, organic matter, etc., are critical to the quality of a soil. Thus, a holistic assessment of soil quality should include physical, chemical, and biological soil parameters as well as the presence of hazardous and potentially toxic chemicals. Therefore, in the present study, a comprehensive soil quality index is presented for the assessment of remediation impact of tree species on coal mine spoil. The resultant index was validated by regression analysis with tree biomass and canopy cover of reclaimed site.

2. Materials and methods

2.1. Study area

The study was carried out in the reclaimed coal mine overburden (OB) dumps of Muraidih opencast projects (latitudes 23°48′13.3″–23°48′12.2″ N and longitudes 86°14′36.0″–86°14″54.3″ E), Jharia Coalfield, Dhanbad, Jharkhand, India. The climate is tropical with summer and winter average temperatures of 44.5 °C and 20.0 °C, respectively. During monsoon (June to October) about 80–85% of the annual rainfall is obtained. The annual average rainfall for the last 10 years is 1598 mm (Mukhopadhyay et al., 2013). The study area experiences severe land degradation due to opencast mining. There are huge OB dumps of 35–40 m height with quarry depths of approximately 60–70 m. The study area was reclaimed in 2000–01 by fast growing, deciduous, and timber yielding tree species.

2.2. Vegetation survey

Acacia auriculiformis, *Cassia siamea*, *Dalbergia sissoo* and *Leucaena leucocephala* were dominant in the reclaimed mine spoil with sparse ground vegetation. Scanty populations of *Albizia lebbeck*, *Azadirachta indica*, *Delonix regia*, *Prosopis juliflora*, and *Zizyphus jujuba* were also observed. All these trees were growing in mixed culture. For this study, 10 trees from each of the dominant species were selected randomly. The relative abundance of each tree species was calculated (Mukhopadhyay et al., 2013). The diameter at the breast height (DBH) of tree species was measured at the height of 1.37 m above the ground level. Height of the trees was measured by a hypsometer (Nikon Forestry Pro, Japan) and their canopy cover by the line intercept method (Johnson and Skousen, 1995). Wood samples for the estimation of specific gravity were collected at 1.3 m height using a stem borer. Volume of fresh wood samples was measured by water displacement method and the samples were dried at 80 °C till constant weight (Chaturvedi, 2010). Stem biomass was obtained by using the equation given by King et al. (2006):

$$\text{Stem biomass} = 0.5 \times (\pi/4) \times \text{WSG} \times (\text{DBH})^2 \times \text{H} \tag{1}$$

where, 0.5 is the form factor, defined as the ratio of stem volume to the volume of a cylinder, H height (m), DBH diameter at breast height (cm), WSG wood specific gravity (g/cm^3) (Chaturvedi et al., 2011). The below-ground biomass was calculated by assuming that root biomass is 25% (for hardwood species) of the total above-ground biomass (Fonseca et al., 2011; IPCC, 2006).

2.3. Collection of mine soil samples

Mine soil samples were collected under the canopy of four dominant tree species (*A. auriculiformis*, *C. siamea*, *D. sissoo*, and *L. leucocephala*) growing on the reclaimed coal mine spoil during November–December 2013. These trees are in mixed culture, for sampling 10 trees were selected randomly. For each tree species, ten replicates of soil samples were collected from 0–15 and 15–30 cm depths. For each replicate, one composite sample was prepared by mixing the three sub-samples collected from three different spots under the respective tree canopy cover. Reference soil samples were also collected from the unplanted mine spoil. For analysis of soil biological properties, field moist soil samples were taken in ice boxes, transported to laboratory, and stored at 4 °C till their analysis. For other physical and chemical analysis, a portion of the sample was air dried at room temperature.

2.4. Soil analyses

Air dried soil samples were sieved through 2 mm sieve to separate and quantify the coarse fraction (Gee and Bauder, 1986). All other soil analyses were carried out on soil fractions <2 mm. Sand, silt, and clay content were determined by the international pipette method (Gee and Bauder, 1986), and bulk density by the metal core sampler method (Blake and Harte, 1986). pH and electrical conductivity (EC) were determined in soil/water (1:2.5; *w*/*v*) suspension using pH meter (Orion Star A214, pH/ISE meter, Thermo Fisher Scientific) and conductivity meter (Eutech Instruments, PCSTestr 35), respectively (McLean, 1982). Soil organic carbon was determined by dichromate oxidation technique (Walkley and Black, 1934); available nitrogen (AN) by the alkaline potassium permanganate method (Subbiah and Asija, 1956). Dehydrogenase activity (DHA) was determined using 2,3,5-triphenyltetrazolium chloride (TTC) as substrate (Klein et al., 1971). Microbial biomass carbon (MBC) was estimated by chloroform fumigation and extraction method (Vance et al., 1987). Results of all the physical and chemical parameters are expressed on air dry weight basis; biological parameters on oven dry basis.