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Environmental soil quality index and indicators for a coal mining soil

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Abstract

Assessment of soil quality is one of the key parameters for evaluation of environmental contamination in the mining ecosystem. To investigate the effect of coal mining on soil quality, opencast and underground mining sites were selected in the Raniganj Coafield area, India. The physical, chemical, biological parameters, heavy metals, and PAHs contents of the soils were evaluated. Soil dehydrogenase (+79 %) and fluorescein (+32 %) activities were significantly higher in underground mine (UGM) soil, whereas peroxidase activity (+57 %) was higher in opencast mine (OCM) soil. Content of As, Be, Co, Cr, Cu, Mn, Ni, and Pb was significantly higher in OCM soil, whereas, Cd was higher in UGM. In general, the PAHs contents were higher in UGM soils probably due to the natural coal burning in these sites. The observed values for the above properties were converted into a unit less score (0–1.00) and the scores were integrated into environmental soil quality index (ESQI). In the unscreened index (ESQI-1) all the soil parameters were included and the results showed that the quality of the soil was better for UGM (0.539) than the OCM (0.511) soils. Principal component analysis was employed to derive ESQI-2 and accordingly, total PAHs, loss on ignition, bulk density, Be, Co, Cr, Ni, Pb, and microbial quotient (respiration: microbial biomass ratio) were found to be the most critical properties. The ESQI-2 was also higher for soils near UGM (+10.1 %). The proposed ESQI may be employed to monitor soil quality changes due to anthropogenic interventions.

1 Introduction

Coal, a combustible rock rich in carbon, is a crucial component of the energy mix that fuels the globe. In many countries, more than 70 % of the electricity generation comes from coal. For more than 150 years, coal has been an important source of energy for both developing and industrial societies. Coal mining is one of the core industries and plays a positive role in the economic development of any country. Its environmental impact cannot be ignored but, to some extent, is unavoidable (Chaulya, 2004). Many of the environmental and health problems attributed to coal are due to mobilization of potentially toxic organic and inorganic components (Swaine and Goodarzi, 1995). Coal is extracted from the earth by opencast and underground mining. Opencast mining is considered one of the most dramatic disturbances in terrestrial ecosystems. The disturbance of green vegetation due to mining and the difficulty for restoration have been reported (Milder et al., 2013). Coal mining can contaminate the nearby soils as atmospheric deposition is the most common source of pollution in soil. Ghose (2007) estimated that a typical open pit coal mine in India emitted 9366.7 kg day^{-1} of total suspended particles (TSP) which accounts for 3.74 kg of TSP per Mg of coal produced. Various mining operations like top soil handing, drilling, blasting, overburden handling by dragline and conveyor; coal handling, loading, unloading, etc. generate huge amounts of dust and ultimately settle down on the nearby soils.

Coal dust contains metal species (like Fe, Cu, Zn, Mn, Pb, Cd, Cr, Ni, Co, V, Ti, Br, Zr, etc.) and organic pollutants. Metal pollution from coal is of concern because some of the elements have high enrichment factors (Masto et al., 2007b). The trace elements present in coal are of concern as some of the elements have higher enrichment factors. Bi is considered as highly enriched in coal with a factor 410, whereas As, Cd, B, Sb, Mo, and Hg are less enriched (factor, 2–10). Coal also contributes to PAHs in the environment. PAHs are characterized by their exceptional toxicities towards many living organisms, reluctance in degradation and high lipophilicity, making them a class of very dangerous compounds. Coals exhibit relatively high PAH concentrations and soil admixed with coal particles has elevated PAH concentrations (Pies et al., 2007).

Soil is also a good indicator of pollution and environmental risks. It is continuously subject to pollution because of its open-system nature. Soil an important natural resource, supports the plant growth and other human needs. But, the presence of pollutants can affect soil quality and impair its life sustaining capacity. It is therefore important to identify the soil characteristics responsible for changes in soil quality, which may eventually be considered as soil quality indicators for assessing environmental sustainability (Masto et al., 2007a). Integrated soil indices based on a combination of soil properties provide a better indication of soil health than individual properties. Moreover an integrated index is essential for quantitative comparison of different soils. Several indices have been proposed to assess soil quality, which were mostly microbial in nature and for agricultural soils. Indexing involves three main aspects: (1) choosing appropriate indicators for a minimum data set, (2) transforming the indicators to scores; and (3) combining the scores into an index (Sinha et al., 2009). Soil quality indices are useful to differentiate between degraded status of soils (Morugán-Coronado et al., 2013). Studies on soil quality indices involving soil contaminants are limited. Thus, the present study was aimed to assess the physical, chemical, biological parameters along with heavy metal and PAH contents of soils near an opencast and underground coal mine. The other objective was to integrate all these parameters into a comprehensive environmental soil quality index (ESQI).

2 Materials and methods

2.1 Study site and soil sampling

Raniganj Coalfield is primarily located in the Asansol and Durgapur subdivisions of Bardhaman district, West Bengal, India. Raniganj Coalfield covers an area of 443.50 km^2 and has total coal reserves of 8552.85 million t. Eastern Coalfields (ECL) reported its reserves as 29.72 billion t that make it the second largest coalfield in the country (in terms of reserves). Surface soil samples (0–0.15 m depth) were randomly collected from the settlements near an opencast mine (Sonepur Bazari) and underground mine (North Serasole) of Raniganj Coalfields. All together 32 samples were collected from the opencast mining (OCM) site and 17 samples from underground mining (UGM) site. A portion of fresh soil samples were refrigerated for analysis of soil biological parameters. The rest of the samples were air dried ground and passed through 2 mm sieve for further analysis.

2.2 Soil analyzes

The methods described by Tandon (1993) and Baruah and Barthakur (1999) were used to determine the following soil properties: bulk density (BD) (soil core method), maximum water holding capacity (by equilibrating the soil with water), porosity (derived from bulk density), pH and EC in water (1 : 2.5, soil / water ratio), soil organic carbon (by potassium dichromate oxidation), and loss on ignition. Active microbial biomass carbon (AMBC) was measured by the glucose nutrient induced respiration method (Islam and Weil, 2000). Soil dehydrogenase activity was determined using the method of Klein et al. (1971). Phenol oxidase and peroxidase were measured with L-DOPA (L-3, 4 di hydroxy phenyl alanine) as substrate in acetate buffer (Robertson et al., 1999). Basal soil respiration (BSR) was measured as the CO_2 evolved from moist soil, adjusted to 60 % WHC, over an incubation period of 10 days at $25 \pm 1\,^{\circ}$C, in the dark (Islam and Weil, 2000). Soil metabolic quotient (AMBC/SOC) was calculated. Specific maintenance respiration rates (qCO_2) were calculated as BSR per unit of active (BSR/AMBC) microbial biomass carbon (Anderson and Domsch, 1990; Islam and Weil, 2000). Phosphatase enzyme (p-nitrophenyl phosphate method, colorimetry); fluorescein diacetate hydrolase activity (FDA) of the soil was determined by the method described by Dick et al. (1996). For analysis of soil heavy metal content, the soil samples were digested in a microwave (ETHOS, Milestone, Italy) as per USEPA 3051A method (USEPA, 2007) and filtered. The metals in the filtrate were determined by ICP–OES (iCAP 6300Duo, Thermo Fisher Scientific, UK). For soil PAH analysis, samples were extracted using 1 : 1 hexane: acetone mixture in microwave as per the USEPA method 3546 (USEPA, 1995). The concentrated extract was analyzed by GC-MS system (Varian 450 GC and 240 MS) for 16 PAHs.

2.3 Environmental soil quality indices

Two types of indexing system was followed to derive the environmental soil quality index (ESQI).

2.3.1 Unscreened transformation

$$\text{ESQI-1} = \sum_{i=1}^{n} S_i/n \qquad (1)$$

Where, S denotes score of observed soil parameter, n is the number of parameters included in the index.

2.3.2 Principal component based ESQI

Principal component analysis (PCA) was used to select the appropriate properties and their weighing factors. PCs with eigen value ≥ 1 and explained at least 5 % of the variation of the data are examined (Sharma et al., 2005). Under a particular principal component (PC), only the variables with high factor loadings were retained for indexing. High factor loadings were defined as having absolute values within 10 % of the highest factor loading (Andrews et al., 2002a). When more than one variable was retained under a single PC, multivariate correlations were employed to determine if the variables could be considered redundant and, therefore, eliminated from the ESQI (Andrews et al., 2002b). If the highly loaded factors were not correlated then each was considered important, and thus, retained in the ESQI. Among well-correlated variables, the variable with the highest factor loading (absolute value) was chosen for the ESQI. Each PC explained a certain amount of variation (%) in the total data set; this percentage provided the weight for variables chosen under a given PC. The final PCA based ESQI equation is as follows:

$$\text{ESQI-2} = \sum_{i=1}^{n} W_i S_i/n \qquad (2)$$

Where W is the PCA weighing factor of the soil properties selected by PCA, and S is their respective scores. To convert the real values of the soil properties in to scores

(S) we used an equation that defined a sigmoidal type (Sinha et al., 2009), with an asymptote tending to 1 and another tending to 0.

$$S = a/(1 + (x/x_0)^b) \quad (3)$$

Where x is the soil property value, a is the maximum score (= 1.00) of the soil property, x_0 is the mean value of each soil property, b is the value of the slope of the equation. The slope was −2.5 for the “more is better curve” and +2.5 for the “less is better curve” to obtain a sigmoidal curve tending to 1 for all the proposed properties.

2.3.3 Statistical analysis

The data were expressed as mean values and compared statistically by t test; P significance is presented. The ESQI was done using PCA (Andrews et al., 2002b). For computation, SYSTAT-12 package was used.

3 Results and discussion

3.1 Basic soil properties and biological parameters

Soil bulk density, porosity, water holding capacity, pH, and electrical conductivity were not significantly differed between the OCM (open cast mine) and UGM (underground mine) soils (Table 1). Mean soil organic carbon of the OCM soil was 2.04 %, whereas the SOC for UGM soil was 1.097 %. The SOC was almost 46 % higher in OCM soil. In line with SOC, the loss on ignition was 65 % higher in OCM soils. Deposition of fine coals on the soil surface could be the reason for the higher SOC and LOI in these soils. Most of the OCM and UGM soils were black colored due to the significant level of coal contamination (Masto et al., 2011).

Soil AMBC, BSR, phenol oxidase, alkaline and acid phosphatase activities were not significantly affected between these two sites. Soil dehydrogenase (+79 %)

and fluorescein (+32 %) activities were significantly higher in UGM soil, whereas peroxidase activity (+57 %) was higher in OCM soil. Different soil may inactivate enzyme reactions by complexing the substrate, by reacting with protein-active groups of enzyme-substrate, or by reacting with the enzyme substrate complex or indirectly by altering the microbial community, which synthesizes enzymes. Enzyme activity may either increase or decrease due to environmental contaminants. Heavy metals affect microbial metabolism by altering the normal enzyme activities, particularly inhibition of a specific enzyme and the effects can be dramatic and systemic (Christensen et al., 1982). The presence of different heavy metals and PAHs in coal contaminated soils might have altered the soil enzyme activities (Masto et al., 2007b).

3.2 Soil heavy metals

As, Be, Co, Cr, Cu, Mn, Ni, and Pb were significantly higher in OCM soil, whereas, Cd was higher in UGM; and Zn was not significantly affected in these two soils (Table 2). Arsenic (As) content in the OCM soils ranged from 0.5 to 8.5 $\mathrm{mg\,kg^{-1}}$ with a mean content of 3.97 $\mathrm{mg\,kg^{-1}}$, however the mean As content in UGM was 2.55 $\mathrm{mg\,kg^{-1}}$. Other elements like, Be (+28 %), Co (+52 %), Cr (+51 %), Cu (+24 %), Mn (+54 %), Ni (+23 %), were also significantly higher in OCM than the UGM soils. Most of the elements are enriched in OCM soil probably due to the relatively higher land disturbances and coal dispersion in OCM site. Among the elements, the content of Co and Cr was > 50 % higher in OCM soils, these elements might have originated from the coal. The rate of release of Cr into the global atmosphere from coal combustion is estimated to be in the order of a few thousands of tons per year. The mean Cr content of coals is only 20 $\mathrm{mg\,kg^{-1}}$ worldwide (Huggins et al., 2000).

Cd was slightly higher in the UGM soils. In Yatagan, Turkey, Yapici et al. (2006) reported that exploration of coal minerals contributed for Cd concentration in the local biota. The Zn content was not significantly affected between the OCM and UGM sites probably the soil Zn is originated from vehicular activities. Tyre treads and tyre dust contains significant amounts of Zn (Apeagyei et al., 2011), thereby it is likely that the contamination of both OCM and UGM soils with Zn is from vehicular activities.

3.3 Soil PAHs

Among the soil PAHs, acenapththylene and phenanthrene were not significantly affected between OCM and UGM soils (Table 3). Naphthalene (+26 %), fluorene (+66 %), anthracene (+43 %), fluoranthene (+44 %), pyrene (+52 %), benz(a)anthracene (+41 %), chrysene (+50 %), benzo(b)fluoranthene (+66 %), benzo(k)fluoranthene (+69 %), benzo(a)pyrene (+62 %), and total PAHs (+24.3 %) were significantly higher in UGM soils. Acenaphthene (+43 %), benzo(g,h,i)perylene (+89 %), and dibenzo(a,h)anthracene (+94 %) were significantly higher in OCM soils. In general the PAHs contents were higher in UGM soils probably due to the natural coal burning in these sites. The said coal mine has experienced mine fires and mining operations were closed for quite a few years. Tsibart et al. (2014) observed higher PAHs content in soils affected by fire. Maximal total concentrations of 14 PAHs were detected in charred peat horizons (up to 330 $\mathrm{mg\,kg^{-1}}$) and in post-fire incipient O horizons (up to 180 $\mathrm{mg\,kg^{-1}}$), but the high-molecular-weight PAHs (benz(ghi)perylene, benz(a)pyrene, benz(k)fluoranthene) were revealed only in charry peat horizons. During coal burning the organic compounds in the coal are partially cracked to smaller and unstable fragments. These fragments, mainly highly reactive free radicals with a very short average lifetime, lead to more stable PAH formation through recombination reactions (Mastral and Callén, 2000). Further, fluoranthene and pyrene are enriched in UGM soils, and are commonly considered as typical pyrogenic products derived from high temperature condensation of lower molecular weight aromatic compounds (Li et al., 2010). PAHs are emitted in the gas and solid phases. Both these PAHs can travel in the atmosphere and settle down on soil, water bodies and other environmental media. Natural mine fire as well as domestic use of coal for cooking in the UGM site might have contributed to elevated PAHs content in the UGM soils. Natural coal fires were not reported in the OCM sites of the present study. Domestic coal burning is also not present in OCM site as the OCM is away from residential area.

3.4 Environmental soil quality index

Individual soil parameter values were normalized on a scale from 0 to 1 based on two types of curve: "more is better" (POR, WHC, and pH. SOC, DHA, FDA, AMBC, BSR, PHOH, POH, ACP, AKP, AMBC/SOC); "less is better" (BD, EC, LOI, heavy metals, PAHs, BSR/AMBC). More is better was designated for pH as the mean pH in both these soil was < 7.0. Less is better was designated for loss on ignition, as it indicates the quantum of coal contamination. The calculated scores were integrated in to ESQI by two indexing methods as below.

3.4.1 Unscreened transformation (ESQI-1)

The index is the summation of the scores obtained by individual indicators, divided by the total number of indicators, here all the soil parameters has equal weightage. ESQI-1 ranged from 0.478 to 0.595 in UGM and 0.383 to 0.603 in OCM. The ESQI was further segregated into physical, chemical, biological, heavy metal, and PAH qualities (Eq. 4) and the data are presented in Fig. 1a. The physical (0.104 vs. 0.097), chemical (0.109 vs. 0.099), biological (0.098 vs. 0.084), and heavy metal (0.126 vs. 0.107) quality was better in UGM than OCM, however, it was reversed for PAHs (0.103 vs. 0.124). Thus the overall mean ESQI was 0.539 and 0.511 for UGM and OCM, respectively. These findings highlight the importance of inclusion of PAHs in soil quality assessment. In many of the past soil quality studies PAHs were not included, the mean ESQI without PAHs would be overestimating the quality of UGM soils.

$$\text{ESQI-1} = 0.2S_{\text{Physical}} + 0.2S_{\text{Chemical}} + 0.2S_{\text{Biological}} + 0.2S_{\text{Heavy metals}} + 0.2S_{\text{PAHs}} \quad (4)$$

3.4.2 Principal component analysis based index (ESQI-2)

All the soil variables were included for principal component analysis. The first five PCs had eigenvalues > 1.00 (Table 4). The highly loaded variable under PC-1 was total PAHs and was included in the ESQI. Likewise in PC-2, LOI, dibenzo(a,h)anthracene, indeno(1,2,3,c,d)pyrene, and benzo(g,h,i)perylene were highly loaded. As these parameters are highly correlated ($r > 0.700$) among themselves and the total PAHs were already included in the ESQI, only LOI from PC-2 was included in the index. Similarly Be, Co, Cr, Ni, and Pb from PC-3 was included from PC-3, all these elements were correlated among themselves, therefore the weight corresponding to PC-3 was equally divided among these elements. BD, POR, and WHC were highly loaded from PC-4, and these parameters were correlated among themselves; only BD was selected for the ESQI. Similarly BSR/AMBC was included in the ESQI from PC-5. Weights for selected variables were determined by the percent variation in the data set explained by the five PCs. The final normalized PCA based soil quality equation is

$$\begin{aligned}\text{ESQI-2} = {} & 0.439S_{\text{total PAHs}} + 0.195S_{\text{LOI}} + 0.031S_{\text{Be}} + 0.031S_{\text{Co}} + 0.031S_{\text{Cr}} + 0.031S_{\text{Ni}} \\ & + 0.031S_{\text{Pb}} + 0.128S_{\text{BD}} + 0.084S_{\text{BSR/AMBC}} \end{aligned} \tag{5}$$

This is probably one of the first studies where total PAHs has been used as a soil quality indicator. In line with PAHs, the LOI was also included in the ESQI. The LOI could be an indirect measure of the coal contamination in the soils, the LOI observed in the soils is much higher than the normal soils. As coal is an organic matter, it contributes to soil LOI and PAHs. The soil PAH is very important in contamination and human exposure point of view. PAH profile in UK soils, indicates that benzo[a]pyrene is a good surrogate marker, being ubiquitous in sites contaminated with PAHs and providing a consistent indicator of the amount of PAHs in contaminated soil (HPA, 2010). Fluoranthene is suggested as a complementary indicator to benzo(a)pyrene (Bostrom et al., 2002). Heavy metals are ubiquitous pollutants coal has also been reported as one of the source of heavy metal pollutants especially Cr, Ni, and CO (Masto et al., 2007b) as some of these elements are enriched in the coal. The bulk density is an important parameter which affects the soil productivity of the coal-mined land because it indicates the suitability of the soil for root proliferation, water-holding capacity, and long-term nutrient availability. It is found to affect the entire biological reclamation process by influencing moisture retention capacity, and porosity. The ratio BSR / AMBC is most appropriately used as an index of adversity of environmental conditions for the soil micro flora and has valuable applications as a relative measure of how efficiently the soil microbial biomass is utilizing carbon sources, and the degree of substrate limitation for the soil microorganisms (Wardle and Ghani, 1995). Soil microorganisms divert more energy from growth to maintenance as stress increases and thus the ratio of respired C to biomass C can be a much more sensitive indicator of stress. The BSR / MBC ratio indicates the carbon turnover rates in the soils, the importance of soil organic carbon in improving the overall soil quality has been reported widely (Debasish et al., 2014; Fialho and Zinn, 2014; Lozano-García and Parras-Alcántara, 2014). Paz-Ferreiro and Fu (2013) reviewed the limitations of using soil biochemical, microbiological, and biological properties for soil quality evaluation.

The ESQI-2 obtained using the PCA is presented in Fig. 1b, where the contribution of each soil indicator parameter on calculated ESQI is also shown, which gives an insight into the cause for the measured ESQI. The ESQI is higher in UGM (+10.1 %) than OCM soil. Total PAHs and LOI are the limiting parameters in UGM (−39.6 %) and OCM (−143 %) soils, respectively.

In general, the UGM has comparatively less environmental impacts than opencast mining. As underground mining operations take place below ground, they generally do not create as much air pollution, contribute less to groundwater, surface water and soil pollution, and are not as visually intrusive. Similar soil quality studies on mining area showed that reclamation of mine soil through plantation could improve the SQI score (Asensio et al., 2013).

4 Conclusions

For both the indexing methods, the underground mine soil has better soil quality values (0.539 and 0.576) than the opencast mines (0.511 and 0.518). Based on principal component analysis total PAHs, loss on ignition, bulk density, Be, Co, Cr, Ni, Pb, and microbial quotient (respiration: microbial biomass ratio) were found to be the most critical soil quality indicators. For the first time, total soil PAH has emerged as an indicator of soil quality and it is pertinent to reinforce that the index is being applied for coal contaminated soils. Another interesting finding is the loss on ignition (an indirect measure of soil organic matter) has been used as an indicator with negative score (less is better). Here again it is applicable only for the coal contaminated soils. The proposed equation as an environmental soil quality index could be valid for establishing the degree of degradation of coal contaminated soils as a function of soil physical, chemical, biological parameters, heavy metals, and PAHs.

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References

Anderson, T. H. and Domsch, K. H.: Application of eco-physiological quotients (qCO_2 and qD) on microbial biomasses from soils of different cropping histories, Soil Biol. Biochem., 22, 251–255, 1990.

Andrews, S. S., Karlen, D. L., and Mitchell, J. P.: A comparison of soil quality indexing methods for vegetable production systems in Northern California, Agr. Ecosyst. Environ., 90, 25–45, doi:10.1016/S0167-8809(01)00174-8, 2002a.

Andrews, S. S., Mitchell, J. P., Mancinelli, R., Karlen, D. L., Hartz, T. K., Horwath, W. R., Pettygrove, G. S., Scow, K. M., and Munk, D. S.: On-farm assessment of soil quality in California's Central Valley, Agron. J., 94, 12–23, doi:10.2134/agronj2002.1200, 2002b.

Apeagyei, E., Bank, M. S., and Spengler, J. D.: Distribution of heavy metals in road dust along an urban-rural gradient in Massachusetts, Atmos. Environ., 45, 2310–2323, doi:10.1016/j.atmosenv.2010.11.015, 2011.

Asensio, V., Guala, S. D., Vega, F. A., and Covelo, E. F.: A soil quality index for reclaimed mine soils, Environ. Toxicol. Chem., 32, 2240–2248, doi:10.1002/etc.2315, 2013.

Baruah, T. C. and Barthakur, H. P.: A Text Book of Soil Analysis, Vikas Publishing House Pvt. Ltd., New Delhi, 1999.

Bostrom, C. E., Gerde, P., Hanberg, A., Jernstrom, B., Johansson, C., Kyrklund, T., Rannug, A., Tornqvist, M., Victorin, K., and Westerholm, R.: Cancer risk assessment, indicators, and guidelines for polycyclic aromatic hydrocarbons in the ambient air, Environ. Health Persp., 110, 451–488, 2002.

Chaulya, S. K.: Assessment and management of air quality for an opencast coal mining area, J. Environ. Manage., 70, 1–14, doi:10.1016/j.jenvman.2003.09.018, 2004.

Christensen, G. M., Olson, D., and Riedel, B.: Chemical effects on the activity of eight enzymes: a review and a discussion relevant to environmental monitoring, Environ. Res., 29, 247–255, doi:10.1016/0013-9351(82)90026-3, 1982.

HPA Contaminated Land Information Sheet: Risk Assessment Approaches for Polycyclic Aromatic Hydrocarbons (PAHs), available at: http://webarchive.nationalarchives.gov.uk/20140714084352/http://www.hpa.org.uk/webc/hpawebfile/hpaweb_c/1287147342113, last access: 30 December 2014, 2010.

Debasish, S., Kukal, S. S., and Bawa, S. S.: Soil organic carbon stock and fractions in relation to land use and soil depth in the degraded Shiwaliks Hills of Lower Himalayas, Land Degrad. Dev., 25, 407–416, doi:10.1002/ldr.2151, 2014.

Dick, R. P., Breakwell, D. P., and Turco, R. F.: Soil enzyme activities and biodiversity measurements as integrative microbiological indicators, in: Methods for Assessing Soil Quality, edited by: Doran, J. and Jones, A., SSSA, Madison, WI, USA, Spec. Publ. no. 49, 247–271, 1996.

Fialho, R. C. and Zinn, Y. L.: Changes in soil organic carbon under eucalyptus plantations in Brazil: a comparative analysis, Land Degrad. Dev., 25, 428–437, doi:10.1002/ldr.2158, 2014.

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Ghose, M.: Generation and quantification of hazardous dusts from coal mining in the Indian context, Environ. Monit. Assess., 130, 35–45, doi:10.1007/s10661-006-9451-y, 2007.

Huggins, F. E., Shah, N., Huffman, G. P., Kolker, A., Crowley, S., Palmer, C. A., and Finkelman, R. B.: Mode of occurrence of chromium in four US coals, Fuel Process. Technol., 63, 79–92, doi:10.1016/S0378-3820(99)00090-9, 2000.

Islam, K. R. and Weil, R. R.: Land use effects on soil quality in a tropical forest ecosystem of Bangladesh, Agr. Ecosyst. Environ., 79, 9–16, 2000.

Klein, D. A., Loh, T. C., and Goulding, R. L.: A rapid procedure to evaluate the dehydrogenase activity of soils low in organic matter, Soil Biol. Biochem., 3, 385–387, doi:10.1016/0038-0717(71)90049-6, 1971.

Li, H., Chen, J., Wu, W., and Piao, X.: Distribution of polycyclic aromatic hydrocarbons in different size fractions of soil from a coke oven plant and its relationship to organic carbon content, J. Hazard. Mater., 176, 729–734, doi:10.1016/j.jhazmat.2009.11.095, 2010.

Lozano-García, B. and Parras-Alcántara, L.: Variation in soil organic carbon and nitrogen stocks along a toposequence in a traditional mediterranean olive grove, Land Degrad. Dev., 25, 297–304, doi:10.1002/ldr.2284, 2014.

Masto, R. E., Chhonkar, P. K., Singh, D., and Patra, A. K.: Soil quality response to long-term nutrient and crop management on a semi-arid Inceptisol, Agr. Ecosyst. Environ., 118, 130–142, doi:10.1016/j.agee.2006.05.008, 2007a.

Masto, R. E., Ram, L. C., Selvi, V. A., Jha, S. K., and Srivastava, N. K.: Soil contamination and human health risks in coal mining environs, International Conference on MSECCMI New Delhi, 19–21 November 2007, 257–265, 2007b.

Masto, R. E., Ram, L. C., Shandilya, P. R., Sinha, S., George, J., and Selvi, V. A.: Selection of bioindicators in coal-contaminated soils of Dhanbad, India, Envir. Earth Sci., 64, 1107–1115, doi:10.1007/s12665-011-0927-x, 2011.

Mastral, A. M. and Callén, M. S.: A review on polycyclic aromatic hydrocarbon (PAH) emissions from energy generation, Environ. Sci. Technol., 34, 3051–3057, doi:10.1021/es001028d, 2000.

Microwave assisted acid digestion of sediments, sludges, soils, and oils (USEPA 3051A): available at: http://www.epa.gov/osw/hazard/testmethods/sw846/pdfs/3051a.pdf, last access: 30 December 2014, 2007.

Microwave Extraction (USEPA 3546): available at: http://www.epa.gov/osw/hazard/testmethods/sw846/pdfs/3546.pdf, last access: 30 December 2014, 1995.

Milder, A. I., Fernández-Santos, B., and Martínez-Ruiz, C.: Colonization patterns of woody species on lands mined for coal in Spain: preliminary insights for forest expansion, Land Degrad. Dev., 24, 39–46, doi:10.1002/ldr.1101, 2013.

Morugán-Coronado, A., Arcenegui, V., García-Orenes, F., Mataix-Solera, J., and Mataix-Beneyto, J.: Application of soil quality indices to assess the status of agricultural soils irrigated with treated wastewaters, Solid Earth, 4, 119–127, doi:10.5194/se-4-119-2013, 2013.

Paz-Ferreiro, J. and Fu, S.: Biological indices for soil quality evaluation: perspectives and limitations, Land Degrad. Dev., doi:10.1002/ldr.2262, online first, 2013.

Pies, C., Yang, Y., and Hofmann, T.: Distribution of polycyclic aromatic hydrocarbons (PAHs) in floodplain soils of the Mosel and Saar River, J. Soils Sediments, 7, 216–222, doi:10.1065/jss2007.06.233, 2007.

Robertson, G. P., Coleman, D. C., Bledsoe, C. S., and Phillip, S.: Standard Soil Methods for Long Term Ecological Research, Oxford University Press, Oxford, 1999.

Sharma, K. L., Mandal, U. K., Srinivas, K., Vittal, K. P. R., Mandal, B., Grace, J. K., and Ramesh, V.: Long-term soil management effects on crop yields and soil quality in a dryland Alfisol, Soil Till. Res., 83, 246–259, doi:10.1016/j.still.2004.08.002, 2005.

Sinha, S., Masto, R. E., Ram, L. C., Selvi, V. A., Srivastava, N. K., Tripathi, R. C., and George, J.: Rhizosphere soil microbial index of tree species in a coal mining ecosystem, Soil Biol. Biochem., 41, 1824–1832, doi:10.1016/j.soilbio.2008.11.022, 2009.

Swaine, D. J. and Goodarzi, F.: Environmental Aspects of Trace Elements in Coal, Springer, The Netherlands, 1995.

Tandon, H. L. S.: Methods of Analysis of Soils, Plants, Waters and Fertilizers, FDCO, New Delhi, 1993.

Tsibart, A., Gennadiev, A., Koshovskii, T., and Watts, A.: Polycyclic aromatic hydrocarbons in post-fire soils of drained peatlands in western Meshchera (Moscow region, Russia), Solid Earth, 5, 1305–1317, doi:10.5194/se-5-1305-2014, 2014.

Wardle, D. A. and Ghani, A.: A critique of the microbial metabolic quotient (qCO_2) as a bioindicator of disturbance and ecosystem development, Soil Biol. Biochem., 27, 1601–1610, doi:10.1016/0038-0717(95)00093-T, 1995.

Yapici, G., Can, G., Kiziler, A. R., Aydemir, B., Timur, I. H., and Kaypmaz, A.: Lead and cadmium exposure in children living around a coal-mining area in Yatagan, Turkey, Toxicol. Ind. Health, 22, 357–362, 2006.

Table 1. Soil physical, chemical and biological properties in the opencast and underground mining site.

Soil parameters	Underground mine (*n* – 17)				Opencast mine (*n* – 32)				
	Min	Max	Mean	SD	Min	Max	Mean	SD	T sig.
BD	1.15	1.59	1.36	0.128	1.20	1.55	1.41	0.096	NS
POR	39.9	56.9	48.7	5.30	35.2	55.2	46.3	4.10	NS
WHC	23.3	43.0	35.4	5.60	24.2	45.4	32.7	4.80	NS
pH	4.90	7.80	6.37	0.818	4.88	8.58	6.28	0.890	NS
EC	0.380	1.12	0.682	0.237	0.208	1.45	0.636	0.356	NS
SOC	0.526	1.99	1.09	0.475	0.508	7.12	2.04	1.31	0.000
LOI	4.36	16.1	9.17	3.45	11.4	24.9	15.9	2.44	0.000
DHA	45.3	264	144	61.0	14.3	67.5	30.7	14.5	0.000
FDA	3.34	14.0	8.53	3.23	1.12	15.5	5.80	3.48	0.009
AMBC	23.3	186	96.2	35.9	20.3	175	92.7	45.7	NS
BSR	498	812	675	90.9	456	861	675	93.3	NS
PHOX	0.007	0.027	0.017	0.006	0.003	0.060	0.020	0.013	NS
POX	0.001	0.027	0.010	0.006	0.005	0.051	0.023	0.012	0.000
ACP	1.29	26.3	9.17	6.36	1.93	35.0	11.6	8.11	NS
AKP	0.323	32.6	9.27	9.03	1.45	37.4	12.8	9.48	NS
AMBC/SOC	0.003	0.017	0.009	0.004	0.001	0.024	0.006	0.006	0.041
BSR/AMBC	3.65	27.8	8.44	5.39	3.76	20.1	10.3	7.40	NS

(SD, standard deviation; BD, bulk density ($\mathrm{Mg\,m^{-3}}$); POR, porosity (%); WHC, water holding capacity (%); EC, electrical conductivity ($\mathrm{dS\,m^{-1}}$); SOC, soil organic carbon (%); LOI: loss on ignition (%); DHA, dehydrogenase activity (mg TPF $\mathrm{kg^{-1}\,h^{-1}}$); FDA, fluorescein diacetate hydrolase activity (mg fluorescein $\mathrm{kg^{-1}\,h^{-1}}$); AMBC, active microbial biomass carbon ($\mathrm{mg\,kg^{-1}}$); BSR, basal soil respiration (mg $\mathrm{CO_2}$-C $\mathrm{kg^{-1}\,day^{-1}}$); PHOX, phenol oxidase activity ($\mathrm{mM\,g^{-1}\,h^{-1}}$); POX, peroxidise activity ($\mathrm{mM\,g^{-1}\,h^{-1}}$); ACP, acid phosphatise activity (mg PNP $\mathrm{kg^{-1}\,h^{-1}}$); AKP, alkaline phosphatise activity (mg PNP $\mathrm{kg^{-1}\,h^{-1}}$); NS, not significant at $P < 0.05$).

Table 2. Soil heavy metal contents in the opencast and underground mining site.

Heavy metals	Underground mine ($n - 17$)				Opencast mine ($n - 32$)				T sig.
($\mathrm{mg\,kg^{-1}}$)	Min	Max	Mean	SD	Min	Max	Mean	SD	
As	0.800	4.50	2.55	0.862	0.500	8.50	3.96	1.82	0.000
Be	0.420	1.52	0.944	0.259	0.660	2.86	1.20	0.500	0.021
Cd	0.001	0.220	0.06	0.070	0.001	0.100	0.012	0.026	0.006
Co	4.60	25.1	14.5	5.85	7.90	54.2	22.0	10.8	0.002
Cr	32.5	93.5	64.3	16.5	50.0	187	97.5	34.4	0.000
Cu	11.3	41.0	21.9	8.57	14.5	43.0	27.1	6.91	0.041
Mn	100	824	436	229	169	5494	947	918	0.005
Ni	12.7	41.2	27.5	8.55	18.9	87.6	33.9	14.4	0.056
Pb	10.7	26.9	17.4	4.42	11.6	73.7	27.3	14.5	0.000
Zn	21.2	89.0	47.8	21.5	24.8	84.3	46.8	15.8	NS

NS, not significant at $P < 0.05$.

Table 3. Soil PAH contents in the opencast and underground mining site.

PAHs (mg kg^{-1})	Underground mine (*n* – 17)				Opencast mine (*n* – 32)				T sig.
	Min	Max	Mean	SD	Min	Max	Mean	SD	
Naphthalene	0.052	0.346	0.173	0.082	0.049	0.300	0.128	0.078	0.070
Acenapththylene	0.200	2.05	0.842	0.564	0.129	1.90	0.650	0.460	NS
Acenaphthene	0.147	3.20	1.68	0.863	0.496	8.40	2.952	1.89	0.002
Fluorene	0.120	2.32	0.845	0.697	0.080	0.978	0.287	0.206	0.004
Phenanthrene	0.373	4.50	1.80	1.17	0.149	2.80	1.20	0.728	NS
Anthracene	0.183	2.40	1.56	0.709	0.141	2.90	0.887	0.650	0.002
Fluoranthene	0.191	2.41	1.31	0.653	0.125	2.17	0.730	0.528	0.003
Pyrene	0.204	2.22	1.39	0.663	0.128	1.40	0.668	0.321	0.000
Benz(a)anthracene	0.167	1.51	0.839	0.479	0.124	1.34	0.496	0.278	0.012
Chrysene	0.224	2.00	1.27	0.559	0.136	1.93	0.631	0.454	0.000
Benzo(b)fluoranthene	0.478	4.20	2.93	1.06	0.286	1.80	1.00	0.460	0.000
Benzo(k)fluoranthene	0.222	2.89	1.27	0.669	0.145	0.935	0.388	0.175	0.000
Benzo(a)pyrene	0.231	3.13	1.54	0.836	0.132	1.40	0.586	0.366	0.000
Benzo(g,h,i)perylene	0.079	0.203	0.128	0.032	0.332	1.99	1.18	0.365	0.000
Dibenzo(a,h)anthracene	0.027	0.145	0.065	0.029	0.365	2.25	1.07	0.429	0.000
Indeno(1,2,3,cd)pyrene	0.021	0.186	0.108	0.037	0.187	1.35	0.58	0.327	0.000
$\sum$PAHs	2.92	33.7	17.8	9.11	3.00	33.8	13.4	7.72	0.007

NS, not significant at $P < 0.05$.

Table 4. Principal component analysis of soil parameters under opencast and underground mining sites.

	Rotated compound matrix				
Principal components	PC-1	PC-2	PC-3	PC-4	PC-5
% Variance	27.00	11.98	9.410	7.936	5.270
% Cumulative variance	27.00	38.99	48.40	56.33	61.60
BD	0.032	0.098	0.03	***0.951***	0.028
POR	0.016	−0.126	−0.032	**0.943**	−0.014
WHC	0.044	−0.049	0.123	**0.855**	0.202
pH	0.067	0.031	0.076	0.233	−0.070
EC	−0.010	0.029	−0.230	0.365	−0.042
SOC	0.024	0.232	0.149	0.182	−0.048
LOI	−0.362	***0.790***	0.157	0.003	−0.040
DHA	0.219	−0.705	−0.206	0.239	−0.049
FDA	0.134	−0.319	−0.163	0.170	0.127
AMBC	0.104	0.013	0.200	0.043	**0.833**
BSR	−0.094	0.024	−0.082	0.076	0.138
PHOX	−0.152	0.067	0.120	−0.155	0.140
ACP	0.062	0.237	−0.198	0.023	−0.527
AKP	−0.199	0.089	−0.031	−0.096	0.030
AMBC/SOC	−0.075	−0.189	0.004	0.045	0.642
BSR/AMBC	−0.113	0.038	−0.161	−0.025	***−0.836***
As	−0.171	0.225	0.369	−0.288	0.030
Be	0.021	0.158	***0.870***	0.135	0.084
Cd	0.162	−0.297	−0.154	0.419	−0.088
Co	−0.054	0.169	***0.845***	−0.089	0.008

Table 4. Continued.

	Rotated compound matrix				
Principal components	PC-1	PC-2	PC-3	PC-4	PC-5
Cr	−0.217	0.187	***0.836***	−0.087	0.117
Cu	−0.117	0.260	0.701	0.456	0.122
Mn	−0.129	0.169	0.669	−0.119	0.086
Ni	−0.176	0.039	***0.848***	0.056	0.142
Pb	−0.055	0.156	***0.894***	−0.170	0.031
Zn	0.181	0.078	0.491	0.478	0.092
POX	−0.111	0.471	0.151	0.002	0.249
Naphthalene	0.683	−0.062	−0.131	0.193	0.003
Acenapththylene	0.782	0.094	−0.119	0.095	0.144
Acenaphthene	0.595	0.656	−0.022	−0.042	−0.052
Fluorene	0.622	−0.327	−0.216	0.048	0.193
Phenanthrene	0.812	−0.106	0.033	0.053	−0.156
Anthracene	0.851	−0.162	−0.017	−0.053	0.033
Fluoranthene	0.812	−0.199	−0.013	0.000	0.077
Pyrene	0.686	−0.461	−0.145	−0.025	−0.020
Benzaanthracene	0.570	−0.313	0.086	0.074	0.041
Chrysene	0.708	−0.336	−0.168	0.000	−0.179
Benzo(b)fluoranthene	0.553	−0.648	−0.166	−0.062	0.155
Benzo(k)fluoranthene	0.437	−0.617	−0.176	−0.088	0.160
Benzo(a)pyrene	0.526	−0.495	−0.132	0.047	0.186
Benzo(g,h,i) perylene	−0.148	**0.874**	0.186	−0.077	−0.147
Dibenzo(a,h)anthracene	−0.118	**0.855**	0.193	−0.039	0.081
Indeno(1,2,3,c,d)pyrene	−0.079	**0.787**	0.168	−0.230	−0.007
Total PAHs	***0.976***	−0.020	−0.078	−0.033	0.047

Boldface factor loadings are considered highly weighed; bold-italic factors correspond to the indicators included in the index.

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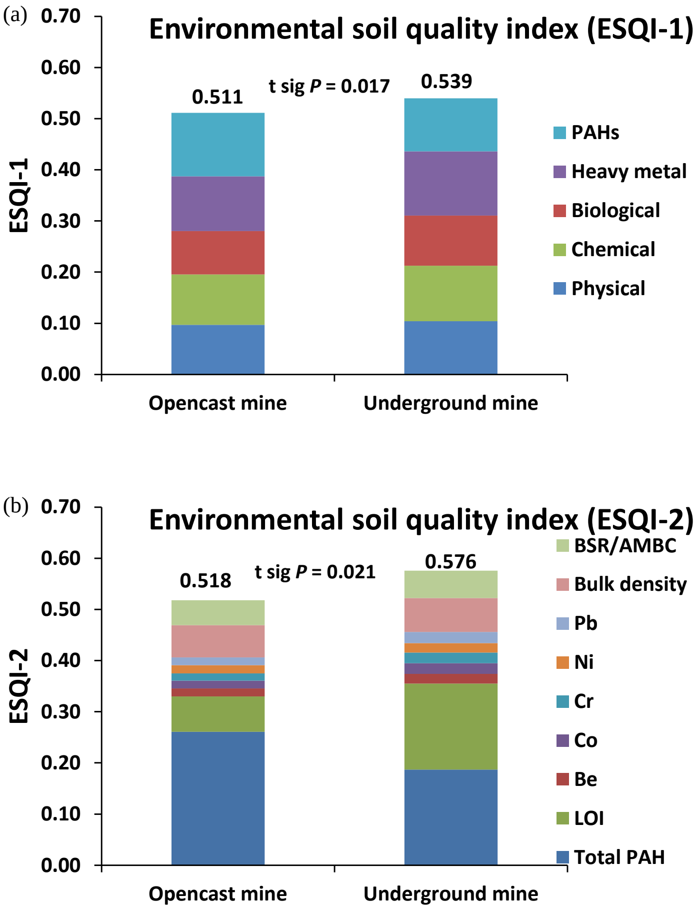

Figure 1. Environmental soil quality index of opencast and underground mine soils by **(a)** unscreened transformations, and **(b)** principal component analysis based index.