

# Coal mining activities change plant community structure due to air pollution and soil degradation

Bhanu Pandey · Madhoolika Agrawal ·  
Siddharth Singh

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**Abstract** The aim of this study was to investigate the effects of coal mining activities on the community structures of woody and herbaceous plants. The response of individual plants of community to defilement caused by coal mining was also assessed. Air monitoring, soil physico-chemical and phytosociological analyses were carried around Jharia coalfield (JCF) and Raniganj coalfield. The importance value index of sensitive species minified and those of tolerant species enhanced with increasing pollution load and altered soil quality around coal mining areas. Although the species richness of woody and herbaceous plants decreased with higher pollution load, a large number of species acclimatized to the stress caused by the coal mining activities. Woody plant community at JCF was more affected by coal mining than herbaceous community. Canonical correspondence analysis revealed that structure of herbaceous community was mainly driven by soil total organic carbon, soil nitrogen, whereas woody layer community was influenced by sulphur dioxide in ambient air, soil sulphate and soil phosphorus. The changes in species

diversity observed at mining areas indicated an increase in the proportion of resistant herbs and grasses showing a tendency towards a definite selection strategy of ecosystem in response to air pollution and altered soil characteristics.

**Keywords** Coal mining · Air pollution · Soil degradation · Community characteristics · Diversity index · Plant ecology

## Introduction

During the historically recent period of worldwide industrialization, the level of human population has been closely related to the amount of energy we have used (Krausmann et al. 2009). Currently energy is mostly produced by burning of fossil fuel such as coal (Veziroglu and Sahin 2008). In order to encounter the energy requisite, the overall coal production and coal mining have staggeringly increased in India, which ranks third amongst top ten coal producing countries (World Coal Association 2011). Mining operations have the potential to demolish flora and fauna and contaminate soil, air and water in the surrounding areas (Ejaz et al. 2014; Si et al. 2010). As a result, deterioration of ecosystem may take place with the loss of sensitive species.

The harmful effects of air pollutants on vegetation have been reported widely (Agrawal and Agarwal 2000; Emberson et al. 2001). Narayan et al. (1994) reported the effects of fluoride pollution on plant community structure at different downwind directions of an aluminium factory. Singh et al. (1994) also showed negative effects of coal fired thermal power plant emissions on herbaceous community structure. Soil nutrient and physico-chemical properties also affect plant communities (de Deyn et al. 2004; Dutta

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B. Pandey · M. Agrawal (✉)  
Laboratory of Air Pollution and Global Climate Change,  
Department of Botany, Banaras Hindu University,  
Varanasi 221005, India  
e-mail: madhoo.agrawal@gmail.com

B. Pandey  
e-mail: bhanubot@gmail.com

S. Singh  
Environmental Management Group, Central Institute of Mining  
& Fuel Research (CSIR), Barwa Road, Dhanbad 826015, India  
e-mail: ssgcmri@yahoo.com

and Agrawal 2003; Hernández and Pastor 2008). Coal mining and active mine fires, vehicular emissions and windblown dust through unpaved roads and overburdens are the main contributors of air pollutants around coal mining areas (Pandey et al. 2014). Sulphur dioxide (SO<sub>2</sub>), nitrogen dioxide (NO<sub>2</sub>) and total suspended particulates (TSP) are the important air pollutants around coal mining areas (Pandey et al. 2014). In coal mining areas, the top soil gets blended with overburden materials and loosely bound soil of overburden through wind may also affect the soil physico-chemical properties (Rai et al. 2010).

Plant community and their species carry out variety of biological services in an ecosystem viz., protecting areas from soil erosion (Trabucchi et al. 2013), defending from floods and other destructive weather conditions (Depietri et al. 2012), reducing the risk of local and global climate change (Mori et al. 2013), recycling nutrients (Jones et al. 2013), pollination and biological control of diseases (Kremen et al. 2007), controlling pollutants and of enormous economic values (Grimm et al. 2008). Plant community structure depends on various environmental factors such as climatic and edaphic factors (Narayan et al. 1994).

Plant species are distributed in variable habitats, but within the limits of the area, species are most abundant in places which represent their ecological optimum, and hence the composition of plant communities is a function of changing habitat conditions along the environmental gradients (Bello et al. 2012). Different air pollutants and altered soil physico-chemical properties affect individual plants and their population via various mechanisms of action, and thus influence the plant community structure, because the optimum value of environmental gradient is different for different species. Plant community structure of an area tends to become established by the selection pressures of the environment. The superimposition of severe pressures on plant community sometimes occurs to allow for feedback mechanisms to operate for selection of resistant species. There is now much concern that the stability of various plant communities has been seriously threatened by increasing concentrations of air pollutants and disturbed soil quality (Gupta et al. 2013; Ulrich et al. 2013).

We studied the air pollution status, soil quality, woody and ground layer plant diversity parameters around Jharia (Jharkhand, India) and Raniganj (West Bengal, India) coal mining areas. We hypothesized that plant community structure in the woody and ground layer is strongly differentiated between coal mining and non-mining areas owing to contrasting air and soil conditions. The site far away from coal mining area will support greater plant diversity because of low loading of air pollutants and better soil quality. We used species distribution curve and constrained ordination (Canonical correspondence analysis—CCA) (Ter Braak 1986) to provide a quantitative

assessment of the importance of the air and soil factors in controlling community composition and diversity. Our specific objectives were to determine the effects of coal mining on plant communities and to test the hypothesis that mixed stress (air+soil) affects differently the individuals of plant community.

## Materials and methods

### Study area

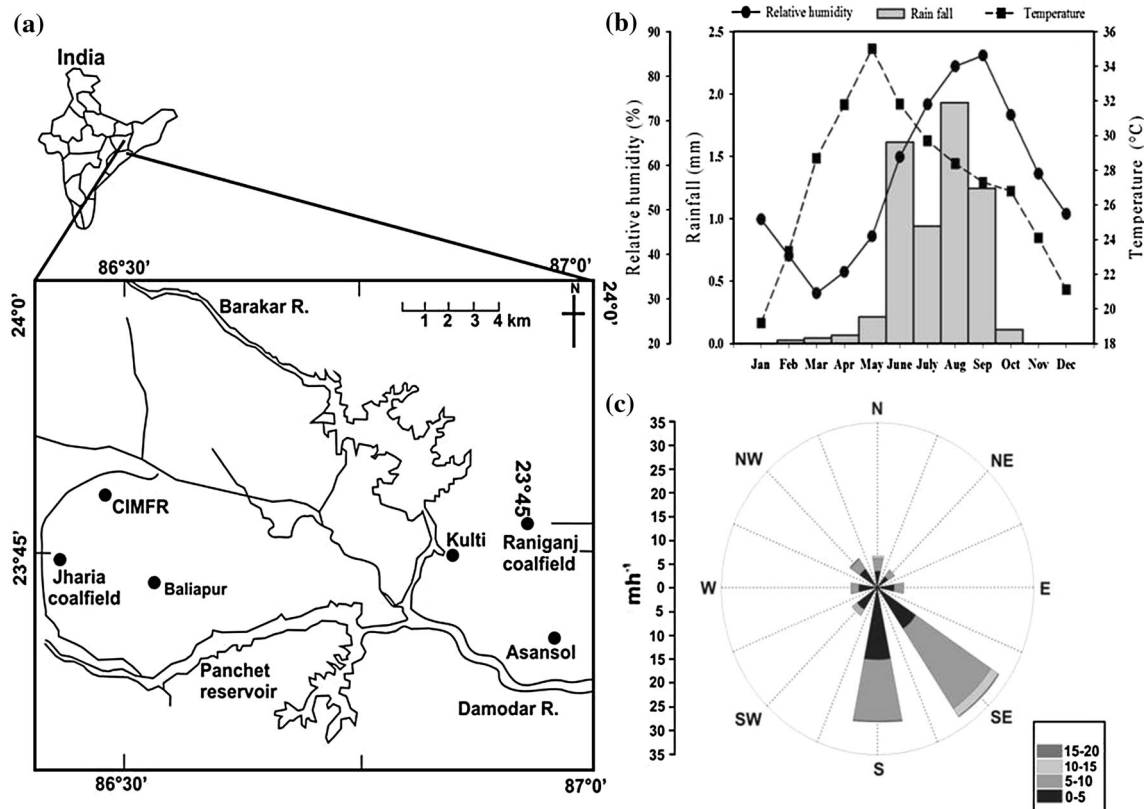
The present study was carried out in Jharia coalfield (JCF) (latitudes 23°39' to 23°48'N, longitudes 86°11' to 86°27'E, 222 m above mean sea level), located in Dhanbad district of Jharkhand state and Raniganj coalfield (RCF) (latitudes 23°25' to 23°55'N, longitudes 86°40' to 87°25'E, 117 m above mean sea level), located in Bardhaman district of West Bengal state of India (Fig. 1a) during 2010–2011. JCF and RCF are the most exploited coalfields because of available metallurgical grade coal reserves. A reference site, Central Institute of Mining and Fuel Research (CIMFR) (latitudes 23°47' to 23°49'N, longitudes 86°23' to 86°25'E, 172 m above mean sea level), was also selected for comparing the air quality and plant community structure, situated about 6 km in north direction from Jharia and 55 km west from RCF (Fig. 1a). The climate is sub-tropical in the study region. The cool winter season is from November to February and May is the hottest month. It remains warm until the monsoon outbreaks towards the middle of June, when the rain starts and the temperature falls and humidity rises. The rainy season continues from July to October. The dominant wind directions in the area are SE/SSE with low calm conditions (5.3 %). Generally the dominant wind speed ranges between 4 and 6 m h<sup>-1</sup> (Fig. 1b). The variations in meteorological parameters in the area are given in Fig. 1c.

### Air monitoring

The air quality was monitored for TSP matter (High volume method), SO<sub>2</sub> (improved West and Gaeke 1956) NO<sub>2</sub> (modified Jacobs and Hochheiser 1958) once in a fortnight at each site for 8 h from 09:00 to 17:00 h during 2010–2011. The methods in detail are given in Pandey et al. (2014).

### Soil analysis

Analyses of soil samples were carried out for pH, total porosity (TP), bulk density (BD), water holding capacity (WHC), total organic carbon (TOC), total nitrogen (N), available phosphorus (P) and sulphate (S) contents. At each site, five sub sites were selected and the soil samples were



**Fig. 1** Location of the study site (a), wind rose diagram of the area during study period (b), and monthly rainfall, relative humidity and temperature during the study period (c)

collected up to 15 cm depth with the help of an auger from three places of each sub site, every 3 months for two consecutive years from 2010 to 2011. Sites for soil sampling were the same where air monitoring was done. Three replicate samples of soil were collected from five sub sites of each selected site. The soil from three replicate sites of sub sites were mixed together to form a composite soil sample and three replicates were used for various analyses. Moisture content and soil pH were determined just after collection of samples, and rest of the soil was air dried and ground to pass through 2 mm sieve. For bulk density and water holding capacity, soil was collected up to 15 cm depth using the soil corer (6.5 cm diameter). Soil organic carbon was determined following modified method of Walkley and Black (1947). Total N in soil was determined using Gerhardt Automatic N Analyzer (Model KB8S, Frankfurt, Germany). Available P was extracted following Olsen et al. (1954) and estimated by the method of Dickman and Bray (1941). Available sulphur in soil was estimated following Williams and Steinbergs (1959).

#### Phytosociological analysis

Biodiversity analysis of the flora was conducted at three study sites (JCF, RCF and CIMFR) at the time of peak

canopy biomass during October 2011. The sites for biodiversity analyses were the same where air monitoring and soil analyses were done. At each site, 25 sub sites were stabilized and  $1 \times 1 \text{ m}^2$  size quadrats were used for herbaceous layer and  $20 \times 20 \text{ m}^2$  size quadrats were used for sampling woody layer community. Presence and absence of species, number of the individual of species and their basal area in each quadrat were recorded. Plant species were identified through Flora of Bihar, India (Singh et al. 2001). Relative frequency, relative density, relative dominance, important value index (IVI), species diversity,  $\beta$ -diversity, species richness, similarity coefficient, equitability and concentration of dominance were calculated. The basal area of the species was taken as an index of dominance for tree species.

#### Statistical analyses

Air monitoring data and soil physico-chemical parameters were processed for one-way univariate analysis of variance (ANOVA) for examining the effects of site on different parameters. Duncan's multiple range tests (DMRT) were performed as post hoc for various measurements after subjecting to one way ANOVA. To best explore the available data, we conducted the multivariate statistical analysis, CCA

using XLSTAT-Pro (Version 2013.1, Addinsoft, Inc., Brooklyn, NY, USA) software for Windows, which can relate the quantitative changes of plant community to environmental gradient directly. For CCA, the five subplots were considered as separate site (15 sites). Eleven environmental variables related with air (TSP, SO<sub>2</sub> and NO<sub>2</sub>) and soil quality (soil pH, TP, TOC, N, BD, P, WHC and S) were included. The statistical significance (at the 5 % level) of relationships between species data (species density) and environmental variables were assessed using the Monte Carlo test on 999 random permutations to test the null hypothesis that plant community were unrelated to environmental variables.

## Results

### Air monitoring

The average concentrations of air pollutants varied significantly between sites, and higher concentrations at JCF and

RCF were recorded compared to CIMFR for both the years of monitoring (Online Resource 1). The trend of mean concentrations of SO<sub>2</sub> and NO<sub>2</sub> was JCF > RCF > CIMFR, while TSP showed a trend of RCF > JCF > CIMFR.

### Soil physico-chemical analyses

Soil pH, TP, WHC, N and P were higher at CIMFR compared to coal mining sites (JCF and RCF) (Online Resource 2). Soil BD, TOC and S were lower at CIMFR than JCF and RCF (Online Resource 2). Significant variations were observed for all soil physico-chemical parameters between the sites except WHC (Online Resource 2).

### Community analyses

The total number of herbaceous species was 23, 19 and 19 at CIMFR, JCF and RCF, respectively. *Alternanthera paronychioides* showed highest relative frequency at JCF followed by RCF, whereas the relative density, relative

**Table 1** RF, RD, RDO and IVI of different herbaceous species present at different study sites

Plant species	Family	Site											
		CIMFR				Jharia				Raniganj			
		RF	RD	RDO	IVI	RF	RD	RDO	IVI	RF	RD	RDO	IVI
<i>Achyranthes aspera</i> L.	Amaranthaceae	2.6	1.7	4.0	8.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Ageratum conyzoides</i> L.	Asteraceae	5.6	6.4	3.6	15.6	4.8	4.9	2.3	12.0	5.4	4.5	2.6	12.5
<i>Alternanthera paronychioides</i> St. Hil.	Amaranthaceae	4.9	6.8	30.5	42.1	5.9	6.2	23.6	35.7	5.8	6.0	27.4	39.2
<i>Amaranthus spinosus</i> L.	Amaranthaceae	2.3	0.8	0.7	3.8	4.0	1.8	2.1	8.0	3.2	2.7	2.5	8.5
<i>Boerhaavia diffusa</i> L.	Nyctaginaceae	3.0	2.1	0.9	6.0	4.0	4.2	1.6	9.9	4.0	4.4	2.0	10.4
<i>Cassia alata</i> L.	Caesalpinaceae	4.6	0.9	10.8	16.3	5.1	1.8	17.6	24.5	6.1	2.9	29.2	38.3
<i>Chrysopogon aciculatus</i> (Retz.) Trin.	Poaceae	3.9	3.2	0.7	7.9	3.3	2.2	1.0	6.6	4.3	1.7	0.4	6.4
<i>Convolvulus alsinoides</i> L.	Convolvulaceae	2.6	1.3	0.1	4.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Cynodon dactylon</i> (L.) Pers.	Poaceae	8.2	26.9	6.7	41.9	7.7	25.0	5.2	38.0	8.3	20.2	5.1	33.7
<i>Cyperus rotundus</i> L.	Cyperaceae	5.9	6.6	1.9	14.3	8.1	12.7	3.0	23.7	6.9	14.1	4.0	24.9
<i>Desmodium trifolium</i> DC	Fabaceae	6.9	8.2	0.3	15.4	8.5	10.5	0.3	19.3	8.3	11.2	0.4	19.9
<i>Dichanthium annulatum</i> Forssk.	Poaceae	5.3	6.1	1.3	12.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Digitaria sanguinalis</i> (L.) Scop.	Poaceae	4.6	1.8	0.8	7.2	6.6	3.5	1.3	11.4	6.5	3.3	1.5	11.2
<i>Eclipta alba</i> (L.) Hassk.	Asteraceae	3.3	4.1	4.1	11.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Eragrostis cynosuroides</i> (Retz.) P. Beauv.	Poaceae	0.0	0.0	0.0	0.0	4.0	1.5	23.7	29.2	0.0	0.0	0.0	0.0
<i>Evolvulus alsinoides</i> L.	Convolvulaceae	8.2	6.7	1.1	16.1	7.4	4.7	0.7	12.7	9.0	5.3	0.9	15.2
<i>Heteropogon contortus</i> (L.) P. Beauv.	Poaceae	4.9	2.9	1.6	9.4	5.9	4.7	2.1	12.7	5.8	5.2	2.8	13.8
<i>Ocimum basilicum</i> L.	Lamiaceae	1.6	0.6	0.4	2.7	4.4	1.1	1.1	6.6	2.2	1.4	1.9	5.4
<i>Parthenium hysterophorus</i> (L.) Sp. PL.	Asteraceae	2.6	4.2	1.9	8.7	2.9	3.4	1.2	7.6	2.9	3.8	1.7	8.3
<i>Setaria glauca</i> (L.) P.Beauv.	Poaceae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.2	1.2	1.7	6.1
<i>Sida cordifolia</i> L.	Malvaceae	6.6	4.2	2.8	13.5	7.4	8.6	4.8	20.7	9.0	8.4	5.7	23.2
<i>Solanum nigrum</i> L.	Solanaceae	3.0	0.7	11.8	15.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Solanum xanthocarpum</i> Schrad. & Wendl.	Solanaceae	2.0	0.8	0.7	3.5	2.6	1.3	2.1	6.0	2.5	1.5	2.0	6.0
<i>Sphaeranthus indicus</i> L.	Asteraceae	2.0	0.6	1.8	4.3	2.6	1.1	2.9	6.7	2.5	1.5	4.7	8.7
<i>Tephrosia purpurea</i> (L.) Pers. Syn.	Fabaceae	5.3	2.5	11.5	19.3	4.8	0.9	3.3	8.9	4.0	0.8	3.6	8.4

dominance and IVI were highest at CIMFR. *Cynodon dactylon* showed highest RF, RDo and IVI at CIMFR. RF and RDo of *C. dactylon* at RCF were higher than at JCF, while RD and IVI were higher at JCF (Table 1).

The number of woody species was 22, 18 and 20 at CIMFR, JCF and RCF, respectively (Table 2). Tree density and canopy cover were higher at CIMFR compared to JCF and RCF. *Butea monosperma* was the most dominant species (IVI = 44.4 and 35.9) followed by *Ficus benghalensis* (IVI = 38.0, 35.2), *Ficus religiosa* (IVI = 35.4, 32.2) and *Psidium guajava* (IVI = 28.9, 29.3) at JCF and RCF. These four species contributed 49.8 and 37.2 % of the total tree density at JCF and RCF, respectively (Table 2). At CIMFR, *F. benghalensis* (IVI = 31.3), *F. religiosa* (IVI = 29.4), *Acacia catechu* (IVI = 20.1) and *Syzygium cuminii* (IVI = 19.2) were dominant species accounting for 28.3 % of the total tree density. RF, RD and RDo for *B. monosperma* were highest at JCF followed by RCF. *Alstonia scholaris*, *Buchanania lanzan*, *Delonix regia* and *Ficus tomentosa* were absent at most polluted sites (Table 2 and Fig. 2).

The Shannon–Wiener diversity index was highest at CIMFR followed by RCF and JCF both for the herbaceous

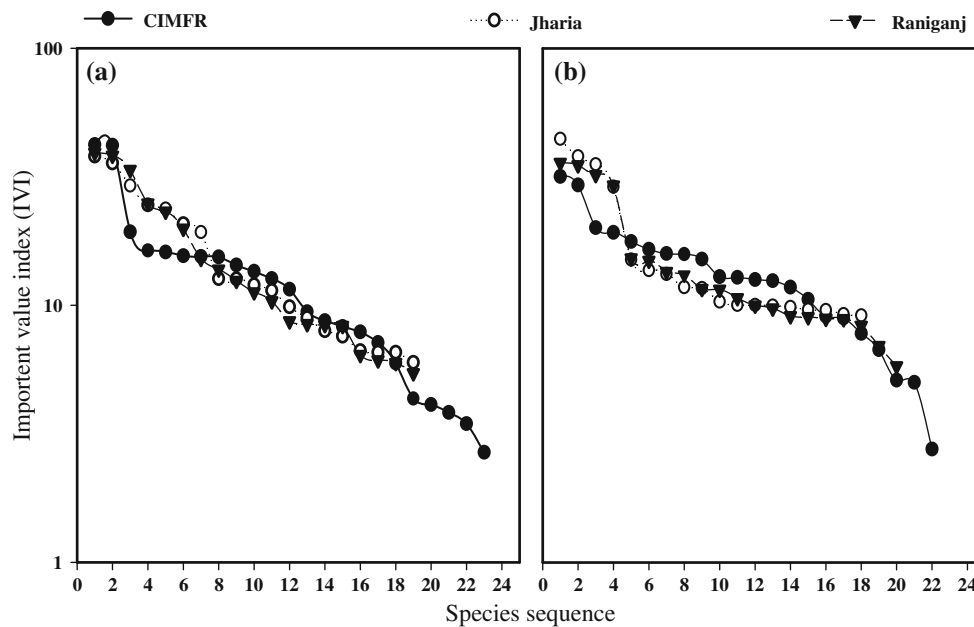
and woody vegetation (Table 3).  $\beta$ -diversity was 1.89, 1.75 and 1.72 for herbaceous vegetation, while 3.11, 2.64 and 2.87 for woody layer at CIMFR, JCF and RCF, respectively. The maximum concentration of dominance and minimum species richness were recorded at the most polluted site i.e. JCF (Table 3).

Species richness was 6.022, 5.061 and 5.004 for herbaceous vegetation and 8.97, 7.36 and 8.22 for woody layer at CIMFR, JCF and RCF, respectively. Evenness for herbaceous species was highest at RCF followed by JCF and CIMFR. Evenness for tree species was highest at CIMFR followed by JCF and RCF (Table 3). JCF and RCF have similarity coefficient of 0.947, while similarity coefficients for RCF with CIMFR and JCF with CIMFR were 0.857 for herbaceous species. For woody layer, the similarity coefficient for JCF–RCF, RCF–CIMFR and JCF–CIMFR were 0.947, 0.857 and 0.850, respectively (Online Resource 3).

Within the CCA eigenvector analysis, we observed that most of the inertia was carried by the first axis. With the second axis, we obtained 86.5 and 75 % of the total inertia for herbaceous and tree species, respectively. Therefore, the

**Table 2** RF, RD, RDO and important value IVI of different woody species present at different study sites

Plant Species	Family	Site											
		CIMFR				Jharia				Raniganj			
		RF	RD	RDO	IVI	RF	RD	RDO	IVI	RF	RD	RDO	IVI
<i>Acacia arabica</i> (Lam.)	Fabaceae	4.0	3.7	2.9	10.5	1.8	3.0	4.4	9.1	2.3	2.0	4.1	8.3
<i>Adina cordifolia</i> Hook. F.	Rubiaceae	4.5	5.9	1.3	11.8	2.4	3.9	3.3	9.6	2.9	2.4	3.6	8.9
<i>Artocarpus heterophyllus</i> Lam.	Moraceae	2.8	2.3	1.6	6.7	0.0	0.0	0.0	0.0	1.7	1.5	2.6	5.8
<i>Azadirachta indica</i> A. Juss.	Meliaceae	2.8	2.3	3.8	8.9	5.3	4.4	5.3	15.1	5.2	4.4	5.4	15.0
<i>Albizia lebeck</i> (L.)	Fabaceae	5.1	7.8	3.1	15.9	6.5	5.4	1.8	13.7	6.3	5.4	1.8	13.5
<i>Aegle marmelos</i> (L.) Correa.	Rutaceae	3.4	2.7	1.6	7.8	5.3	4.4	2.0	11.7	5.2	4.4	2.0	11.5
<i>Alstonia scholaris</i> (L.) R. Br.	Apocynaceae	4.5	4.1	4.3	12.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Acacia catechu</i> Willd.	Fabaceae	7.9	8.7	3.5	20.1	5.3	4.4	2.0	11.8	5.2	4.4	2.1	11.6
<i>Bombax ceiba</i> L.	Malvaceae	4.0	3.2	8.0	15.1	2.4	2.0	5.3	9.6	1.7	2.0	5.3	9.0
<i>Borassus flabellifer</i> L.	Arecaceae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1	2.9	4.8	8.9
<i>Buchanania lanzan</i> Spreng.	Anacardiaceae	5.6	5.9	4.9	16.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Butea monosperma</i> (Lam.) Taub.	Fabaceae	1.1	0.9	0.7	2.8	14.1	18.2	12.1	44.4	13.2	15.1	7.6	35.9
<i>Corymbia citriodora</i> (Hook.)	Myrtaceae	0.0	0.0	0.0	0.0	3.5	3.0	3.9	10.3	1.1	2.9	5.0	9.1
<i>Delonix regia</i> (Boj.) Raf.	Fabaceae	6.2	6.4	5.1	17.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Ficus benghalensis</i> L.	Moraceae	7.9	6.4	17.4	31.7	10.6	9.4	18.1	38.0	10.3	9.8	15.1	35.2
<i>Ficus racemosa</i> L.	Moraceae	4.0	3.2	5.3	12.5	2.4	2.0	5.7	10.0	2.3	2.0	5.8	10.0
<i>Ficus religiosa</i> L.	Moraceae	7.3	7.3	14.7	29.4	11.2	9.9	14.4	35.4	10.9	9.8	11.5	32.2
<i>Ficus tomentosa</i> L.	Moraceae	2.3	1.8	0.9	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Holoptelea integrifolia</i> (Roxb.)	Ulmaceae	4.5	5.9	2.4	12.8	4.1	3.4	2.3	9.9	4.0	3.4	2.3	9.7
<i>Madhuca indica</i> J. F. Gmel.	Sapotaceae	3.4	3.2	2.5	9.1	5.3	4.9	3.0	13.2	5.7	5.9	3.7	15.3
<i>Psidium guajava</i> L.	Myrtaceae	6.2	6.8	2.8	15.8	12.9	12.3	3.7	28.9	12.6	13.7	3.0	29.3
<i>Syzygium cuminii</i> (L.) Skeels.	Myrtaceae	6.2	5.9	7.1	19.2	2.4	2.0	5.6	10.0	2.3	2.0	6.4	10.7
<i>Saccopetalum tomentosum</i> (Roxb.)	Annonaceae	4.0	3.7	5.0	12.6	2.9	3.4	3.6	10.0	4.0	4.4	4.7	13.1
<i>Terminalia arjuna</i> L.	Combretaceae	2.3	1.8	1.0	5.1	1.8	3.9	3.5	9.2	1.7	2.0	3.3	7.0



**Fig. 2** Species distribution curve of herbaceous (a) and woody plants (b) at different study sites

**Table 3** Species richness, evenness,  $\beta$ -diversity, Shannon–Wiener index and concentration of dominance of the herbaceous and woody species at different study sites

Site	Species richness	Evenness	$\beta$ -diversity	Shannon–wiener index	Concentration of dominance
Herbaceous vegetation					
CIMFR	6.022	1.940	1.891	2.642	0.110
Jharia	5.061	1.967	1.746	2.516	0.114
Raniganj	5.004	2.024	1.715	2.588	0.099
Vascular vegetation					
CIMFR	8.970	2.213	3.107	2.971	0.055
Jharia	7.360	2.120	2.640	2.666	0.087
Raniganj	8.219	2.107	2.873	3.742	0.080

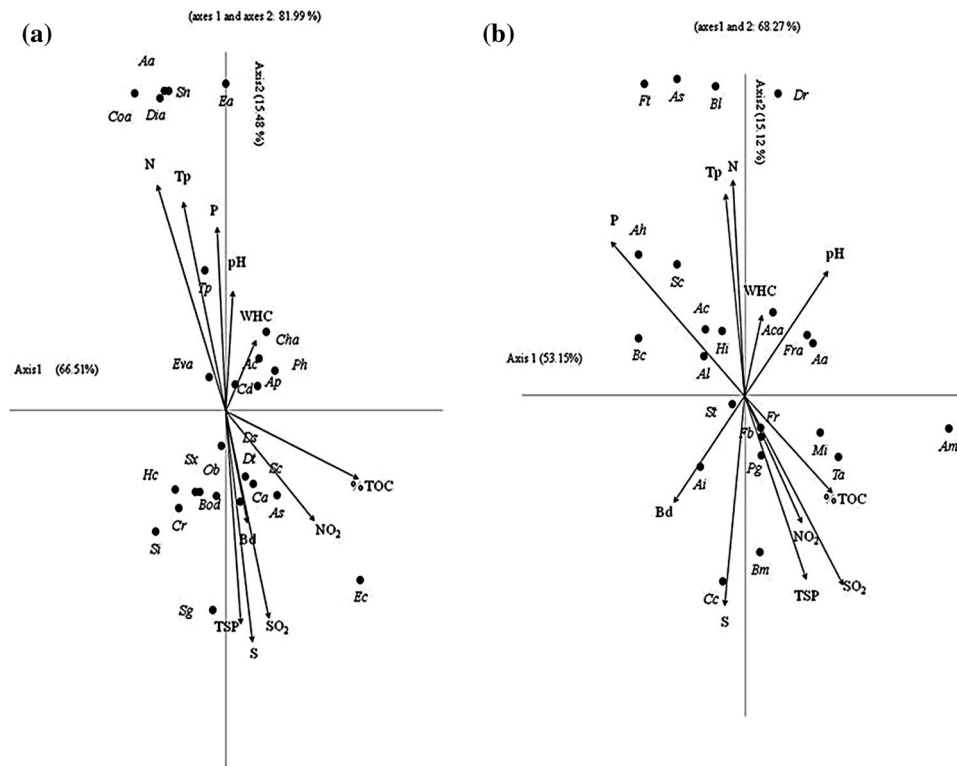
relationships between the species and the variables were analyzed by two-dimensional CCA map. The synthetic gradient extracted by CCA ordination diagram consists the points showing species and classes for qualitative environmental variables, and arrows for quantitative environmental variables (Fig. 3a, b). The total inertia (the summation of canonical and non-canonical eigenvalues) was 5.521 for ground vegetation and 4.593 for woody layer. The eigenvalues for two axes were 0.026 and 0.011 for herbaceous vegetation, and 0.027 and 0.026 for woody layer.

**Discussion**

**Air quality**

The concentration of SO<sub>2</sub> at JCF and RCF exceeded the prescribed limit of National Ambient Air Quality Standards (NAAQS) India (80  $\mu\text{g m}^{-3}$ ; CPCB(Central Pollution

Control Board 2009). High SO<sub>2</sub> at JCF and RCF sites may be ascribed to active mine fires in these mines (Wang and Xiao, 2004). Concentration of NO<sub>2</sub> was below NAAQS (80  $\mu\text{g m}^{-3}$ ; CPCB, 2009) guidelines at all the three sites. High concentrations of NO<sub>2</sub> at JCF and RCF may be mainly due to combustion processes, including vehicle exhaust, coal, oil and natural gas, with some emissions during blasting. TSP concentration exceeded the prescribed limit of NAAQS (500  $\mu\text{g m}^{-3}$ ; CPCB 1995) at JCF and RCF. As compared to the present study, lower concentrations of TSP (368  $\mu\text{g m}^{-3}$ ) and SO<sub>2</sub> (65  $\mu\text{g m}^{-3}$ ) and higher concentration of NO<sub>2</sub> (52  $\mu\text{g m}^{-3}$ ) were recorded by Ghose and Majee (2000) at JCF and higher TSP (598  $\mu\text{g m}^{-3}$ ), but lower SO<sub>2</sub> (48  $\mu\text{g m}^{-3}$ ) and NO<sub>x</sub> (37  $\mu\text{g m}^{-3}$ ) concentrations in coal mining area of Sambalpur, India by Chaulya (2004). The sources of fugitive dust at coal mining areas include overburden removal, blasting, mineral haulage, mechanical handling operations, minerals stockpiles and site restoration (Appleton et al. 2006).



**Fig. 3** Ordination of the herbaceous (a) and woody species (b) species by canonical correspondence analysis. *TOC*, total organic carbon; *WHC*, water holding capacity; *Bd*, Bulk density; *TP*, total porosity; *N*, total nitrogen; *P*, total phosphorus; *S*, Sulphate; *Aa*, *Achyranthes aspera*; *Ac*, *Ageratum conyzoides*; *Ap*, *Alternanthera paronychioides*; *As*, *Amaranthus spinosus*; *Bod*, *Boerhaavia diffusa*; *Ca*, *Cassia alata*; *Cha*, *Chrysopogon aciculatus*; *Coa*, *Convolvulus alsinoides*; *Cd*, *Cynodon dactylon*; *Cr*, *Cyperus rotundus*; *Dt*, *Desmodium trifolium*; *Dia*, *Dichanthium annulatum*; *Ds*, *Digitaria sanguinalis*; *Ea*, *Eclipta alba*; *Ec*, *Eragrostis cynosuroides*; *Eva*, *Evolvulus alsinoides*; *Hc*, *Heteropogon contortus*; *Ob*, *Ocimum basilicum*; *Ph*, *Parthenium*

*hysterophorus*; *Sg*, *Setaria glauca*; *Sc*, *Sida cordifolia*; *Sn*, *Solanum nigrum*; *Sx*, *Solanum xanthocarpum*; *Si*, *Sphaeranthus indicus*; *TP*, *Tephrosia purpurea*; *Aa*, *Acacia Arabica*; *Ac*, *Adina cordifolia*; *Ah*, *Artocarpus heterophyllus*; *Al*, *Azadirachta indica*; *Al*, *Albizia lebbek*; *Am*, *Aegle marmelos*; *As*, *Alstonia scholaris*; *Aca*, *Acacia catechu*; *Bc*, *Bombax ceiba*; *Bf*, *Borassus flabellifer*; *Bl*, *Buchanania lanzan*; *Bm*, *Butea monosperma*; *Cc*, *Corymbia citriodora*; *Dr*, *Delonix regia*; *Fb*, *Ficus benghalensis*; *Fra*, *Ficus racemosa*; *Fr*, *Ficus religiosa*; *Ft*, *Ficus tomentosa*; *Hi*, *Holoptelea integrifolia*; *Mi*, *Madhuca indica*; *Pg*, *Psidium guajava*; *Sc*, *Syzygium cumini*; *St*, *Saccopetalum tomentosum*; *Ta*, *Terminalia arjuna*

### Soil characteristics

The extensive coal mining in the area has reduced the soil pH at JCF and RCF. Coal mining typically exposes sulphur-containing pyrites that oxidize to sulphuric acid when exposed to oxygen, water and certain aerobic bacteria, leaving low soil pH (Gitt and Dollhopf 1991). Increase in soil sulphur (10–100 times) and low pH near coal mining area at Lisbon, Columbiana have also been reported (Liu and Lal 2013). Use of heavy vehicles during coal mining for transportation of coal and overburden material exerts high ground pressure. Therefore compaction takes place, and results in high bulk density, low porosity and low water holding capacity of the soil in coal mining areas (Bradshaw 1997; Maiti 2013). The low N content in soil of JCF and RCF as compared to CIMFR may be due to lack of adequate amount of mineralisable organic nitrogen, lower mineralization and nitrification rates, reduced vegetation

cover and lack of microbial activity (Maiti 2013). In acidic soil, phosphorous forms insoluble Fe and Al phosphate (dos Santos et al. 2013), so its available form reduced in soil near JCF and RCF. High TOC value is probably due to fossil carbon present in the soil of coal mining areas (Kriibek et al. 1998). Low inorganic N and low available P near the site of stripe mining have been reported at Ohio, USA (Boerner et al. 1998).

### Vegetation structure

In the present study, *A. paronychioides* and *C. dactylon* were the most dominant species of the herbaceous community at all the sites (Table 1). *A. paronychioides* is not a native of the area, but become very prevalent (Tanveer et al. 2013). High RF and RDo of *A. paronychioides* and *C. dactylon* suggested its growth under a wide range of environmental variables. It has also been suggested that

wide distribution of some species is a result of evolution rather than innate physiological tolerance and pollution level (Bradshaw 1993). Higher plasticity of invasive species than native is reported at low resource systems (Sun et al. 2010).

The polluted sites, JCF and RCF were species poor compared to reference site CIMFR (Table 1). *Achyranthes aspera*, *Convolvulus alsinoides*, *Dichanthium annulatum*, *Eclipta alba* and *Solanum nigrum* are most sensitive as these were present at CIMFR and completely absent from the coal mining areas (Table 1). *Eragrostis cynosuroides* and *Setaria glauca* are polluphilic species as these were only present at the polluted sites (JCF and RCF). *Ageratum conyzoides*, *Chrysopogon aciculatus*, *Evolvulus alsinoides*, *Parthenium hysterophorus* and *Tephrosia purpurea* also showed lower IVI at CIMFR compared to JCF and RCF, and therefore are also tolerant to coal mining activities (Table 1).

*Alstonia scholaris*, *B. lanzan* and *F. tomentosa* are described as native species in the area (Bauri 2013). Their lower IVI suggests their sensitivity to altered air and soil conditions, due to excessive coal mining activities in JCF and RCF. Species such as *F. beghalensis*, *F. religiosa*, *P. guajava*, *M. indica*, *A. indica*, *A. marmelos* and *C. citriodora* showing highest IVI at polluted sites are resistant (Table 2).

Although some species showed resistance or polyphallic behaviour, but the numbers of species participated in community structure as dominants or co-dominants were higher at CIMFR compared to JCF and RCF. This result suggests that a large number of species acclimatize to stress conditions originated due to coal mining activities. As variations in environmental factors tax the adaptive abilities of organisms, only those species which are adapted to new conditions or those which can become accustomed to the new conditions, participate in the community formation (Agrawal and Agarwal 2000). The species vulnerable to the air pollution and altered soil properties are removed and more tolerant species become widespread (Buma and Wessman 2013). Air pollutants and altered soil properties in the area due to coal mining activities modified the response of the vegetation either by acting synergistically or antagonistically.

### Species diversity

Shannon–Wiener diversity index suggests that the coal mining sites are suffered due to heavy pollution load and the most sensitive species have disappeared leaving only tolerant species represented by a large number of individuals. The stability of the community is related to the species diversity, the higher the value of the diversity index, the greater will be the stability of community structure and

function. Species diversity and concentration of dominance are inversely related. The plant community is heterogeneous at CIMFR because of low pollution load at this site, favouring the growth, survival and regeneration of natural vegetation and new arrivals. However, the vegetation closest to coal mining subsequently lost sensitive plant species, which created a niche that became available to opportunistic and more tolerant species, which became abundant at polluted sites. Evenness of community increased, whereas species richness declined at the sites having higher pollution load. Evidently species richness had greater influence on species diversity than evenness observed in this study. Coal mining activities had a negative influence on species composition as shown by the higher similarity coefficient value between JCF and RCF and lower similarity coefficient with CIMFR for both woody and herbaceous communities. Similarity coefficient of the study areas reflects that effects of the coal mining were more pronounced at JCF. The results also suggest that tree community at JCF was more affected by coal mining than herbaceous community.

The curve of IVI versus species sequence in decreasing order of IVI showed a log normal pattern at CIMFR (Fig. 2). It is known that undisturbed stable and equilibrium communities follow a lognormal pattern of distribution (Cepelova and Munzbergova 2012). The shape of the distribution curve slipped from a lognormal at JCF and RCF sites, having altered air and soil characteristics. The slipping of curves towards geometric series was less pronounced for herbaceous compared to woody layer. The species distribution curve clearly suggests that both herbaceous and woody plant communities at JCF and RCF are negatively affect by coal mining activities (Fig. 2).

### Canonical correspondance analysis

The relative importance of a single parameter is depicted in the CCA ordination diagramme by the length of their corresponding lines (Ter Braak 1987, Ter Braak and Verdonschot 1995). CCA analysis revealed that structure of herbaceous community was mainly driven by soil TOC and N, whereas woody layer was influenced by SO<sub>2</sub>, soil sulphate and P. For herbaceous and woody layer, the first axis showed strong positive correlation with N and TP and strong negative correlation with soil sulphate, TSP and SO<sub>2</sub> (Fig. 3a, b). The second axis showed only strong positive correlation with TOC.

*Amaranthus spinosus*, *Cassia alata*, *Digitaria sanguinalis*, *Setaria glauca*, *Desmodium trifolium* and *Sida cordifolia* were common where TOC, NO<sub>2</sub>, SO<sub>2</sub> and soil sulphate were high and soil N and P were low. These species seem to be resistant to coal mine emission and low nutrients. While *A. aspera*, *C. alsinoides*, *D. annulatum*,



*E. alsinoides* and *T. purpurea*, common at sites where soil N was high and TOC, NO<sub>2</sub>, SO<sub>2</sub> and soil sulphate were low, are sensitive to coal mine emissions. Abundance of *A. aspera*, *C. alsinoides* and *D. annulatum* was low at all study sites, as these species are found distant to both axes in CCA biplot (Fig. 3a). *B. diffusa*, *C. rotundus*, *D. trifolium*, *H. contortus*, *S. xanthocarpum* and *S. indicus* were found near the first axis and are also resistant to air emission and consequent altered soil qualities around coal mines (Fig. 3a).

For woody vegetation, the CCA showed that SO<sub>2</sub> and TSP in air, soil P, N and S were important environmental factors (Fig. 3b). *F. religiosa*, *F. benghalensis*, *P. guajava*, *B. monosperma*, *C. citriodora*, *M. indica* and *T. arjuna* seemed to be resistant species as their density at coal mining areas were high. *F. religiosa*, *F. benghalensis*, *P. guajava* and *B. monosperma* showed very close relations towards TSP, SO<sub>2</sub> and NO<sub>2</sub>. *A. scholaris*, *B. lanzan* and *F. tomentosa* seemed to be sensitive to coal mining emissions. The other sensitive species such as *A. heterophyllus*, *S. cumini* and *A. cordifolia* showed very close relation to soil P (Fig. 3b).

## Conclusion

Distinct changes in the community structure were recorded at coal mining areas. The changes in species diversity observed at mining areas indicated an increase in the proportion of resistant herbs and grasses showing a tendency towards a definite selection strategy of ecosystem in response to air pollution and altered soil characteristics. According to canonical correspondence analysis, sulphate, phosphate, total N and total organic carbon concentrations in soil and TSP, SO<sub>2</sub> and NO<sub>2</sub> in ambient air were major factors governing the community structure at the coal mining areas. Large scale and long term biodiversity assessment programme should be taken around coal mining areas to understand the community composition changes and development of resistance in herbaceous plants undergoing low level stresses in such areas. Natural reestablishment of herbaceous vegetation on coal mined dumps should be studied to understand the natural recolonization of degraded land. Assessment of herbaceous vegetation for its socio-economic input to the inhabitant of the area should also be conducted. Since trees are good in absorbing air pollutants and mitigating the climate of the area, efforts should be taken to conserve the tree species still existing in the area and more plantations of resistant species should be tried to reduce the cost of health burden on the community.

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