Phytoremediation: An Advance Approach for Stabilization of Coal Mine Wastelands

Debalina Kar and Debnath Palit

Contents

D. Kar
Department of Conservation Biology, Durgapur Government College,
Durgapur, West Bengal, India

D. Palit (✉)
Department of Botany, Durgapur Government College, Durgapur, West Bengal, India

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Abstract

Wastelands (WLs) are characterized by the habitats that have lost the power to exhibit resilience in a way to revert back the process of degradation while conserving the biota and the stability the habitat conditions. Revegetation is one of the widely used techniques for stabilization of dump, thereby maintaining ecological equilibrium in the area. Phytoremediation (PR) strategies involve the use of different plant species in combating the alterations in the environmental conditions induced due to natural and artificial causes. Considering the importance of all these perspectives in optimization of opencast coal mined areas, the present work was planned and executed in selected sites of Raniganj Coalfield areas in Burdwan district of West Bengal. On the basis of the observation on the plant species assemblages of the WL, it is apparent that the landscape is heterogeneous with differences in the quality of the patches represented through the species of plants. Heterogeneity was noticed due to different abundance of plant species in different wastelands. The growth pattern of the nine plants in pot culture over the period of 1 year reflects the potentials of the plants to be incorporated in the restoration strategy of the WL subjected to coal mining activity in the past. The growth of neem (*Azadirachta indica*) was not same as that of Indian laburnum (*Cassia fistula*) or shisham (*Dalbergia sissoo*), which however reflects the varying level of importance of these species in organizing the community. Although the differences in the species-specific growth pattern were demonstrated in the pot culture, the ability to tolerate wide variations in the soil conditions provides evidence in their use in PR of the WL. Among the plant species, the differences in the cadmium (Cd) and mercury (Hg) adsorption varied for Indian laburnum significantly reflected through the t-test. The selected plant species considered in the study will be able to reduce the metal load and modulate the soil conditions of the WL, thereby facilitating the process of restoration of the degraded ecosystems of the concerned geographical area.

Keywords

Coal mine · Ecorestoration · Phytoremediation · Revegetation · Raniganj · Wastelands

Abbreviations

ALIN	Average length of internode
Cd	Cadmium
DA	Discriminant function analysis
Hg	Mercury
MS	Mine spoil
NAB	Number of axillary bud
NB	Number of branches
NN	Number of node
PR	Phytoremediation
WL	Wasteland

1 Introduction

At the early stages of an ecosystem development, soils constitute a critical controlling component. Without the progress of natural processes of soil development, ecosystems would remain in an underdeveloped condition. Mine spoil (MS) heaps are composed of coarse rocks excavated during the deep coal mining operations and associated coal processing. Mining activity changes natural condition of landscape and biological communities (Down and Stocks 1977; Ahmad and Singh 2004; Sarma 2005; Kiro et al. 2017; Datta et al. 2017; Kumar et al. 2017; Raj et al. 2018). Natural plant communities get disturbed due to mining activities, and following the mining, the habitats become impoverished presenting a very rigorous condition for its growth (Jhariya et al. 2013, 2016).

Mining operations, which involve extraction of minerals from the earth's crust, are second after agriculture as the world's oldest and important activity. Mining tends to make a notable impact on the environment, and the impact varies in severity depending on whether the mine is working or abandoned, the mining methods used and the geological conditions (Bell et al. 2001; Mondal et al. 2014; Mahalik and Satapathy 2016). Due to unscientific mining process, reduction of forest cover; erosion of soil in a great scale; pollution of air, water and land; and reduction in biodiversity had occurred (UNESCO 1985). The problems of waste rock dumps become devastating to the landscape around mining areas (Ghose 1996; Dutta and Agrawal 2002; Banerjee et al. 2004; Singh and Singh 2006; Ekka and Behera 2011; Meena et al. 2016).

Increasing growth pattern of each plant species of wastelands (WLs) enacts as a positive mode of revegetation strategy. A total number of ten plant species, viz. *Acacia mangium* (mangium*)*, *Acacia cracicarpa (northern wattle)*, *Cassia siamea (kassod)*, *Dendrocalamus strictus (male bamboo)*, *Dalbergia sissoo (Shisham)*, *Gliricidia sepium (Mexican lilac)*, *Pterocarpus santalinus (red sandalwood)*, *Sesbania grandiflora (Agati)*, *Stylo hamate (Caribbean stylo)* and *Stylo scabra (shrubby stylo),* were selected for the evaluation of growth performance in pot and filled condition in Lalmatia coalfield, Jharkhand, India. It was noticed that the morphometric assessment in terms of shoot height and number of branches under the influence of treatment ($T_{1–9}$) indicates that the effect of different treatments on growth of the raised plant over the control (T_1) in poly bags under green house was appreciable. All the plants showed maximum increase in shoot height and number of branches in tripartite combination (Arshi 2017).

In the context of increasing mined land degradation, both the ecological and economic imperatives demand that restoration of land be prioritized, and for that it is required to maintain an equilibrium between development and environment through implementation of strategies of ecorestoration.

In view of this, the present study aims to formulate a strategy for ecorestoration of opencast coal mining sites through inoculation of appropriate amendments in the mine spoils to transform them into soil and revegetation by appropriate tree species selected through pot culture experimental trials using spoils with and without amendments. As a prerequisite to such a programme, a precise account of the vegetation that tend to develop in the mine-affected areas needs to be prepared as the index of the successional trend and natural autophytoremediation (PR) process in progress. Moreover, for ecorestoration there is a collateral need to assess physicochemical properties of the underlying substratum in temporal scale and optimize the same, if necessary, with suitable amendments.

2 Mine Wasteland: Definition, Types and Genesis

WL literally means that land or area of land on which not much can grow or which has been spoiled in some way so as to become unsuitable for cultivation. WLs are synonymous with drastically disturbed lands where the native vegetation and animal communities have been removed and the topsoil has been lost, altered and buried. Such lands will not become naturally rehabilitated within the life of time of man through normal succession process (Chandra 1992; Sagar et al. 2015). In practice, WL can be defined as "areas where current biomass production seldom exceeds 20 per cent of its overall potential".

From a resource point of view, a WL is that land which is presently lying either unused or cannot be used to its optimum potential due to some constraints. WL thus is an index of the country's use strategy of land resource.

2.1 Origin of Wastelands

Degradation of land takes place due to various reasons such as deforestation, unscientific cultivation, salinity, alkalinity, waterlogging, wind erosion, etc. The degradation of environment in dry land areas is basically attributable to the increasing biotic pressure for the fragile ecosystems in the absence of adequate investments and appropriate management practices to augment and conserve the land and water resources. Maximum WLs are created due to clearing of natural forests.

2.2 Types of Wastelands

National Wasteland Development Board in 1985 classifies WL into two categories:

1. Cultivable WL
2. Uncultivable WL

The cultivable WLs have been classified into:

(a) Gullied and/or ravenous lands
(b) Undulating land without shrub;
(c) Surface waterlogging land and marsh

(d) Salt-affected land
(e) Shifting cultivation area
(f) Degraded forestland
(g) Degraded pasture/grazing land
(h) Degraded forest plantations
(i) Strip lands
(j) Sand dunes
(k) Mining/industrial WL

Uncultivable WLs which cannot be used for vegetation are classified as (a) brown rocky/stony/shut of rocks, (b) steep sloppy areas and (c) snow-covered and/or glacier lands.

3 Special Emphasis on Coal Mine Wasteland

Mining activity imposes serious damage to the landscape and biological communities and its severity profoundly noticed in mining status, methods and condition of geological position (Bell et al. 2001; Singh et al. 2007; Sadhu et al. 2012; Mondal et al. 2014). Mine WL generally comprises the bare stripped area, loose soil piles, waste rock and overburden surfaces, subsided land areas and other degraded land by mining facilities, among which the waste rocks often pose extreme stressful conditions for restoration. Disruption of soil components such as soil horizons and structure, soil microbe populations and nutrient cycles inhibits the aesthetic value of the landscape which results in vegetation destruction and deteriorates soil profile (Kundu and Ghose 1997; Sheoran and Sheoran 2009; Mbaya and Hashidu 2013). Soil erosion, air and water pollution, toxicity, geo-environmental disasters, loss of biodiversity, loss of economic wealth, etc. are the major effects of mine wastes (Wong and Bradshaw 1982; Sheoran et al. 2008; Singh et al. 2014; Ashoka et al. 2017). The mineral extraction process must ensure return of productivity of the affected land. With rising environmentalism, synchronized post-mining reclamation of the degraded land has become an included part of the whole mining range (Ghose 1989, 2001, 2004; Haigh 1993).

4 Spoil Formation and Its Characteristics

Opencast mining is a developmental activity, which is bound to damage the natural ecosystem by several mining activities. During opencast mining, the overlying soil is removed, and the fragmented rock is heaped in the form of overburden dumps (Ghosh 2002). Dump materials are left over the land in the form of overburden dumps. These occupy a large amount of land, which loses its original use and generally gets soil qualities degraded (Barapanda et al. 2001). As the dump materials are generally loose, fine particles from it become highly prone to blowing by wind.

These get spread over the surrounding fertile land and disturb plant's natural quality and growth of fresh leaves. It has been found that overburden dump top materials are usually deficient in major nutrients. Hence, most of the overburden dumps do not support plantation. The physicochemical properties of overburden dump materials are site specific and differ from one dump to another dump due to different geological deposit of rocks (Lovesan et al. 1998; Rai et al. 2011; Kumar et al. 2017a).

5 Physicochemical Characteristics of Coal Mine Spoil

To characterize the physical and chemical properties of the MS, samples were analysed for different parameters. Out of eleven, six physical parameters such as pH, soil conductivity, bulk density, particle density, porosity and water holding capacity and five chemical parameters like organic carbon, available nitrogen, available phosphate-phosphorous, available potassium and available sodium were analysed. The climate condition that prevails in the study area provides three seasons in a year, i.e. pre-monsoon (March to June), monsoon (July to October) and post-monsoon (November to February). Spoil samples were collected seasonally (Table 1). The materials used and methods followed during the course of studies are described below.

Table 1 Analytical methods of spoil analysis followed in the present work

SN	Parameters	Methods followed
1.	Soil pH	Electronic pH metre in 1:10 soil water suspension as described by Jackson (1972)
2.	Soil conductivity (μs)	Electronic conductivity metre in 1:2 soil water suspension as described by Jackson (1972)
3.	Bulk density (g/cm^3)	Gupta (2004)
4.	Particle density (g/cm^3)	Black (1965)
5.	Porosity (%)	Black (1965)
6.	Water holding capacity (%)	Saxena (1998)
7.	Organic carbon (%)	Volumetric analysis method (Walkley 1947) as described by Muhr et al. (1965)
8.	Available nitrogen (kg ha^{-1})	Kjeldahl method as described by Subbiah and Asija (1956)
9.	Available phosphorus (kg ha^{-1})	Olsen's method as described by Olsen et al. (1954)
10.	Available potassium (kg ha^{-1})	Flame photometer method as described by Black (1965)
11.	Available sodium (kg ha^{-1})	Flame photometer method as described by Black (1965)

6 Indigenous Vegetation Structure

The problems of overburden dumps during mining become devastating to the landscape; as a result, natural plant communities get disturbed and the habitats become impoverished, presenting a very rigorous condition for plant growth.

The possible effects of the variability of the soil quality can translate into differential colonization and establishment of the plant species. The variability may facilitate the heterogeneity of the plant species assemblages in the concerned sites which may be reflected through the analysis of the vegetation of the sites.

The observations on the plant diversity and the soil features in the selected sites of the WL of Raniganj Coalfield, West Bengal, revealed the presence of at least 114 different angiosperms belonging to 40 families (Table 2). Considerable differences in the relative abundance of the plant species were observed that substantiates the differences in the colonization ability and the niche requirements of the species.

Table 2 The plant species observed in course of sampling the selected sites of the WL abandoned colliery of Raniganj, West Bengal, India

Sl. No.	Plant name	Abbreviation used in text	Relative abundance
Family: Acanthaceae			
1	*Andrographis echioides* Nees	ANEC	0.06 ± 0.03
2	*Andrographis paniculata* Nees	ANPA	0.24 ± 0.05
3	*Ruellia tuberosa* L.	RUTU	0.09 ± 0.04
Family: Agavaceae			
4	*Agave sisalana* Perrine	AGSI	0.10 ± 0.04
Family: Aizoaceae			
5	*Trianthema portulacastrum* L.	TRPO	0.04 ± 0.02
Family: Alangiaceae			
6	*Alangium lamarckii* Thwaites	ALLA	0.19 ± 0.04
Family: Amaranthaceae			
7	*Alternanthera pungens* Kunth	ALPU	0.05 ± 0.02
8	*Alternanthera sessilis* (L.) R.Br. ex DC.	ALSE	0.02 ± 0.02
9	*Alternanthera tenella* Colla	ALTE	0.22 ± 0.06
10	*Amaranthus spinosus* L.	AMSP	0.67 ± 0.13
11	*Amaranthus viridis* L.	AMVI	0.59 ± 0.09
12	*Gomphrena celosioides* Mart.	GOCE	0.21 ± 0.04
Family: Apocynaceae			
13	*Alstonia scholaris* (L.) R.Br.	ALSC	0.06 ± 0.04
14	*Thevetia neriifolia* Juss. ex Steud.	THNE	0.05 ± 0.02
Family: Arecaceae			
15	*Phoenix sylvestris* (L.) Roxb.	PHSY	0.18 ± 0.04
Family: Asclepiadaceae			
16	*Calotropis gigantea* (L.) W.T.Aiton	CAGI	2.13 ± 0.21
17	*Calotropis procera* W.T.Aiton	CAPR	0.38 ± 0.07

(continued)

Table 2 (continued)

Sl. No.	Plant name	Abbreviation used in text	Relative abundance
18	*Hemidesmus indicus* (L.) R.Br. ex Schult.	HEIN	0.11 ± 0.04
19	*Pergularia daemia* (Forssk.) Chiov.	PEDA	0.09 ± 0.03
Family: Asteraceae			
20	*Cnicus wallichii* Hook.f.	CNWA	0.57 ± 0.24
21	*Eclipta alba* (L.) Hassk.	ECAL	0.29 ± 0.06
22	*Mikania scandens* (L.) Willd.	MISC	0.10 ± 0.04
23	*Spilanthes paniculata* Wall.	SPPA	0.18 ± 0.05
24	*Tridax procumbens* L.	TRPR	0.51 ± 0.09
25	*Vernonia cinerea* (L.) Less.	VECI	0.64 ± 0.11
26	*Xanthium strumarium* L.	XAST	0.80 ± 0.12
27	*Eupatorium odoratum* L.	EUOD	0.82 ± 0.11
Family: Capparaceae			
28	*Cleome gynandra* L.	CLGY	0.16 ± 0.05
29	*Cleome viscosa* L.	CLVI	0.19 ± 0.05
Family: Combretaceae			
30	*Terminalia arjuna* (Roxb. ex DC.) Wight & Arn.	TEAR	0.02 ± 0.01
Family: Commelinaceae			
31	*Commelina benghalensis* Forssk.	COBE	0.06 ± 0.02
Family: Convolvulaceae			
32	*Ipomoea maxima* (L.f.) Sweet	IPMA	0.03 ± 0.02
33	*Ipomoea pes-tigridis* L.	IPPE	0.06 ± 0.02
34	*Ipomoea pinnata* Hochst. ex Choisy	IPPI	0.06 ± 0.03
Family: Cucurbitaceae			
35	*Coccinia cordifolia* Cogn.	COCO	0.33 ± 0.06
36	*Trichosanthes cucumerina* L.	TRCU	0.04 ± 0.02
Family: Cyperaceae			
37	*Cyperus rotundus* L.	CYRO	0.06 ± 0.02
38	*Kyllinga monocephala* Muhl.	KYMO	0.20 ± 0.06
Family: Euphorbiaceae			
39	*Acalypha indica* L.	ACIN	0.19 ± 0.05
40	*Croton bonplandianus* Baill.	CRBO	0.96 ± 0.16
41	*Emblica officinalis* Gaertn.	EMOF	0.05 ± 0.02
42	*Euphorbia antiquorum* L.	EUAN	0.03 ± 0.02
43	*Euphorbia hirta* L.	EUHI	0.17 ± 0.04
44	*Jatropha curcas* L.	JACU	0.06 ± 0.02
45	*Jatropha gossypiifolia* L.	JAGO	0.75 ± 0.10
46	*Phyllanthus amarus* Schumach. & Thonn.	PHAM	0.33 ± 0.07
Family: Fabaceae			
47	*Acacia arabica* (Lam.) Willd.	ACAR	0.33 ± 0.09
48	*Acacia auriculaeformis* Benth.	ACAU	1.56 ± 0.18
49	*Acacia nilotica* (L.) Delile	ACNI	0.05 ± 0.02
50	*Atylosia scarabaeoides* (L.) Benth.	ATSC	0.02 ± 0.02

(continued)

Table 2 (continued)

Sl. No.	Plant name	Abbreviation used in text	Relative abundance
51	*Butea monosperma* (Lam.) Taub.	BUMO	0.08 ± 0.03
52	*Cassia alata* L.	CAAL	0.63 ± 0.11
53	*Cassia fistula* L.	CAFI	0.08 ± 0.03
54	*Cassia obtusifolia* L.	CAOB	0.33 ± 0.07
55	*Cassia siamea* Lam.	CASI	0.06 ± 0.03
56	*Cassia sophera* L.	CASO	0.36 ± 0.11
57	*Cassia tora* L.	CATO	1.03 ± 0.14
58	*Crotalaria pallida* Aiton	CRPA	0.02 ± 0.01
59	*Dalbergia sissoo* Roxb.	DASI	1.07 ± 0.12
60	*Desmodium gangeticum* (L.) DC.	DEGA	0.02 ± 0.02
61	*Pongamia glabra* Vent.	POGL	0.44 ± 0.09
62	*Tephrosia purpurea* (L.) Pers.	TEPU	0.52 ± 0.10
63	*Tephrosia villosa* (L.) Pers.	TEVI	0.37 ± 0.08
64	*Teramnus labialis* (L.f.) Spreng.	TELA	0.02 ± 0.01
Family: Flacourtiaceae			
65	*Flacourtia indica* (Burm.f.) Merr.	FLIN	0.06 ± 0.03
Family: Lamiaceae			
66	*Clerodendrum viscosum* Vent.	CLVIS	0.58 ± 0.09
67	*Gmelina arborea* Roxb.	GMAR	0.02 ± 0.01
68	*Hyptis suaveolens* (L.) Poit.	HYSU	0.44 ± 0.12
69	*Leonurus sibiricus* L.	LESI	0.17 ± 0.05
70	*Leucas aspera* (Willd.) Link	LEAS	0.18 ± 0.05
71	*Ocimum canescens* A.J.Paton	OCCA	0.29 ± 0.06
72	*Vitex negundo* L.	VINE	0.25 ± 0.04
Family: Malvaceae			
73	*Abutilon indicum* (L.) Sweet	ABIN	0.08 ± 0.03
74	*Sida acuta* Burm.f.	SIAC	0.56 ± 0.09
75	*Sida cordata* (Burm.f.) Borss.Waalk.	SICO	0.33 ± 0.06
76	*Sida cordifolia* L.	SICOR	0.11 ± 0.05
77	*Urena lobata* L.	URLO	0.25 ± 0.06
Family: Meliaceae			
78	*Azadirachta indica* A.Juss.	AZIN	1.08 ± 0.12
Family: Menispermaceae			
79	*Stephania japonica* (Thunb.) Miers	STJA	0.02 ± 0.01
Family: Mimosaceae			
80	*Albizia lebbeck* (L.) Benth.	ALLE	0.33 ± 0.07
Family: Moraceae			
81	*Ficus benghalensis* L.	FIBE	0.20 ± 0.04
82	*Ficus cunea* Steud.	FICU	0.30 ± 0.05
83	*Ficus religiosa* L.	FIRE	0.11 ± 0.03
Family: Myrtaceae			
84	*Syzygium cumini* (L.) Skeels	SYCU	0.10 ± 0.04
Family: Nyctaginaceae			

(continued)

Table 2 (continued)

Sl. No.	Plant name	Abbreviation used in text	Relative abundance
85	*Mirabilis jalapa* L.	MIJA	0.02 ± 0.01
Family: Papaveraceae			
86	*Argemone mexicana* L.	ARME	0.39 ± 0.09
Family: Pedaliaceae			
87	*Pedalium murex* L.	PEMU	0.02 ± 0.02
Family: Poaceae			
88	*Aristida adscensionis* L.	ARAD	0.17 ± 0.05
89	*Chloris barbata* Sw.	CHBA	0.06 ± 0.03
90	*Cynodon dactylon* (L.) Pers.	CYDA	3.49 ± 0.33
91	*Eragrostis coarctata* Stapf	ERCO	0.55 ± 0.10
92	*Eulaliopsis binata* (Retz.) C.E.Hubb.	EUBI	0.24 ± 0.05
93	*Heteropogon contortus* Beauv. ex Roem. & Schult.	HECO	0.25 ± 0.06
94	*Oplismenus compositus* P.Beauv.	OPCO	0.17 ± 0.05
95	*Panicum maximum* Jacq.	PAMA	0.07 ± 0.03
96	*Poa annua* L.	POAN	0.01 ± 0.01
97	*Saccharum munja* Roxb.	SAMU	2.34 ± 0.17
98	*Saccharum spontaneum* L.	SASP	3.17 ± 0.23
Family: Polygonaceae			
99	*Polygonum barbatum* L.	POBA	0.03 ± 0.02
Family: Rhamnaceae			
100	*Ziziphus oenoplia* (L.) Mill.	ZIOE	0.06 ± 0.02
Family: Rubiaceae			
101	*Dentella repens* J.R.Forst. & G.Forst.	DERE	0.07 ± 0.03
102	*Spermacoce hispida* L.	SPHI	0.03 ± 0.02
Family: Scrophulariaceae			
103	*Scoparia dulcis* L.	SCDU	0.27 ± 0.06
Family: Simaroubaceae			
104	*Ailanthus excelsa* Roxb.	AIEX	0.19 ± 0.05
Family: Solanaceae			
105	*Datura metel* L.	DAME	0.40 ± 0.07
106	*Physalis minima* L.	PHMI	0.04 ± 0.02
107	*Solanum nigrum* L.	SONI	0.10 ± 0.03
108	*Solanum sisymbriifolium* Lam.	SOSI	2.23 ± 0.24
109	*Solanum surattense* Burm.f.	SOSU	0.24 ± 0.05
Family: Tiliaceae			
110	*Triumfetta rhomboidea* Jacq.	TRRH	0.20 ± 0.06
Family: Ulmaceae			
111	*Holoptelea integrifolia* (Roxb.) Planch.	HOIN	0.12 ± 0.03
Family: Verbenaceae			
112	*Lantana camara* L.	LACA	0.33 ± 0.07
Family: Vitaceae			
113	*Cayratia trifolia* (L.) Domin	CATR	0.04 ± 0.02
Family: Zygophyllaceae			
114	*Tribulus terrestris* L.	TRTE	0.04 ± 0.03

7 Wasteland Reclamation Through Phytoremediation Technology

The fulfilment of the demands for coal may increase the destabilized conditions of the ecosystems in the land mining areas, which is contrary to the objectives of the sustainable development. Thus to continue with the coal extraction and reduce the damage to the terrestrial ecosystem, simultaneous monitoring and remediation strategies need to be adopted to keep the pace of the economic development without affecting the ecosystem balance of the concerned landscape. An increased concern for environment evoked concurrent land restoration strategy to keep the balance of resource exploitation and ecological balance (Jhariya et al. 2018a, b). PR strategies, including the augmentative plantation of desired species in the degraded ecosystems subjected to the coal extraction in the past, are promoted as a feasible alternative to restore the ecological balance and reclamation of the landscape. Thus assessment of the vegetation and soil quality followed by the selection of the plants for the ability to restore the ecosystem processes are essential to predict about the impact of coal mining and the prospective restoration of the degraded ecosystems (Jha and Singh 1991; Bradshaw 1997; Wong 2003; Kumar et al. 2017; Meena et al. 2014; Banerjee et al. 2018). In apprehension of PR as a prospective tool to restore the ecological stability of the concerned landscape, an attempt is made through the evaluation of vegetation and soil quality along with the growth assessment of selected plants using Raniganj, West Bengal, India, as a model geographical area.

8 Pot Experiment

8.1 Selection of Suitable Plant Species for Reclamation

Long-term monitoring field experiments were set up at Durgapur Government College campus garden in 2013–2014. In pot culture experiments, suitable tree species for revegetation of MS were screened. The feasibility of directly implanting the tree species on a pot as a means of revegetation of MS was evaluated. For selection of suitability of plant species for revegetation of MS, species characteristics such as adaptability of plant species to the particular physical and chemical conditions of MS and longevity of established plants were considered (Rodrigues 1996). Choice of multipurpose trees can be of economic and social significance (Montagnini et al. 1995; Sanchez et al. 1985; Nair 1989; Young 1989). The availability, growth, adaptability and longevity are important parameters in selecting suitable tree species for revegetation purpose. In the present context, the plants were selected in compliance with their indigenous nature and adaptation to the local ecological and climatic conditions, supported through the ecological survey of the concerned WL. The trial using multiple species will increase the chance of selecting the appropriate with higher probability than trials using single or few species.

Consistent to this proposition, the features that qualified the plant species for the present experimental study are:

(a) Adapted to grow, spread and reproduce under severe conditions
(b) Leguminous species to fix atmospheric nitrogen and ameliorate the soil by addition of organic matter through plant litter
(c) Fruit yielding trees to attract birds, butterflies and other forms of wildlife and also encourage soil fauna
(d) Plantation species with good economic, social and aesthetic value for local population
(e) Fast-growing indigenous and exotic species to accelerate plant succession
(f) Help in the control of erosion and stabilization of mine dump
(g) Fire hardy, unbrowsable and stress tolerant (Singh et al. 2004)

Thus the multifunctional role of the plants with the ability to tolerate the odd soil and ecological conditions of the WL formed the basis for selection in the present study. The nine plants considered for the present study are Indian laburnum, Aonla (*Emblica officinalis*), shisham, neem, karanj (*Pongamia glabra*), siris (*Albizia lebbeck*), Indian elm (*Holoptelea integrifolia*), earleaf acacia (*Acacia auriculiformis*) and mahogany (*Swietenia macrophylla*), all being collected and planted as saplings in the earthen pots.

8.2 Sapling Collection

Saplings of nine selected tree species were collected from Durgapur Forest Nursery (maintained by the Divisional Forest Officer, Durgapur Division), Muchipara, with due permission to procure the saplings for the study. Thirty healthy saplings of each species were collected from the nursery and transported to Durgapur Government College campus experimental garden. Upon reaching the experimental station, individual plant species were planted in each pot for acclimatization and subsequent initiation of the experiment. Five replicates of each selected tree sapling were set up under six treatments. Overall 270 saplings were planted for screening out to determine the growth pattern and prospective use in PR technology for restoration of the degraded WL.

8.3 Experimental Design

Following collection of the plant species and appropriate maintenance in the local conditions, selected numbers of the saplings were planted in earthen pots consisting of varied kinds of soil conditions. The experimental design followed the pattern of randomized block design where the nine plants in appropriate replicates were allowed to grow in the earthen pots consisting of soils mimicking the WL conditions. In this design, the soil types formed treatment variable with the six levels represented as (a) MS, (b) garden soil (for control), (c) MS + compost, (d) MS + husk, (e) MS + fly ash and (f) MS + chemical fertilizer.

Plant growth parameters like shoot length, number of node (NN), average length of internodes (ALIN), number of axillary bud (NAB) and number of branches (NB) were selected as response variables representing the increment in the size and the biomass of the plants. Changes in the height and branching pattern are regarded as indicators of the growth of the plants. For each plant species and soil conditions, five replicates were considered. During the initial phase consisting of a period of 4 weeks, if a particular sapling failed to exhibit growth represented through erected stem and no wilting, and yellow colouration of leaves, the particular plant was considered as a representative sample for the study. In case the sapling failed to exhibit the indication of the growth, it was rejected and not considered for further study. Thus, in the initial stage, the number of replicates considered remained quite high, which was reduced as a maintenance error or otherwise due to the logistic reasons. Throughout the study, at least five replicates of a particular plant species under particular soil condition were available for monitoring growth.

In pot culture techniques, each pot was filled with MS, garden soil and MS with different treatment manures, fertilizers, fly ash and husk separately, and 3-month-old saplings were transplanted in the pot. Healthy saplings of nine tree species were planted up with the onset of monsoon in 6 cm depth in pot at model garden of Durgapur Government College Campus. Each pot was measured with the height 25 cm and diameter 40 cm. Experiments were set up in completely randomized block design with five replications (Kulkarni et al. 2007). Growth characteristics were measured up to 12 months. Each specific technique of pot culture experiment was documented in plates.

8.4 Materials Used in Pot Experiments

The treatment material selection is the important phase to set revegetation technology and PR technique. Materials were selected on the basis of several characters: (i) NPK content, (ii) organic carbon content, (iii) availability of the material, (iv) effectiveness in field use and (v) previous use experience (based upon review and literature). Based upon the availability and cost and suitability in the field condition, four treatment components such as compost, husk, fly ash and chemical fertilizer were selected for establishing PR technique. Following treatments were given, such as (a) MS, (b) garden soil (for control), (c) MS + compost, (d) MS + husk, (e) MS + fly ash and (f) MS + chemical fertilizer.

8.5 Maintenance During Experiment

The experimental garden was maintained through regular watering and removal of weed from the pots. Special attention was taken to those plants which were affected by wandering herbivore insects and interference of human, animals, rainfall and high temperature. The conditions were maintained such that the growths of the plants are measured without any effects of extraneous variables.

9 Growth Performance After Reclamation

Plant growth comprises three distinct phenomena, i.e. increase of cell, longitudinal growth of the cell (maturation stage) and horizontal growth of the cell. To access the growth through morphological expression, some vegetative growth parameters were introduced for measurement of plant growth. The observations for the morphological growth attributes were taken at every month of study period from the treatment field. Data for shoot length, NN, number of internodes, NAB and NB were collected for monthly basis.

(i) *Length of shoot* – The plants from each pot were measured, and height of those plants was scaled from ground level to the tip of the stem (axillary bud).
(ii) NN – Node indicates leaf, branch, and axillary bud originated structure, i.e. how many leaves, branches or axillary bud bearing angles present in the shoot.
(iii) ALIN – Internode was calculated by the following formula: shoot length/no. of nodes.
(iv) NAB – Leaves and branches are originated from axillary buds. Such axillary buds were measured for each plant species. Axillary buds are directly proportional to the plant growth.
(v) NB – Branches of each plant species were counted during the survey period.

All the plants selected for the study exhibited growth reflected through the changes in the morphological features, monitored over the entire observation period of 1 year. The data revealed significant variations among the plant species in terms of the morphological features, reflected through the discriminant function analysis (DA) (Fig. 1). As portrayed in the biplot (Fig. 1e), the ordination of the plants remained significantly different except for neem and Indian laburnum pair. The significant variations among the plants were observed from the Fisher's distance (Fig. 1d). The relative contribution of the explanatory variables (morphological features) (Fig. 1f) to the extracted factors remained contrastingly different, observed through the standardized discriminant function coefficient. Wilks' λ value of 0.279 justified the discrimination of the plant species with approximately about 75% variations of the data being explained by the extracted factors F1 and F2 (Fig. 1c). The multivariate analysis was extended using the soil treatment conditions as explanatory variables for the observed differences in the plant morphological features irrespective of the species. As shown in Fig. 2, the DA enabled segregation of the soil conditions (treatments) significantly, suggesting that the changes in the morphological features of the plants were differentially affected by the soil conditions (Fig. 2f). The Fisher's distance between the treatments remained significantly different (Fig. 2c) among the treatment pairs excepting for the soil (S) and spoil and husk (SP+H) treatments. The contributions of the morphological variables (explanatory variables) to the observed variations in the soil conditions remained significant in terms of the standardized discriminant function coefficient (Fig. 2d). The morphological variables could be segregated in different coordinates as shown in the biplot Fig. 2e. The results indicate that the soil treatment conditions affected the

(a)

Wilks' Lambda	**0.279**
F (Observed value)	119.524
F (Critical value)	1.395
DF1	40
DF2	14069
p-value	< 0.0001
Alpha	0.05

(b)

	F1	F2	F3	F4	F5
Eigenvalue	0.744	0.419	0.237	0.117	0.046
Discrimination (%)	47.588	26.795	15.161	7.495	2.961
Cumulative %	47.588	74.383	89.544	97.039	100.000
Canonical correlations	0.653	0.543	0.438	0.324	0.210

(c)

	CAF	EMO	DAS	AZI	POG	ALL	HOI	ACA
EMO	120.819							
DAS	287.905	215.305						
AZI	*9.159*	91.330	198.419					
POG	155.733	156.778	173.026	127.334				
ALL	45.121	101.555	177.367	29.870	47.639			
HOI	54.918	32.774	155.467	32.602	88.203	45.803		
ACA	290.182	104.410	194.969	219.118	218.385	196.582	160.141	
SWM	22.501	76.159	241.635	19.732	138.027	63.692	21.140	228.104

(d)

	F1	F2	F3	F4	F5
SL	0.355	**1.460**	0.659	-0.132	-0.734
NN	0.314	-0.882	-0.240	**1.058**	0.846
ALIN	-0.156	-0.285	-0.015	-0.237	**1.187**
NAB	0.281	-0.460	0.620	**-0.764**	-0.264
NB	0.396	-0.142	**-0.998**	-0.382	-0.004

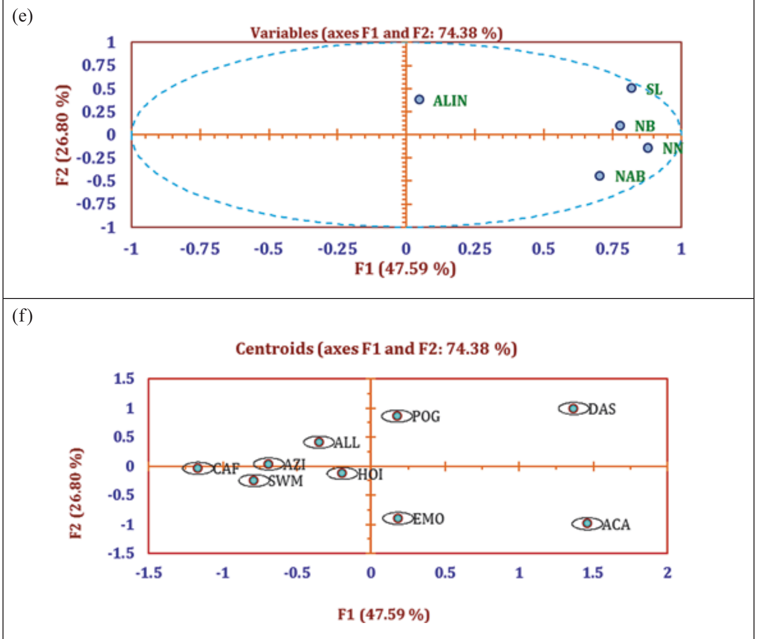

Fig. 1 The results of the DA for the observed variations in the response variables (plant species) against the explanatory variables (plant morphological features). (**a**) Wilks' lambda value, (**b**) eigenvalues and canonical correlations, (**c**) Fisher's distance (all except the value in *italic* is significant), (**d**) standardized canonical discriminant functions, (**e**) biplot with the ordination of the explanatory variables and (**f**) biplot with the ordination of the response variables

(a)

Wilks' Lambda	**0.911**
F (Observed value)	12.269
F (Critical value)	1.507
DF1	25
DF2	12000
P-value	< 0.0001
Alpha	0.05

(b)

	F1	F2	F3	F4
Eigenvalue	0.072	0.015	0.008	0.001
Discrimination (%)	74.931	15.670	8.131	1.268
Cumulative %	74.931	90.601	98.732	100.000
Canonical correlations	0.260	0.122	0.088	0.035

(c)

	S	SP	SP+C	SP+CF	SP+FA
SP	4.879				
SP+C	21.338	35.024			
SP+CF	3.986	14.604	12.330		
SP+FA	*3.125*	6.019	33.017	10.625	
SP+H	*1.989*	7.959	23.919	*2.428*	5.561

(d)

	F1	F2	F3	F4	F5
SL	0.504	0.101	0.344	0.524	0.585
NN	0.314	-0.442	0.671	0.424	0.275
ALIN	0.288	0.626	0.267	-0.414	0.531
NAB	0.334	0.123	0.734	0.407	-0.410
NB	0.970	-0.201	0.039	0.118	0.056

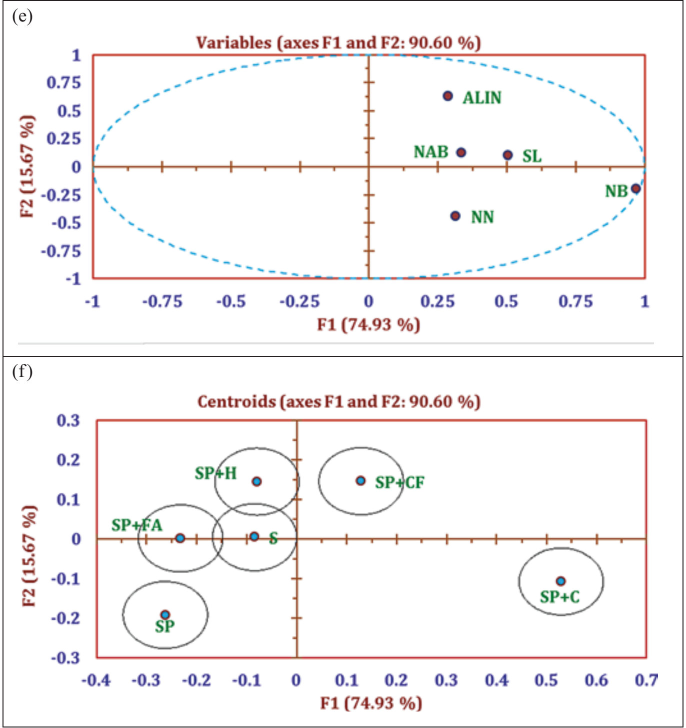

Fig. 2 The results of the DA for the observed variations in the response variables (plant morphological features) against the explanatory variables (soil treatment conditions). (**a**) Wilks' lambda value, (**b**) eigenvalues and canonical correlations, (**c**) Fisher's distance (all except the value in italic is significant), (**d**) standardized canonical discriminant functions, (**e**) biplot with the ordination of the explanatory variables and (**f**) biplot with the ordination of the response variables

morphological features of the plants irrespective of the taxonomic identity, and thus the growth of the plants was dependent on the treatments.

Nonetheless, the plants observed in the present study were capable of exhibiting growth in different soil conditions, mimicking the continuum of the soil quality observed in WL subjected to opencast coal mining in the past. Earlier studies on these plants have shown prospect of the use in revegetation of the altered soil conditions in abandoned coal fields of Jharia in India (Sheoran et al. 2010).

Globally, land mass subjected to coal mining activities in the past has been reclaimed through revegetation, though the selection of the native species has been given priority. The process reinstates the seral stages in the continuum of community development, and therefore the use of the grasses and herbs is less likely being useful. Instance from Poland (Woch et al. 2013; Piekarska-Stachowiak et al. 2014; Verma et al. 2015), England (Rostanski 2005) and China (Cheng and Lu 2005; Donggan et al. 2011; Huang et al. 2015; Zhang et al. 2015) suggests that the reclamation of the WL formed due to past mining activity can be augmented through the plantation of selected and desired plant species. Selection of the plant species is crucial in order to enhance the structuring of the community. The tolerance to the existing soil conditions remains an important criterion for selection of the plant species suitable for the restoration of the degraded landscape. In the present instance, the selected plant species, Indian laburnum, Aonla, shisham, neem, karanj, siris, Indian elm, earleaf acacia and mahogany, qualified as tolerant species, owing to their growth under the different treatment conditions. The growth of these plants reflects their tolerance to the soil conditions and supports their use in the restoration process of the degraded WLs that were subjected to active coal mining activities in the past. As reflected in the results of the present study, the use of these plant species in the PR of the WL through active plantation may restore the WL created through coal mining activities in the past.

10 Heavy Metal Accumulation Effect

The heavy metal accumulation capability of the nine plant species was assessed using cadmium (Cd) and mercury (Hg) as model metals. In toxicological parlance as well as for the physiology of biota, Cd and Hg are considered as toxic, interfering with the physiological, biochemical and genetic process of biota. Mining activities add Cd and Hg in the soil, thereby enhancing their entry in the food chain of the concerned ecosystem. Reducing the heavy metals from the soil will reduce their recurrence in higher magnitude in the different trophic levels. Bioaccumulation by plants of terrestrial ecosystems delinks the flow of the metals through the trophic levels. Thus, PR strategy using the leguminous plants can be a way of reducing the availability of the heavy metals in the ambient environment. In order to estimate the amount of the metal load present in the plant tissue and the soil, selected number of plants was uprooted from each of the treatments. In all instances, the preparations were made to evaluate the heavy metal content in the plant tissue using at least three replicates from six different treatments. The data were recorded against Cd and Hg separately.

The amount of heavy metal adsorbed in the plant tissues remained considerably different with respect to the soil treatment conditions (Fig. 3), as well as on the basis of the plant species considered (Fig. 4). A comparison of the Cd and Hg adsorbed by the plants reflected differences with the soil treatment conditions and among the plants as well. Among the plant species, the differences in the Cd and Hg adsorption varied for the species Indian laburnum significantly reflected through the t-test (Fig. 5). Irrespective of the soil treatment conditions, the bioconcentration factor of the two heavy metals remained comparable with the ambient soil conditions (Fig. 6).

Although the concentration of the metals in the plants was considerably high, the significant deviation from unity (reflecting lower concentration that is present in the soil) indicates a relatively less satisfactory adsorption, particularly for Cd. Perhaps the differences in the adsorption of the two heavy metals are connected to the

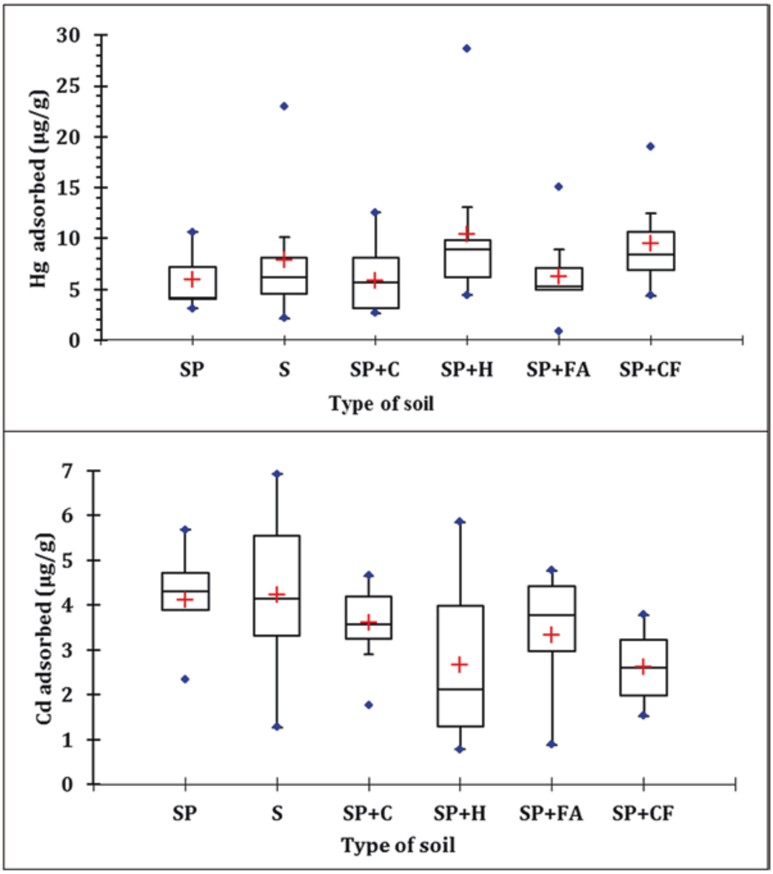

Fig. 3 Box-plot representation of the two metals (Hg and Cd) adsorbed by the plants under different soil conditions used as treatments. The variations in the soil type were used as explanatory variable for the observed differences in the metal adsorption by the plants (n = 9 replicates per soil treatment per metal)

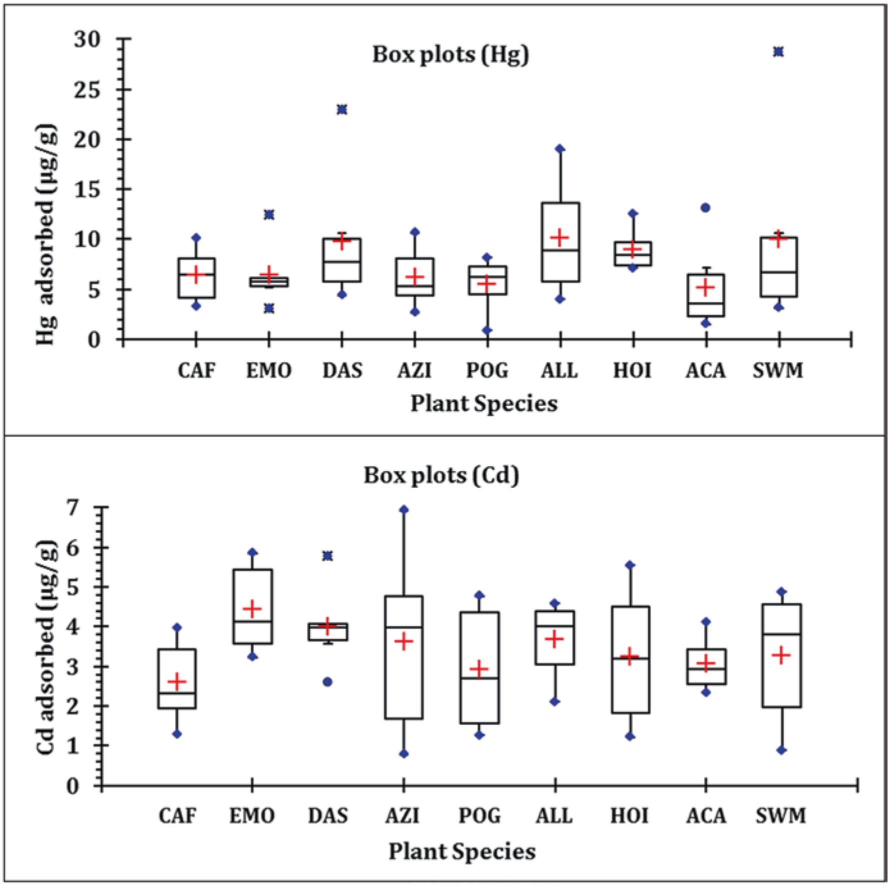

Fig. 4 Box-plot representation of the amount of the two metals (Hg and Cd) adsorbed by the nine different plant species considered in the present study (n = 6 observations per plant species per metal)

chelating system of the plants and associated physiology that are crucial in trapping the metals through the translocation process and further conversion to the plant metabolites. Alternatively, the time elapsed between the growth of the plants and corresponding metal accumulation were not synchronized for which the adsorption process may have been affected on the whole. It is apparent from the results that the plants selected for the present study are capable of changing the soil conditions from the degraded WL to a stable condition along with their growth and increase in biomass. The use of the plants for revegetation of WL implies that the establishment of the plant and subsequent growth will result in the changes in the soil conditions.

One of the bases of considering the phytoremediation process of the WL subjected to the coal extraction in the past is to reinstate the stable soil conditions both physical and chemical, using the plant species as a biological resources. In

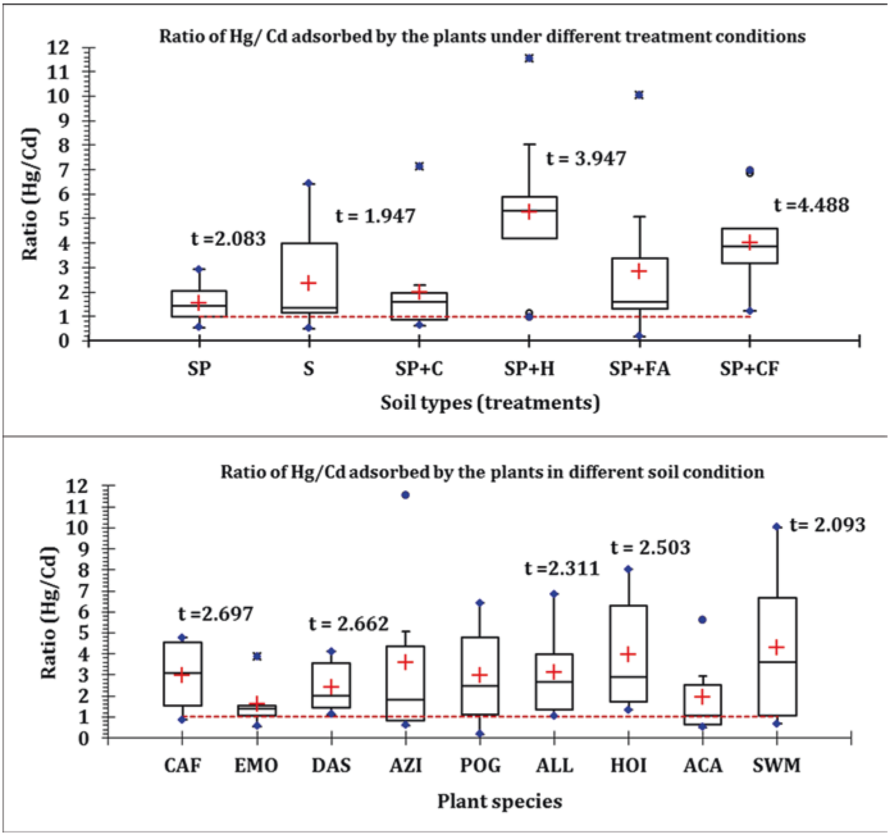

Fig. 5 The difference in adsorption of Hg and Cd by the different plant species under six different soil conditions expressed as a ratio (Hg/Cd). The reference line represents absolute similarity in the adsorption without any difference, and the values above or below the reference line represent the deviation from unity signifying the variation in the adsorption of the two metals. A one-tailed t-test was applied to justify the difference being significant or not at df = 8 for the soil treatments and at df = 5 for the plants. The significant values are marked in bold ($P < 0.05$)

terrestrial ecosystems the establishment of the plant species alters the conditions of the associated soil owing to the aggregation of the soil microbes attracted towards the plant exudates, eventually creating the rhizosphere. The rhizospheric soil is enriched with the microbes that facilitate the remodelling of the soil conditions, which further provides a positive feedback to extend the plant growth. In essence, the growth of the plants triggers the expansion of the rhizosphere followed by the changes in the soil quality parameters. As observed in the present instance, all the nine plants influenced the changes in the soil conditions along with the adsorption of the metals like Hg and Cd. Although variations in the extent of the changes in the soil conditions were obvious with reference to the initial soil conditions and the plant species, the bioaccumulation capability was an addition function that increased

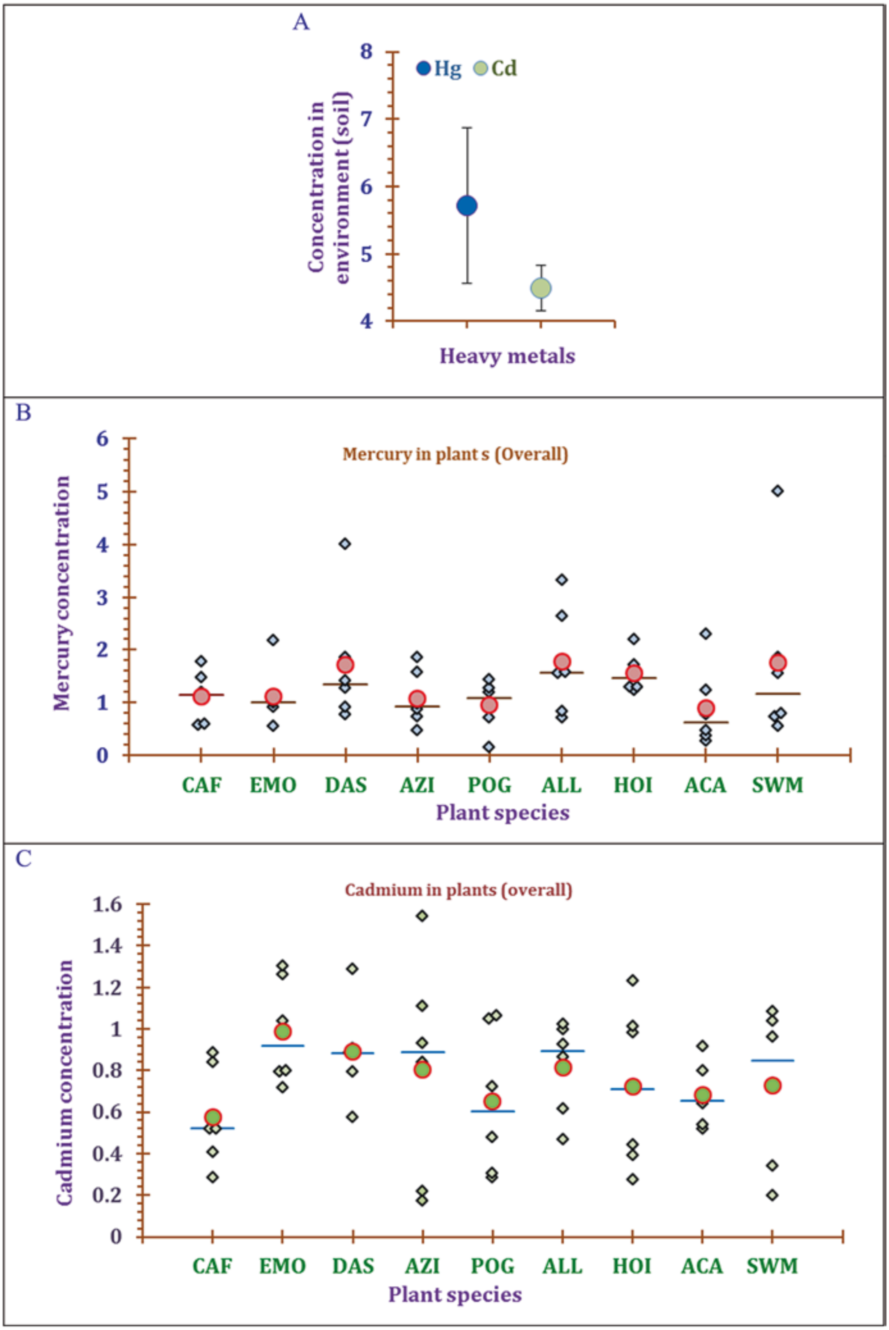

Fig. 6 The overall concentration (μg/g) of the heavy metals and Cd in soil (**a**) and the plants (**b** – Hg; **c** – Cd), irrespective of the soil treatments observed through whole tissue assay (n = 6 replicates per plant). The scatterplots in **b** and **c**, with the round filled circles, represent mean values, while the horizontal lines represent the median values for each panel (plant species)

the ecosystem services delivered by the plants. In the context of restoration of the landscape of the WL of the colliery region, the use of the plants can be considered as a suitable alternative to augment the soil conditions along with reduction in the level of the heavy metals. The success of the PR using plant species in augmented remodelling of the soil along with reduction of the heavy metals requires selection of the appropriate plant species (Pulford and Watson 2003).

Although the long generation time of the plant species defends the growth of the metal-tolerant species, the accumulation of the same enables their use in the metal-contaminated soil sites like the abandoned coal mines and allied landscapes. Bioavailability of the metals and subsequent uptake by the plants depend on several factors of the ambient soil and the existing plant species (Pulford and Watson 2003; Yadav et al. 2017). Earlier studies have shown that the plants like *Dalbergia sissoo* are able to remodel the soil and extract the heavy metals from sites containing high sulphur content in abandoned coal mine areas of Assam (Dowarah et al. 2009).

Phytostabilization and phytoextraction are highlighted as two common process of alteration of the soils of the WL of abandoned coal fields as well as other mining areas (Wong 2003). The results of the present study substantiate the selected nine plant species are capable of stabilizing the soil conditions along with the accumulation of heavy metals thereby facilitating the reinstatement of the soil to the stable conditions for further plant assemblages. In the course of demonstrating the ability of the plants Indian laburnum, Aonla, shisham, neem, siris, mahogany, etc. for the soil reclamation process, the present study substantiates the prospect of PR process aided through revegetation of abandoned coal fields. The ability of the plants in restructuring the ecological succession process is also established through their potential to grow under the diverse soil conditions mimicking the abandoned coal fields. However, the selection of the plant species should be done judiciously to reinstate the seral stages in the continuum of the succession. The changes in the soil conditions towards a favourable condition for the future community establishment may require uninterrupted time period so that the long-term benefits are achieved through revegetation and introduction of the plants in the coal field sites.

11 Restoration of Mined Wastelands: A Way Towards Sustainability

The large-scale land disturbances associated with mining operations and related concerns about the environmental effects have triggered an increasing number of rehabilitation programmes which aim for the restoration of natural ecosystems disturbed by mining. Restoration of mine sites often improves the physical and chemical characteristics of substrate and ensures the return of vegetation cover (Bradshaw 1987; Schaller 1993; Lindenmayer and Hobb 2008; Kumar et al. 2017). If specific problems hindering ecosystem redevelopment can be identified, a cure can be designed using or mimicking natural processes. According to Dobson et al. (1997), this process of identification and intervention is the essence of ecological restoration.

The most common response to land degradation has been abandonment or reliance on natural succession to restore lost soil fertility, species richness and biomass productivity (Parrotta et al. 1997; Ambasht and Ambasht 2012; Sihag et al. 2015). However, the process of natural succession on surface-mined soils is slow due to the removal of topsoil, resulting in elimination of soil seed bank and root stocks and due to soil profile disturbances (Parrotta et al. 1997; Kumar et al. 2017; Chaturvedi and Singh 2017). As many as 50 or 100 years can elapse before a satisfactory vegetation cover develops on mine waste (Bradshaw 1997). Redevelopment of advanced communities may take a millennium or more (Dobson et al. 1997).

An important goal of ecological rehabilitation is to accelerate natural successional processes so as to increase biological productivity, reduce rates of soil erosion, increase soil fertility and increase biotic control over biogeochemical fluxes within the recovering ecosystems (Parrotta 1992). Analysis of different natural successions on natural and artificial substrates suggests that one of the important factors limiting the rate of development is the process of immigration of taxa (Miles and Walton 1993; Ash et al. 1994). There are genuine difficulties in appropriate species reaching a particular site, especially if they have heavy seeds, unless they already occur in the immediate vicinity (Bradshaw 1997). Artificial revegetation is often used to facilitate the generally slow natural rehabilitation process (Bradshaw 1983; Leopold and Wali 1992). Artificial seeding of grasses and legumes or both has been a commonly used method to stabilize unconsolidated mine tailings and to encourage natural invasion of tree and shrub seedlings. This ultimately improves site fertility and moisture retention capacity (Vogel 1973). Once the abandoned mine lands have vegetation growing on the surface, the regeneration of these areas for productive use has begun, and off-site damages are minimized. In addition, establishment of the vegetation on an abandoned mine land also improves the aesthetics of the area.

Overburden is the geologic material above coal seams and below the developed soil horizons (Helm 1995). Buried seeds and rhizomes are normally absent in overburden (Singh et al. 1996). This fact makes seed reserves in the topsoil an important resource that, if handled correctly, can be used successfully to recover disturbed areas by natural vegetation (Iverson and Wali 1982; Hopkins and Graham 1983; Bellairs and Bell 1993). Since most of the soil seed reserves are found in the surface 5–10 cm (Iverson and Wali 1982; Roberts 1981; Putwain and Gillham 1990), upper 5–10 cm topsoil is recommended to be removed and replaced on the top of overburden material. However, the collection, storage and use of topsoil for restoration of mine areas are limited in many parts of the world (Noyd et al. 1997). Therefore, recent reclamation strategies have centred on creating soil that will support short-term establishment of native plant species and will sustain long-term successional development (Pfleger et al. 1994).

Harrington (1999) describes plantation-related activities used in restoration of damaged sites. According to him, the first step should be stabilization of soil surface by contours, debris dams, mulch, etc. Compaction of soil also needs to be reduced by mechanical disruption. If needed, macroporosity of the soil can be improved by incorporation of wood and shale. Soil toxicity in terms of pH, metals and salts has to be reduced by suitable amendments and plantation of resistant species and cultivars. Once suitable vegetation starts growing, herbivory and physical damage can be reduced by controlled access, fencing and trapping (Harrington 1999).

Tree Species in Reclamation of Wasteland Vast areas of land all over the world have been rendered unproductive by human activities (Choi and Wali 1995). The situation is particularly alarming in tropical areas where forest loss and degradation, as well as degradation of land of those earlier supported forests, are proceeding at unprecedented rates (Parrotta et al. 1997). Ecosystem destruction by mining for coal, quarrying for minerals and other processes to meet demands of industries is an inevitable part of civilization (Bradshaw 1983). The increasing human need for these resources will certainly accelerate further degradation of natural habitats, as most of the mining areas are on the land which was previously occupied by forests. All these will lead to acceleration of erosion of biological diversity and creation of several other environmental problems.

Plantations on MS Plantation is the oldest technology for the restoration of lands damaged by human activity (Filcheva et al. 2000; Meena and Yadav 2014; Kumar et al. 2016; Jhariya and Yadav 2018). A primary objective for achieving satisfactory rehabilitation of a mined landscape is to establish a permanent vegetation cover. There is increasing evidence that forest plantations can play a key role in harmonizing long-term forest ecosystem rehabilitation or restoration goals with near-term socioeconomic development objectives (Parrotta et al. 1997). Plantations can play a critical role in restoring productivity, ecosystem stability and biological diversity to degraded areas (Schaller 1993). Relative to unplanted sites, plantations have a marked catalytic effect on native forest development (succession) on severely degraded sites (Parrotta et al. 1997).

Numerous studies have demonstrated that land rehabilitation benefits from plantations because it allows jump-starting succession (Ang 1994; Khemnark 1994). The catalytic effects of plantations are due to changes in understorey microclimatic conditions (increased soil moisture, reduced temperature, etc.), increased vegetational-structural complexity and development of litter and humus layers that occur during the early years of plantation growth. The development of a plantation canopy can alter the understorey microclimate and the soil physical and chemical environment to facilitate recruitment, survival and growth of native forest species. Otherwise, native species would only very slowly, if ever, regenerate on degraded sites (Uhl et al. 1982; Pandey et al. 1988; Soni et al. 1989). Thus, plantations accelerate the development of genetic and biochemical diversity on degraded sites.

Plantations have an important role in protecting the soil surface from erosion and allowing the accumulation of fine particles (Bradshaw 1997). They can reverse degradation process by stabilizing soils through development of extensive root systems. Once they are established, plants increase soil organic matter (O'Connell 1986; Gill et al. 1987; Montagnini and Sancho 1990), lower soil bulk density, moderate soil pH, bring mineral nutrients to the surface and accumulate them in available form (Bradshaw 1997; Sanchez et al. 1985; Chakraborty and Chakraborty 1989; Sharma and Gupta 1989). Their root systems allow them to act as scavengers of nutrients not readily available. The plants accumulate these nutrients and redeposit them on the soil surface in organic matter, from which nutrients are much more readily available by microbial breakdown. This is exhibited in the levels of available phosphorus and potassium in afforested colliery spots (Knabe 1973).

Most importantly, some species can fix and accumulate nitrogen rapidly in sufficient quantities to provide a nitrogen capital, where none previously existed, more than adequate for normal ecosystem functioning (Bradshaw 1997). Once the soil characteristics have been restored, it is not difficult to restore a full shoot of plant species to form the required vegetation (Dobson et al. 1997). According to Faulconer et al. (1996), other advantages are that establishment of desirable tree species capable of maintaining the site will slow or prohibit invasion of less desirable weedy species, will provide economic returns in the long term, will aid in developing wildlife habitat and will promote hydrologic balance in the watershed.

Reforestation of polluted sites is part of a realistic, low-cost, ecologically sound and sustainable reclamation strategy for bringing polluted sites into productive use (Dickinson 2000). Planting trees on these sites initiates soil development and nutrient cycling and improves the aesthetic value of the site. The ecological basis through plantation for rehabilitation of damaged tropical lands has been described by Lugo (1992). Selection of appropriate plant species would be very important to ensure a self-sustainable vegetation cover. Because of deep roots, trees are able to loosen compacted soil to greater depths than grasses. The potential use of trees as a suitable vegetation cover for heavy metal-contaminated land has received increasing attention over the last 10 years (Glimmerveen 1996). Trees can maintain sustainable bionetwork through numerous processes such as maintenance of soil organic matter, rhizosphere growth and improved soil biological activity. In a given time, new self-sustaining leaf litter and litter fall will be created by trees which help in formation of humic substances (Filcheva et al. 2000).

Species Selection for Plantations The choice of plantation species is likely to greatly influence both the rate and the trajectory of rehabilitation processes (Parrotta 1992).The establishment of a permanent cover of vegetation not only involves growing plants, but it necessitates bringing into being a plant community that will maintain itself indefinitely without attention or artificial aid and support native fauna (Rodrigues 1996). Such performance could be achieved by selecting species adapted to grow, spread and reproduce under severe conditions, provided both by the nature of the dump material and the exposed situation on the dump surface (Rodrigues 1996).

The presence of certain tree species in a productive system can result in better soil structure and increased soil nutrient availability (Montagnini and Sancho 1990; Sanchez et al. 1985; Nair 1989; Young 1989). Among species that may be considered suitable for a given degraded site, there may be considerable variations in their capacity to stabilize soils, increase soil organic matter and available soil nutrients and facilitate understorey development. These variables include susceptibility to pests and diseases, patterns of aboveground and root biomass accumulation, nutrient utilization and allocation, nutrient use efficiency, nutrient re-translocation, litter production and fine root turnover, rates of litter decomposition (O'Connell 1986; Gill et al. 1987) and the presence of secondary compounds that may inhibit the activity of decomposing organisms. While most species appear to act as catalysts for ecosystem rehabilitation, broadleaf species seem to give better results than conifers (Parrotta et al. 1997). Of these, fast-growing species that represent lower successional stages should have preference, particularly those known to establish and grow well on degraded sites. In addition to their potential effects on soil fertility, species choices must be guided by seed and seedling availability, local uses for the species and economic aspects (Montagnini et al. 1995).

Trees can potentially improve soils through numerous processes, including maintenance or increase of soil organic matter, biological nitrogen fixation, uptake of nutrients from below the reach of roots of under storey herbaceous vegetation, increase water infiltration and storage, reduce loss of nutrients by erosion and leaching, improve soil physical properties, reduce soil acidity and improve soil biological activity (Filcheva et al. 2000; Buragohain et al. 2017). Given time, new self-sustaining topsoils are created by trees (Filcheva et al. 2000). However, impact of trees on soil fertility depends on their nutrient-cycling characteristics such as litter chemistry and decomposition (Montagnini et al. 1995). In addition to the nutrient sink function due to mass accumulation, some plantation species exhibit high nutrient use efficiency and may be more effective nutrient sink than the other species. In temperate environment, slower-growing, broadleaved native trees are regarded as better for amenity but less efficient for timber production (Filcheva et al. 2000). Indigenous species are preferable to exotics because they are most likely to fit into a fully functional ecosystem and to be climatically adapted (Piha et al. 1995). According to Harrington (1999), if there are native species available that are suited to the current soil and site conditions, the regeneration methods have been worked out for the desired species, and the resources are available to cover the cost, and then clearly the re-establishment of native species rather than exotics should be preferred.

12 Ecological Restoration of Mined Wasteland: Management Implication

Goals in this regard are to check further degradation; sustainable use of degraded lands; increase biomass availability along with nourishing soil; and restore ecological balance. This can be done by participatory approach with the help of local people in the planning and management of lands. Ecosystem approaches in management considering watershed would ensure integration of various ecological components (both biotic and abiotic). This would also help in enhancing the socioeconomic status of a region. Similar approaches practised in drier districts like Anantapur

(Andhra Pradesh), Tumkur, and Bangalore Rural (Karnataka) have yielded positive results with increase in land productivity and groundwater levels in the respective watersheds.

- People-friendly action programme helps local people and organizations in rehabilitating and improving the degraded lands. In this regard, management aspects are:
  - Fixing target areas (degraded forest area and pastures, public and private WL, farmlands with lower productivity).
  - Assessing the infrastructure available to meet the requirement.
  - Finding the possibilities of involving the government, NGOs and local people. The key elements of a participatory approach are local peoples' priorities; provision of secure rights and gains to the poor; flexible approaches; working with local groups and institutions; and capacity building of motivated local people.
- Government has to give priority in terms of funding, encouragement, and policy-making
- Mechanisms by which local people, NGOs and other groups can contribute to the implementation and monitoring of WL development programme on a regular basis.
- Promoting conservation of natural resources through traditional knowledge.
- Promoting ideas to consider the village as an ecosystem and to maintain its integrity.
- Providing examples of the practices done at different places.
- Integrated village ecosystem planning with watershed approach needs to be espoused for sustainable development.

This would enhance the total natural resource base by restoration and management of degraded lands, production of basic biomass needs of the village community and equity in distribution of biomass resources.

13 Phytoremediation and Restoration: Future Perspectives

The remediation of soil that is heavily contaminated due to coal or metal mining involves excavation, removal of soil to secured land fields and filling of topsoil, which is expensive and requires site restoration. Alternatively, the contaminated soil may be dealt with bioremediation or PR, which is the use of plants or other biological measures to remove, destroy or sequester hazardous substances from the soil and waste piles (Ojuederie and Babalola 2017). An account of specific plant species that have been used to combat different types of soil pollution has been given by Prasad (2004). However, restoration of mine waste piles depends on the substrate characteristics and ability of the plant species to proliferate in the substratum.

Due to the extreme consequences, environmental contamination with heavy metals, particularly lead and Hg, is a significant concern. Now faced with these overly extensive environmental problems, a cost-effective means of remediation pertinent to the contaminated areas must be found. There are a number of conventional remediation technologies which are employed to remediate environmental contamination with heavy metals such as solidification, soil washing and permeable barriers. But a majority of these technologies are costly to implement and cause further disturbance to the already damaged environment. PR is evolving as a cost-effective alternative to high-energy, high-cost conventional methods. It is considered to be a “Green Revolution” in the field of innovative cleanup technologies (Henry 2000).

PR of mine land offers a great challenge, to restore its productivity and fertility and also to re-establish the ecological cycles in the rhizosphere with identification of suitable plant species and also the amendment of some suitable blending material on such degraded land. It is one of the widely used emerging techniques for soil remediation, to remove pollutants from the environment or to stabilize them (Salt et al. 1998). Conventional PR techniques mostly involve growing plants, to remove pollutants or to stabilize the contaminated site. But long-term sustainability on coal MS dumps requires a scientific approach. Selective microorganism’s inoculation at such sites increases the better survivability, growth and biomass of the plants. PR of the coal MS dumps therefore needs an integrated biotechnological approach, which includes blending of spoil with organic waste and inoculation with biofertilizers and mycorrhizal fungi to achieve revegetation and restoration of fertility of these dumps.

PR does not require expensive equipment or highly specialized personnel, and it is relatively easy to implement. It is capable of permanently treating a wide range of contaminants in a wide range of environments. However, the greatest advantage of PR is its low cost compared to conventional cleanup technologies (Raskin and Ensley 2000; United States Environmental Protection Agency 2000). The most important challenge is to improve the efficiency of phytotechnologies depending upon dissemination of results, risk assessment, public awareness and acceptance of this green technology, as well as the promotion of networking between scientists, industrials, stakeholders, end users, non-governmental organizations and governmental authorities which are major issues that must be tackled to ensure that PR programmes are implemented successfully.

14 Conclusion

In view of ecological restoration of coal mine WL, the present study explored the vegetation pattern and the soil quality, using Raniganj Colliery, West Bengal, India, as a model geographical area. The objective of the study was to highlight the ecosystem conditions of the WL using the vegetation pattern and the soil quality as surrogates. Evaluation of the growth pattern of nine different plant species against six different soil conditions was made to highlight the prospective use in enhanced vegetation of the WL to restore the seral stages in successional continuum. Plant growth induces changes in the soil conditions following the generalized assembly rules of the community organization, which was also assessed for the selected plants along with the ability to bioaccumulate the heavy metals from the ambient soil. The information on the plant species assemblages and the soil quality provided a basis to comment on the prospect of the ecorestoration of the WL following the principles of PR.

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