Reclamation of mining-generated wastelands at Alkusha–Gopalpur abandoned open cast project, Raniganj Coalfield, eastern India

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Abstract Biological reclamation on a 10-year-old mine spoil at Alkusha–Gopalpur, Raniganj Coalfield, Eastern India was carried out during 1992. Effects have been measured yearly in terms of species suitability, spoil chemical quality, and biodiversity of natural succession till 1997. It has been determined that out of 14 plant species selected for reclamation, the successful ones are *Acacia auriculoformis*, *Acacia arabica*, *Albizzia lebbek*, *Leucena leucocephala*, and *Gmelina arborea*. Impaired pH, available mass nutrients (N, P, K), organic carbon, exchangeable cations and cation exchange capacity have been found to increase whereas trace elements have been found to decrease. There is an indirect relationship between the survival percentage and trace element intake capacity of the planted saplings.

Keywords Eastern India · Mine spoil · Raniganj coalfield · Reclamation

Introduction

Raniganj Coalfield is the oldest and most celebrated coalfield in India. Prolonged and extensive mining of coal in the area since the 18th century has resulted in severe geoenvironmental (Vartanyan 1989; Aswathanarayana 1995) degradation, any comprehensive appraisal of which has not been attempted earlier. Among the various geoenvironmental impacts of mining, degradation of land is by far the most significant. Land, which is one of our most important natural resources, thus needs to be tended carefully and conserved.

In the present study area, mining of coal was carried out mainly through the open-cast method, which results in the dumping of large amounts of overburden. This overburden originates from the consolidated and unconsolidated materials overlying a coal seam and, when disturbed and haphazardly mixed during mining activity, is called mine spoil. In these mine spoils, the geomorphic system is in disequilibrium because of the destruction of the balance between landforms and processes, which accelerates erosion rates. As soon as mining disturbs this geology–soil–plant stability circuit, ecological chaos takes place. Thus, these mine spoils in the study area occur as pockets of a disturbed ecosystem (Wali 1989). In the study area, land degradation in the form of gullied land, nutrient poverty, and metal mobilization have been identified (De 2001) as being vigorous because of the cumulative effect of erosion and leaching. In an attempt to restore the pristine ecological equilibrium in these disturbed ecosystems, biological reclamation has been attempted as a case study in one of these old mine spoils at the Alkusha–Gopalpur abandoned Open Cast Project (OCP) under the Salanpur Area of Eastern Coalfields Limited (ECL), Government of India.

The objective of this study was to understand the efficiency of restoration of mine spoils through biological means.

Study area

Biological reclamation was undertaken on 10-year-old mine spoil at Alkusha–Gopalpur abandoned OCP (lat. 23°46′42″N and long. 86°54′06″E) during 1992. It is 13 km NW of Asansol town in the Barddhaman District of West Bengal, India. Alkusha–Gopalpur OCP started production in 1966 and ceased in 1981. It now extends over an area of 19.20 ha, of which mine spoil (continuous, 7–10 m high above ground level) covers an area of 13.80 ha, whereas the rest constitutes an arcuate-shaped abandoned quarry filled with water (Fig. 1).

The mine spoil at Alkusha–Gopalpur is composed of weathered products of sandstones, shales, and conglomerates of the Barakar Formation. The sandstones, the majority of the spoil, being feldspathic in nature, are easily

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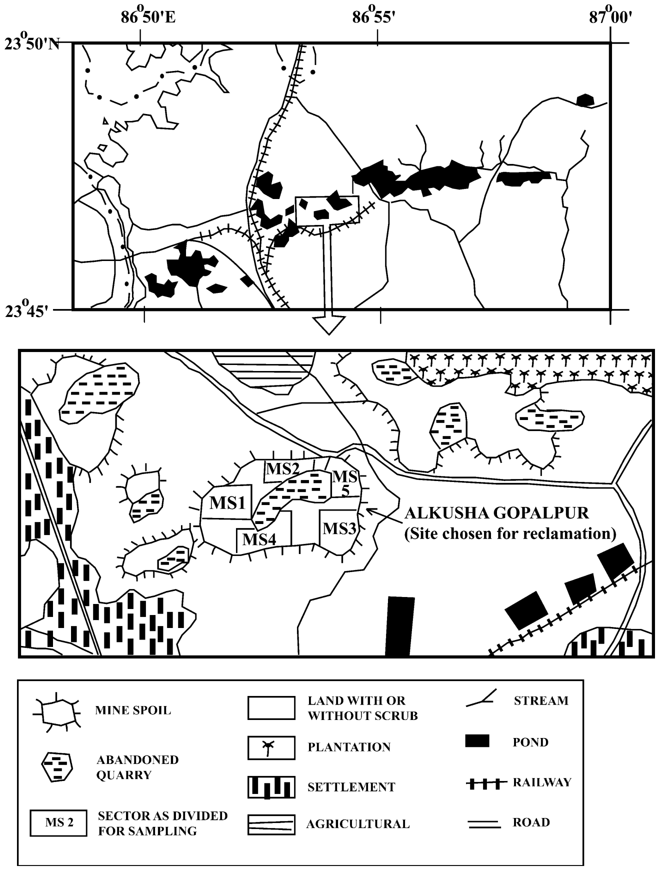

Fig. 1
Location of the reclaimed site at Alkusha–Gopalpur, Raniganj Coalfield, eastern India

prone to weathering and erosion and, thus, are responsible for considerable spread of the spoil material over the surrounding unmined land, and has eventually made the face of the overburden (OB) dump gently (5–15°) during the 10-year span of abandonment. The shales are carbonaceous and, these together with the low-grade waste coal associated with the area, have imparted a black look to the spoil.

Materials and methods

Sampling and analytical methods

To understand the physical, mineralogical, chemical, and nutritional properties of the mine spoil, it has been divided into five sectors (Fig. 1). Soils were collected from each of these five sectors in a composite manner, taking five to eight random soil samples from each sector during February 1992 (before reclamation), March 1993, February 1994, February 1995, and March 1996 (after reclamation). These were air-dried, pooled, and intimately mixed, and a smaller portion of these homogenized samples (nearly 500 g) were drawn and sieved to 60 mesh size before laboratory analysis. The samples were analyzed for texture, pH, electrical conductivity (EC), organic carbon, available N, P, K, exchangeable cations (Ca, Mg, Na, and K), cation exchange capacity (CEC), and heavy metals (Fe, Mn, Zn, Cu, Ni, Co, Cr, Pb, Cd, and As).

Physical properties, such as absolute specific gravity, bulk density, particle density, % pore space, and maximum water holding capacity of the mine spoil, were determined using Keen's box (Black 1965).

Mechanical analysis of soil was carried out by the hydrometer method, and textural classes were identified using a triangular diagram standardized by the United States Department of Agriculture as depicted in Fig. 6.4b in Biswas and Mukherjee (1992).

The soil pH and EC were determined by pH meter and conductivity meter in a 1:2.5 and 1:5 suspensions of soils and distilled water, respectively. The organic carbon was determined by the Walkley and Black method (Black 1965). Available nitrogen was estimated by the alkaline permanganate method; available phosphorus was extracted from the soil by Bray's reagent and was determined by the molybdenum-blue method, and available potassium was extracted from the soil by 1 N ammonium acetate solution and was determined with a atomic absorption spectrophotometer (AAS) [Thermo Jarrell Ash-AA-Scan 1]. The exchangeable cations and CEC were measured following the methods in Black (1965) and Jackson (1967).

For estimation of heavy metal concentrations in these soils, 1 g of each of the homogenized samples was digested with 25 ml 1:1 nitric acid for about 24 h. The solute was separated by filtering and its volume was made up to 50 ml with distilled water. The solution was used to determine the heavy metal concentrations (except arsenic) by AAS analysis. For the estimation of arsenic, 5 g of each sample was digested with 20 g of caustic soda for 1 h. The solute was separated by filtering and its volume was made up to 100 ml with distilled water. An aliquot of the solution was used for the determination of arsenic with a spectrophotometer.

At the end of fifth year, in 1997, trace element concentrations in the twigs of some selected planted species were also estimated to determine their variability in absorbing different trace elements from the mine spoil. To estimate the concentration of trace elements in the twigs of planted species, 1 g of each of the air-dried samples (twigs) was digested with 50 ml 1:4 perchloric and nitric acids, respectively, for about 24 h. The solute was separated by filtration and its volume was made up to 50 ml with distilled water. The solution was used to determine the trace element concentrations, through AAS analysis.

Species selection for reclamation

A total of 14 species were selected for the present reclamation program (Table 1). During species selection, the pre-mining occurrence of species was primarily considered. The dominant species of the area before mining were *Shorea robusta*, *Terminalia tomentosa* followed by *Anogeissus* spp., *Boswellia* spp., *Madhuca* spp., *Pterocarpus* spp., *Acacia catechu*, *Tectona grandis*, *Lagerstroemia* spp., *Diospyros* spp., *Adina cordifolia*, *Buchanania* spp. etc. (Negi 1983). Among the above native plants, the most dominant species, *Shorea robusta* and *Terminalia tomen-*

Table 1
Name of the plant species selected for reclamation during July 1992 on Alkusha–Gopalpur mine spoil

Name of species		Nature of the species
Scientific	Local	
1. *Shorea robusta*	Sal	Native
2. *Terminalia tomentosa*	Asan	Native
3. *Tectona grandis*	Segun	Native
4. *Madhuca latifolia*	Mahua	Native
5. *Dalbergia sissoo*	Sisu	Neighboring
6. *Sizygium cumini*	Jam	Neighboring
7. *Zizyphus mauritiana*	Kul	Neighboring
8. *Terminalia arjuna*	Arjun	Neighboring
9. *Anacardium occidentale*	Badam	Neighboring
10. *Gmelina arborea*	Gamar	Introduced
11. *Albizzia lebbek*	Siris	Introduced
12. *Leucena leucocephala*	Subabul	Introduced
13. *Acacia auriculoformis*	Akashmani	Introduced
14. *Acacia arabica*	Babla	Introduced

tosa, were tried along with a few less frequent species such as *Tectona grandis* and *Madhuca latifolia*. These native plants were chosen to see whether they would regenerate in these derelict lands.

In addition to these native species, some neighboring species, occurring to the south of the study area (Negi 1983), were also studied. The latter are *Zizyphus mauritiana*, *Sizygium cumini*, *Dalbergia sissoo*, and *Teminalia arjuna*. Keeping in mind the highly degraded condition of the area, some tolerant species were used as introduced species into the region. These are *Acacia auriculoformis*, *A. arabica*, *Leucena leucocephala*, *Albizzia lebbek*, and *Gmelina arboria*.

Reclamation procedures

Saplings of the selected species were raised in a nursery through polythene seed beds during February 1992. During March 1992, the primary vegetation cover was cleared from the mine spoil and was burnt on the spoil, primarily to check for weed infestation, and to increase the soil organic matter as far as possible. There are two major problems in the mine spoil for plant development: (1) a coarse loamy texture with poor water-holding capacity, and (2) nutrient scarcity, particularly of nitrogen. To increase the available nitrogen concentration in soil, a nitrogen fixing leguminous plant (dhanicha) was introduced during April 1992. Simultaneously, the grass *Veteveria zizinoides*, with a typical adventitious root system, was planted in linear trenches parallel to the contour at 3-m intervals for slope stabilization and to check erosion. By virtue of its serrated leaf margin it also acted as natural fencing to prevent grazing. In the third week of July 1992, the dhanicha was also cleared and crushed on the mine spoil. During this time, as many as 5,000 pits, each with a diameter of 30 cm and a depth of 60 cm, were dug and filled with the dug-up material treated with Jalshakti, a non-toxic, biodegradable, water-binding polymer, which remains active for 9 months (developed by National Chemical Laboratory, Pune). Jalshakti was introduced to overcome the poor water-holding capacity of the mine spoil. During the fourth week of July 1992, when 60% assured rainfall was 70 mm (Mishra 1994), saplings of the selected 14 species were planted with a frequency given in Table 2 in a rain-fed condition.

Vegetation survey

Supervised qualitative vegetation surveys were carried out during February 1992 before reclamation, and yearly thereafter during the falls of 1993–1996 to understand the natural succession. During the second vegetation survey (after the reclamation program, 1–3 September 1993), the numbers of surviving planted saplings were counted and the height and girth of randomly selected saplings were also measured.

Results and discussion

Before reclamation

The physical properties have been depicted sector wise in Table 3. A perusal of the table indicates that the maximum water-holding capacity of the mine spoil is low although the medium is sufficiently porous (pore space ranges between 55.7 and 63.9%). Mechanical analysis of the finer fractions (<2 mm) of the spoil indicates a sandy loam texture where sand content is, in general, greater than 70% (Table 4), imparting insufficient water-retention capacity to this mine spoil for plant production (Dollhopf and others 1981).

X-ray diffraction analysis (Courtesy: Geological Survey of India, Eastern Region, Calcutta) of the silt–clay fractions of this mine spoil reveals that the clays are dominantly of kaolinitic type, followed by illite (Table 5). There are

Table 2
Frequency of the planted saplings in the present reclamation program

Size of quadrate	Number of species in a quadrate laid down													
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Mean
0.2×0.2 m	5	3	3	2	5	4	5	5	4	5	2	5	4	4
0.4×0.4 m	8	6	5	4	6	5	7	6	6	6	4	6	5	5.7
0.6×0.6 m	12	10	9	7	9	8	10	11	9	10	8	8	8	9.1
0.8×0.8 m	14	10	11	10	12	9	10	12	9	13	10	10	9	10.7
1×1 m	14	13	11	11	12	10	12	12	11	13	12	10	10	11.6
1.2×1.2 m	14	13	11	11	12	10	12	14	13	14	12	10	10	12
1.4×1.4 m	14	14	14	13	14	12	12	14	13	14	14	12	13	13.3
1.6×1.6 m	14	14	14	14	14	14	12	14	14	14	14	14	14	13.8
1.8×1.8 m	14	14	14	14	14	14	14	14	14	14	14	14	14	14

Table 3
Physical properties of mine spoil at Alkusha–Gopalpur during February 1992

Sample no.	Sampling depth (cm)	Absolute specific gravity	Bulk density	Particle density	Pore space (%)	Water-holding capacity
AMS1	0–30	2.01	1.11	2.63	63.9	31.2
AMS2	0–30	2.06	1.06	2.69	58.4	28.4
AMS3	0–30	2.13	1.09	2.81	61.6	31.1
AMS4	0–30	2.09	1.17	2.64	55.7	25.5
AMS5	0–30	2.12	1.13	2.75	59.4	27.8

Table 4
Mechanical analysis and textural classes of mine spoil at Alkusha–Gopalpur during February 1992

Sample no.	Depth of sampling (cm)	Sand (%)	Silt (%)	Clay (%)	Textural class
AMS1	0–30	72.9	16.3	10.8	Sandy loam
AMS2	0–30	71.9	19.4	8.7	Sandy loam
AMS3	0–30	76.5	10.9	12.6	Sandy loam
AMS4	0–30	68.4	19.1	12.5	Sandy loam
AMS5	0–30	73.8	18.1	8.1	Sandy loam

traces of pyrite, pyrrhotite, and arsenopyrite. Kaolinite, being the dominant clay mineral, is responsible for imparting very low plasticity, swelling, and water-retention capacity to the clay fraction (Biswas and Mukherjee 1992). Chemical properties are depicted in Table 6. The spoils are acidic (pH 5.57–5.68), with low organic carbon. The acidic nature of the mine spoil is due to the maximum leaching of basic cations (Kundu and Ghose 1994), which, in turn, renders the medium unsuitable for plant growth because microbial activity and nutrient availability are optimum at the pH range of 6–7 (Braddy 1988). The spoil is also characterized by a deficit in major available macronutrients, particularly nitrogen, with a very low cation exchange capacity. The poor availability of nitrogen to plants growing in mine spoil may be due to the lack of mineralizable organic nitrogen and to lower mineralization rates (Reeder and Berg 1997). Trace metal concentrations were also detected in (acid) extractable form (Table 7), and indicate that the spoil is heavily enriched in copper, manganese, zinc, lead, nickel, chromium, and arsenic. The solubility of iron, manganese, and copper, which are present at toxic levels in this acid medium, may increase due to the mild acid rain (pH 4.9) the area experiences in the early part of the monsoon (De and Banerjee 1998).

A total of 17 species, belonging to 10 families, occurred on this mine spoil as a natural succession during the vegetation survey before reclamation. Among them, three species were from shrubs and 14 species were from herbs, whereas there were no trees (Table 8). All these species were sparsely distributed. *Calotropis gigantica* and *Lantana camara* among the shrubs, and *Evolvulus alsinoides, Tridax procumbens* and *Solanum xanthocarpum* among the herbs, were the most abundant species. Low diversity, poor abundance, and a thin density of species in this mine spoil were because of the coarser texture of the spoil, with low water- and nutrient-holding capacities. Root devel-

Table 5
XRD analysis of the silty clay fractions of mine spoil at Alkusha–Gopalpur during February 1992

Sample no.	Constituents detected				
	Major	Minor	Good amount	Considerable amount	Trace amount
AMS1	Quartz	Kaolinite	Illite	Pyrite	–
AMS2	Quartz	Kaolinite	–	Illite, Pyrite	Arsenopyrite
AMS3	Quartz	Kaolinite	Illite	Pyrite	Pyrrhotite
AMS4	Quartz	Kaolinite	Illite	–	Pyrite, Pyrrhotite, Arsenopyrite
AMS5	Quartz	Kaolinite, Illite	–	–	Pyrite

Table 6
Chemical and nutritional properties of mine spoil at Alkusha–Gopalpur during February 1992

Sample no.	AMS1	AMS2	AMS3	AMS4	AMS5
Depth of sampling (cm)	0–30	0–30	0–30	0–30	0–30
pH	5.57	5.62	5.66	5.59	5.68
EC (dS m^{-1})	0.219	0.149	0.193	0.231	0.249
Organic carbon (%)	0.36	0.34	0.42	0.39	0.40
Available nutrients (mg kg^{-1})					
Nitrogen	56.0	93.0	56.0	49.0	52.5
Phosphorus	4.0	3.25	5.25	4.75	4.50
Potassium	81.1	86.3	69.0	77.7	64.8
Exchangeable cations [C mol (p+) kg^{-1}]					
Calcium	2.13	2.26	1.93	2.21	2.28
Magnesium	0.91	0.83	0.96	1.10	1.17
Sodium	0.64	0.27	0.58	0.45	0.41
Potassium	0.06	0.11	0.04	0.12	0.07
Cation exchange capacity [C mol (p+) kg^{-1}]	5.7	5.3	5.9	6.0	6.2

opment was restricted and was found mainly in the upper 10 cm of the spoil.

Table 7
Trace element concentrations in mine spoil at Alkusha–Gopalpur during February 1992

Sample no.	AMS1	AMS2	AMS3	AMS4	AMS5
Depth of sampling (cm)	0–30	0–30	0–30	0–30	0–30
Iron (g kg^{-1})	15.3	17.1	18.4	16.3	18.9
Mn (mg kg^{-1})	210.4	236.7	239.3	216.0	221.4
Zinc (mg kg^{-1})	186.3	197.3	208.3	183.0	200.1
Copper (mg kg^{-1})	13.3	12.3	17.4	13.9	16.1
Nickel (mg kg^{-1})	6.3	8.9	10.7	9.3	10.4
Cobalt (mg kg^{-1})	3.4	4.1	4.6	2.9	4.3
Chromium (mg kg^{-1})	16.6	13.3	18.1	17.2	16.8
Lead (mg kg^{-1})	21.6	26.4	23.6	24.3	27.9
Cadmium (mg kg^{-1})	0.09	0.08	0.12	0.09	0.15
Arsenic (mg kg^{-1})	5.12	3.41	6.78	5.38	6.36

After reclamation

Efficiencies of planted species

As far as growth rate is concerned, the tallest growing species is *Leucena leucocephala*, with a mean vertical height of 245 cm and a mean girth of 57.7 cm (Table 9), measured during 1–3 September 1993. The species with mean vertical heights greater than 100 cm are *Albizzia lebbek* (152 cm), *Acacia auriculoformis* (150 cm), *Dalbergia sissoo* (144 cm), *Gmelina arboria* (128 cm), and *Acacia arabica* (125 cm). In terms of survival, the successful species (in order of survival %) are *Acacia auriculoformis* (95%), *A arabica* (89%), *Albizzia lebbek* (86%), *Leucena leucocephala* (81%), and *Gmelina arborea* (75%).

The first four species (in order of survival %) are in the family of Fabaceae, and had very good growth rates and the highest survival percentages in this nutritionally poor medium. These species have the ability to fix atmospheric

Table 8
Primary vegetation cover on mine spoils at Alkusha–Gopalpur during February 1992

Name of species: Scientific	Local	Family	Frequency of occurrence
Shrubs			
Calotropi gigantica	Akanda	Asclepiadaceae	Less frequent
Ipomoea spp.	Amari	Convolvulaceae	Rare
Lantana camara	Putush	Verbenaceae	Frequent
Herbs			
Cynodon dactylon		Poaceae	Abundant
Dactyloctenium aegyptium		Poaceae	Less frequent
Eragrostis atrovirens		Poaceae	Rare
Eragrostis coaretala		Poaceae	Rare
Ageratum conyzoides		Asteraceae	Less frequent
Croton bonplandiaum		Euphorbiaceae	Less frequent
Euphorbia hirta		Euphorbiaceae	Rare
Evolvulus nummularies		Convolvulaceae	Less frequent
Occinum basalicum		Lamiaceal	Rare
Solanum xanthocarpum		Solanaceae	Abundant
Tephrosia perpuria		Papilionaceae	Rare
Tridax procumbens		Asteraceae	Abundant
Veronia cinerea		Asteraceae	Rare
Evolvulus alsinoides		Convolvulaceae	Abundant

Table 9
Vegetative growth of the planted saplings and their survival (%). *n* Number of individuals measured; *SD* standard deviation

Name of species		*n*	Growth (cm)				Survival (%)
			Vertical		Girth		
Scientific	Local		Mean	SD	Mean	SD	
Acacia auriculoformis	Akashmani	28	150	40.9	9.6	2.0	95
Acacia arabica	Babla	26	125	31.9	6.0	1.17	89
Albizzia lebbek	Siris	20	152	36.3	7.7	1.78	86
Leucena leucocephala	Subabul	30	245	57.7	12.3	2.43	81
Gmelina arboria	Gamar	18	128	36.6	8.0	1.29	75
Terminalia arjuna	Arjun	20	83	18.7	4.4	0.91	68
Dalbergia Sissoo	Sisu	22	144	35.2	8.6	1.22	64
Zizyphus mauritiana	Kul	20	92	17.3	3.3	0.70	53
Anacardium occidentale	Badam	22	32	6.0	3.1	0.64	49
Tectona grandis	Segun	26	77	14.3	5.3	1.0	45
Madhuca latifolia	Mahua	16	29	4.7	3.5	0.40	38
Syzygium cumini	Jam	22	37	11.4	2.4	0.35	30
Shorea robusta	Sal	9	26	5.0	2.0	0.17	4
Terminalia tomentosa	Asan	–	–	–	–	–	–

nitrogen by bacteria (such as *Rhizobium*) in nodules on their roots (Maiti and Banerjee 1994). The presence of legumes in N-deficient soils helps to increase dry matter production and increases the growth of associated plants (Jeffery and others 1975). A few species, such as *Terminalia arjuna*, *Dalberga sissoo*, and *Zizyphus mauritiana*, responded appreciably, as is indicated from their moderate survival percentage (>50%, Table 9). Among these three species, *Dalbergia sissoo* had a high growth rate, with a mean height of 144 cm within 1 year, also indicating a suitable choice for the area. The less frequent indigenous species, such as *Tectona grandis* and *Madhuca latifolia*, showed moderate to poor growth rates with poor survival percentages. *Tectona grandis* with its higher growth rate compared with *Madhuca latifolia* may seem to be a better choice in contrast to the latter, but planting the latter with other species may be desirable because this species enriches the soil through its root nodules (Rao 1994). Very poor to zero survival percentage of the dominant indigenous species, such as *Shorea robusta* and *Terminalia tomentosa*, may be indicative of the changed ecosystem (Wali 1989) of the mine spoil. *Shorea robusta* was found to be relatively slow growing in the area with 26 cm mean height at the age of 1 year.

Changes in mine spoil

Species diversity in natural vegetation

Yearly vegetation surveys revealed that the numbers of naturally appearing new species in successive years (during 1993–1996) were 9, 23, 37, and 26 (Table 10). At the end of fourth year, i.e., in 1996, a total of 95 species (cumulative of all the years) occurred as a natural succession, of which 10 were trees, 12 were shrubs, and 73 were herbs. A progressive richness in species diversity in successive years indicates replenishment of the ecosystem on this derelict land.

Table 10
Occurrences of new species on mine spoil as natural succession after reclamation

Year of survey	Number of new species encountered			
	Trees	Shrubs	Herbs	Total
1993	0	3	6	9
1994	2	3	18	23
1995	2	4	31	37
1996	6	2	18	26
Total	10	12	73	95

Chemical properties

There was a very slow but steady rise in average pH from 1992 to 1997 (Table 11). The reason behind this is not clearly known. It may be due to the absorption of trace elements by the plant species. The rise in average pH of 0.24 in 5 years may be negligible because, in certain years, pH was found to decrease in certain sites. However, a pH of >5 is most suitable for nitrogen fixation (Lyle 1987) because bacteria will not penetrate many of the legumes at pH <5. A change in conductivity was also observed from 0.208 dS m^{-1} in the first year to 0.177 dS m^{-1} in the fifth year (Table 11). There was a marginal deterioration of conductivity from the third year onwards. Conductivity in natural soils varies between 0.200 and 0.800 dS m^{-1} and is required for optimum plant growth (Beer 1964). Initially, organic carbon was very low (0.38%) in the area. As more and more primary colonizers invaded in successive years, the level of organic carbon increased, reaching 0.65% at the end of fifth year. The increment of organic carbon was 18.4, 22.2, 5.4, 8.6, and 3.2% for 1st, 2nd, 3rd, 4th, and 5th years, respectively. It has been well established that nitrogen accumulation and generation of the nitrogen cycle is the most important factor in soil development in mining-generated wastelands (Dancer and others 1977; Marrs and others 1981).

Available nutrients

In Alkusha–Gopalpur, initial available nitrogen was 55.3 ppm, which increased to 179.2 ppm at the end of fifth year (Table 11). The maximum increment (100%) at the end of the 2nd year was attributed to *Dhanicha*, the nitrogen fixing leguminous plant, introduced before reclamation. The increments in successive years were a result of inclusion of the leguminous (e.g., *Leucena*, *Acacia* etc.) species selection for reclamation. It has been reported that most legumes can fix 50–150 kg N $year^{-1}$ (Coppin and Bradshaw 1982). The main source of available P in mine

Table 11
Changes in nutritional status of the mine spoil after reclamation. *CEC* Cation exchange capacity; *EC* electrical conductivity

Month and year of sampling	pH	EC	Organic C%	N	P	K	Available exchangeable				CEC
		(dS m^{-1})		(ppm)	(ppm)	(ppm)	C mol (p+) kg^{-1}				C mol (p+) kg^{-1}
Sampling							Ca	Mg	Na	K	
February 1992	5.62	0.208	0.38	55.3	4.35	75.8	2.16	0.99	0.49	0.08	5.82
July 1992	Reclamation										
February 1993	5.73	0.199	0.45	110.6	5.65	87.8	2.72	1.12	0.71	0.10	6.58
January 1994	5.74	0.210	0.55	131.6	5.60	95.9	2.78	1.12	0.68	0.12	6.80
February 1995	5.81	0.198	0.58	145.6	7.15	99.2	2.79	1.18	0.80	0.12	7.04
February 1996	5.83	0.185	0.63	163.8	6.95	107.9	2.95	1.21	0.80	0.15	7.30
February 1997	5.86	0.177	0.65	179.2	8.05	114.2	3.03	1.26	0.86	0.16	7.60

spoil is the breakdown of spoil materials and precipitation from the atmosphere (Coppin and Bradshaw 1982). Many workers have observed that the total P of mine spoils may equal or exceed those of unmined soils, but the plant available phosphorous in most of the spoils is invariably in the deficiency range (Yamanoto 1975; Safaya 1979). In the present study area, at the end of the 5th year, available phosphorous increased to 8.05 ppm, which is nearly double the concentration of what was present before. It has been estimated that available potassium at 100 ppm is sufficient for plant growth, 50–100 ppm indicates moderate deficiency range, and 0–50 ppm indicates high deficiency (Gammel 1990). In the Alkusha–Gopalpur reclaimed area, available potassium concentration was found to improve from a moderate deficiency range present before afforestation, to sufficient concentration in the 4th year of afforestation (Table 11).

Exchangeable cations

Exchangeable cations were also found to increase in successive years, though at very low rates. The improvement in the exchangeable calcium concentration indicates improved spoil physical properties (Biswas and Mukherjee 1992). CEC is an indication of the nutrient storage capacity of the soil. With the passage of time, CEC was found to increase, indicating a successive enhancement of nutrient storage capacity of the mine spoil. At the end of the 5th year, the CEC of the mine spoil was 7.60 ml 100 g^{-1} (Table 11).

Trace elements

It is important to note that the concentration of all the trace elements decreased in successive years through the reclamation period (Table 12). This reduction was probably due to the intake of trace elements by the planted species on the OB dump. Mobilization of trace elements to the surrounding lands, possibly due to acid rain (De and Banerjee 1998), may also be cited as one of the causes for depletion of trace element concentrations through successive years.

Trace element concentrations in the twigs of some planted species

Different plant species and cultivars vary widely in their ability to grow on nutritionally deficient or toxic soils, and at the same time may take up varying amounts of specific elements. The concentration of elements in plants is related to the stage of growth, and is usually greatest in young plants. Additionally, the concentration of trace elements varies between plant parts and is related to their mobility in the plant, varying with the element and the level of supply (Bowie and Thorton 1985).
In the present study, the twigs of different species were found to contain various concentrations of different trace elements (Table 13). The lack of a “placebo” group (i.e., plants grown in the surrounding unmined (native) soil without any treatment/external application) in this study hinders the comparison between the “control” group and

Table 12
Changes in trace element concentration of the mine spoil after reclamation. All values are in mg kg^{-1}, except iron, which is in g kg^{-1}

Month and year of sampling	Fe	Mn	Zn	Cu	Ni	Co	Cr	Pb	Cd	As
February 1992	17.2	224.8	195.1	14.6	9.1	3.86	16.4	24.8	0.11	5.39
July 1992	Reclamation									
February 1993	16.7	223.1	192.2	13.9	8.5	3.64	16.8	24.3	0.09	5.15
January 1994	16.2	215.2	181.5	13.9	8.3	3.44	15.6	24.0	0.09	5.14
February 1995	16.1	211.3	174.4	13.5	8.0	3.12	15.5	23.9	0.06	5.10
February 1996	15.7	207.9	168.4	13.1	7.7	3.10	15.2	23.6	0.06	5.13
February 1997	15.3	201.5	163.1	12.9	7.26	2.74	14.7	23.1	0.05	5.07

Table 13
Heavy metal concentrations in the twigs of some selected planted species on the mine spoil of Alkusha–Gopalpur. Co and Cd are below their respective detection limits. *n* Number of samples, All values are in ppm. *NS* Natural succession; *SD* standard deviation; *BDL* below detection limit

Plant name		Survival	*n*	Fe		Mn		Zn		Cu		Cr		Pb		Ni	
Scientific	Local	(%)		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Acacia auriculoformis	Akashmani	95	5	129.0	10.79	23.6	1.51	15.2	2.36	3.86	0.58	2.34	0.63	1.82	0.57	1.65	0.58
Acacia arabica	Babla	89	6	260.0	9.24	46.0	3.51	25.7	3.52	12.5	1.41	2.41	0.59	2.73	0.51	3.53	0.96
Leucena leucocephala	Subabul	81	5	152.5	10.61	19.8	3.24	33.2	3.02	10.42	1.09	6.65	1.11	3.41	0.72	5.0	1.51
Dalbergia sisoo	Sisu	64	5	223.7	14.99	39.2	3.29	41.4	2.46	8.96	1.10	7.49	0.90	4.16	0.97	5.72	2.52
Zizyphus mauritiana	Kul	53	5	577.0	17.56	41.4	5.18	44.3	4.89	15.98	1.72	8.32	1.11	7.25	3.66	BDL	–
Anacardium occidentale	Badam	49	5	153.5	9.95	54.0	5.38	31.3	3.79	11.0	1.27	3.10	0.33	5.62	3.13	6.82	2.02
Tectona grandis	Segun	45	4	613.8	18.24	33.7	3.53	23.4	4.25	18.0	2.02	9.2	0.89	12.89	1.70	10.3	4.26
Butea monosperma	Palash	NS	4	147.5	12.24	30.3	2.47	41.7	3.89	17.1	1.86	9.72	2.20	7.57	3.44	14.2	3.76

Table 14
Correlation coefficient matrix (n=35) for survival (%) and trace element concentrations in the twigs of some selected planted species at Alkusha–Gopalpur mine spoil

	Survival (%)	Iron	Manganese	Zinc	Copper	Chromium	Lead	Nickel
Survival (%)	1.00							
Iron	–0.60*	1.00						
Manganese	–0.43	0.14	1.00					
Zinc	–0.48	0.29	0.30	1.00				
Copper	–0.63*	0.81*	0.35	0.38	1.00			
Chromium	0.59*	0.66*	–0.21	0.52	0.51	1.00		
Lead	–0.70*	0.71*	0.13	0.13	0.71*	0.56	1.00	
Nickel	–0.40	0.07	0.13	–0.06	0.25	0.23	0.45	1.00

*Statistically significant at 99% confidence level

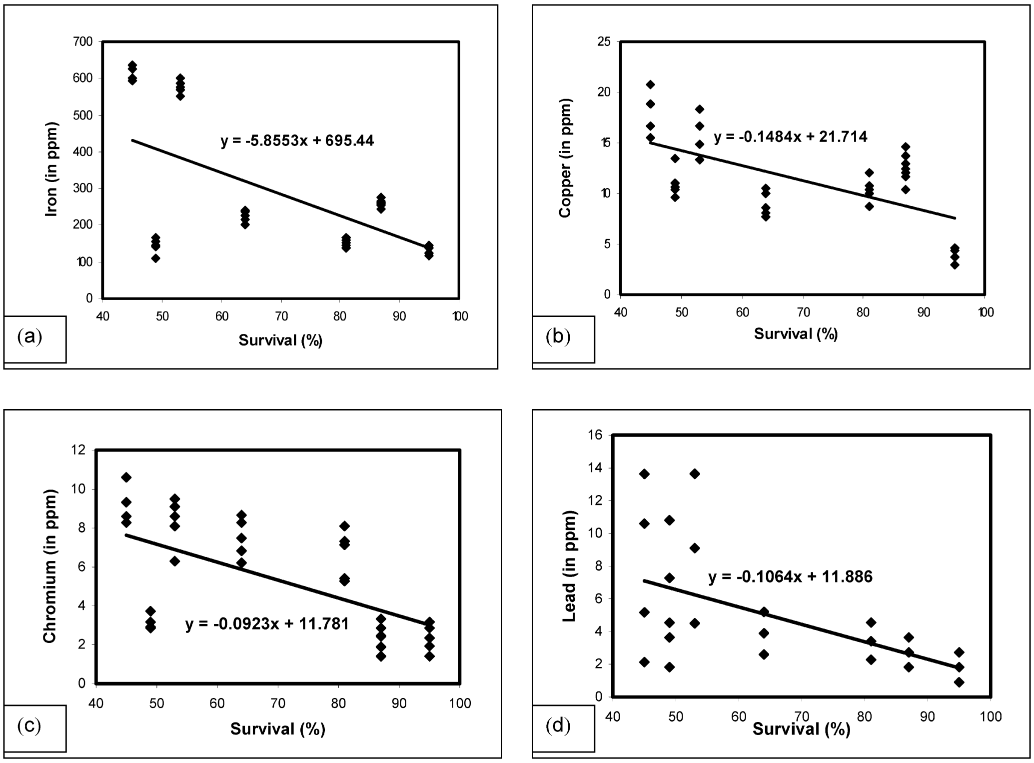

Fig. 2
Regression lines of **a** iron, **b** copper, **c** chromium, **d** lead concentrations versus survival (%) of some selected planted species

the "placebo" group. It would have been interesting to observe whether any direct/indirect relationship existed between the survival percentages and trace element intake capacity of the planted saplings by comparing the two groups. It has indeed been observed that there is an indirect relationship between the survival percentage and the trace element intake capacity of the planted saplings in the "control" group (Table 14). The species with low survival percentages were found to contain high concentrations of trace elements. This is particularly true for iron (Fig. 2a), copper (Fig. 2b), chromium (Fig. 2c), and lead (Fig. 2d). Hence, the introduction of these species with low survival rates , such as kul, badam, and segun, is also very important for the reduction of trace element concentrations in the OB dump.

The OB dumps act as potential sources for the trace elements in the surrounding soil, surface water, and groundwater. These trace elements are absorbed at various percentages by the plants, although they re-enter the spoil through plant litter and are again redeposited in the twigs and other plant parts. Thus, a cycle of trace elements has been generated in this OB dump, which ultimately retards the rate of trace element mobilization into the surrounding geoenvironment.

Conclusion

The following are the significant findings emerging from the present study.

1. Among the 14 species investigated in this reclamation program, the successful species according to survival percent are *Acacia auriculoformis*, *A arabica*, *Albizzia lebbek, Leucena leucocephala*, and *Gmelina arborea*, all of which are "introduced" species; poor survival rate of the native species, such as *Shorea robusta* and *Terminalia tomentosa*, is indicative of a "changed ecosystem" (Wali 1989) of the mine spoil.

2. A progressive richness in species diversity in natural vegetation (9 in 1993 to 95 in 1996) indicates rejuvenation of the ecosystem in this derelict land.
3. There is a steady rise in pH, available N, P, K concentrations, exchangeable cations, and CEC of the mine spoil as a direct effect of biological reclamation.
4. Trace element concentrations were found to decrease in the mine spoil in successive years. This may be attributed to the intake of microelements by the planted saplings and natural vegetation that invaded after reclamation on this mine spoil.
5. The survival and the trace element intake capacity of the planted saplings are inversely correlated. The species with low survival percentage were found to contain high concentrations of trace elements, particularly iron, copper, chromium, and lead.

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