Chapter

Ecological Restoration of Degraded Habitats of Jajang Iron and Manganese Ore Mines, Keonjhar, Odisha, India

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Abstract

Mining activities in Jajang iron and manganese ore mines located in Keonjhar district of Odisha, India starting from mineral explorations to production and transport are causing environmental damage in many ways, which includes deforestation, loss of topsoil, accelerated soil erosion, migration of wildlife and avifauna, and addition of air pollutants and dust to the atmosphere. In connection to this, the current study was an attempt to regain the original ecological status of the degraded areas of Jajang iron and manganese ore mines caused due to mining by Rungta Mines Limited. To achieve this indigenous plant species for restoration were selected from mining forests and plantations. Species selection from mining forests was made through systematic phytosociological analysis that involved measurement of Importance Value Index (IVI), regeneration values of tree species and their economic uses. On the other hand, species selection from plantations was made based on their growth, productivity, economic uses and adaptation to terrain and soil types. Shrubs and grasses were selected based on their relative index and abundance, respectively. The top 15 tree and 16 grass species as well as all six shrub species were selected from mining forests and plantations were considered for restoration. The findings of the study may also aids in the faster restoration of degraded habitats with initial human facilitation as the soils of degraded areas were similar to that of the mining forest. To speed up the recovery process after-care and monitoring have also been suggested or advised.

Keywords: Growth, Importance Value Index (IVI), Mining, productivity, Restoration, Vegetation

1. Introduction

Ecological restoration often known as eco-restoration is the process of recreating, initiating or accelerating the recovery of degraded habitats [1]. The adverse effect of disturbances include the full removal of vegetation cover and topsoil, which completely changes the topography of the area, deterioration of esthetics, impacts on surrounding ecosystems, and cause the major environmental changes that alter both ecosystem structure and function [2]. These disturbances are the negative outcome of opencast mining. In pacifying the adverse impacts caused due to mining activity on the local environment, mining-degraded areas are either reclaimed, by restoring a neglected area to some use or rehabilitated, by providing circumstances for a new and considerably different use [3] in order to mitigate the negative effects of mining activities on the surrounding ecosystem. To achieve this, two restoration techniques are to be used namely physical, technical, or engineering restoration, which is high cost and accounts for 60 to 90% of the total restoration cost and biological restoration, which is low cost and requires multi-disciplinary inputs [4].

The normal recovery of mining-degraded sites takes time for plant and animal species to colonize [5–7]. However, in many degraded areas, conventional recovery practices combined with biological restoration through human involvement can speed up the restoration process [8, 9]. Until now, there has not been much focus on restoring these degraded lands. Recent awareness followed by stringent enforcement of rules and regulations has generated consciousness about the environment. In some places of India restoration has been tried on an experimental basis [10–13]; [8] through the introduction of plantation programs. Plantation of indigenous plant species has attempted restoration through such approaches and as a consequence, the degraded areas have been restored [14].

Restoration is the recreation of entire communities of organisms that are closely modeled on those occurring naturally, whereas reclamation is any purposeful effort to return a damaged ecosystem to some type of beneficial usage [15–17]. In several situations, it would appear that it is reclamation rather than restoration which is attempted. Restoration needs knowledge of indigenous biological resources for understanding the species response to micro-environmental features and edaphic conditions [18–20]. Information on these aspects aids not only in the selection of species that are adapted to local conditions [13] but also in the rapid recovery of the ecosystem once such species have been planted [21, 22]. In these conditions, this piece of research is the outcome of a study that encompassed all of the factors needed to aid in ecological restoration of disturbed areas at Jajang iron and manganese ore mine in Keonjhar district, Odisha.

The Jajang iron and manganese ore mine area in Keonjhar district, Odisha has been disturbed due to mining since 1957. The area with dry deciduous forests contains good quality minable iron and manganese ore deposits. To undertake the mining activities some parts of the forest covers were cleared. Presently dumping is being done in well-vegetated valleys that adversely affected the vegetation. Thus the present study aimed to fix a set of phytosociological and growth related parameters of plant species that are linked to species success, as well as an ecological framework for selecting suitable species from the nearby mining forest and plantation to restore the degraded areas of Jajang iron and manganese ore mine, Odisha.

2. Study area

The Jajang Iron and Manganese Ore Mine (JIMOM) $21^0\ 55^{/}\ 00^{//}$ to $21^0\ 56^{/}\ 35^{//}$N latitude and $85^0\ 25^{/}\ 00^{//}$ to $85^0\ 27^{/}\ 10^{//}$ E longitude having a lease area of about 666.15 ha include 247 ha of forest area and 41.97 ha of dump area (**Figures 1** and **2**).

In this area, mining has been done in 377.18 ha and 41.97 ha or nearly about 42 ha have been used as a dump. The rate of extraction of ore is around 16.5 million tons per annum (MTPA) and the ore to waste ratio is 1:0.043. The mines lease area includes the following:

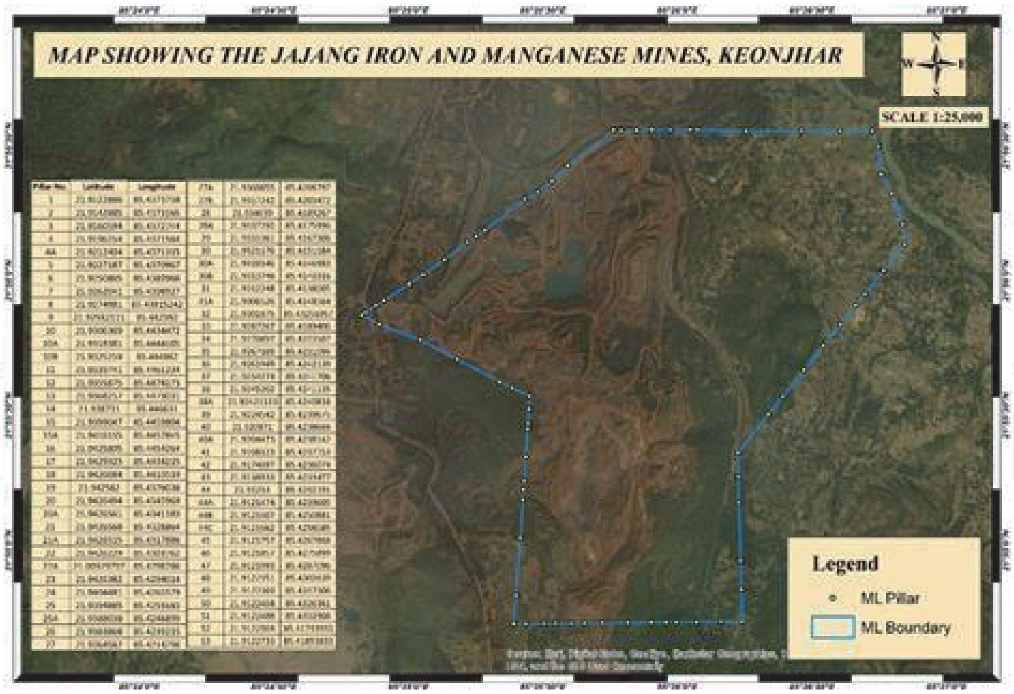

Figure 1.
Google earth view of Jajang iron and manganese ore mine at Keonjhar. ML: Mining lease.

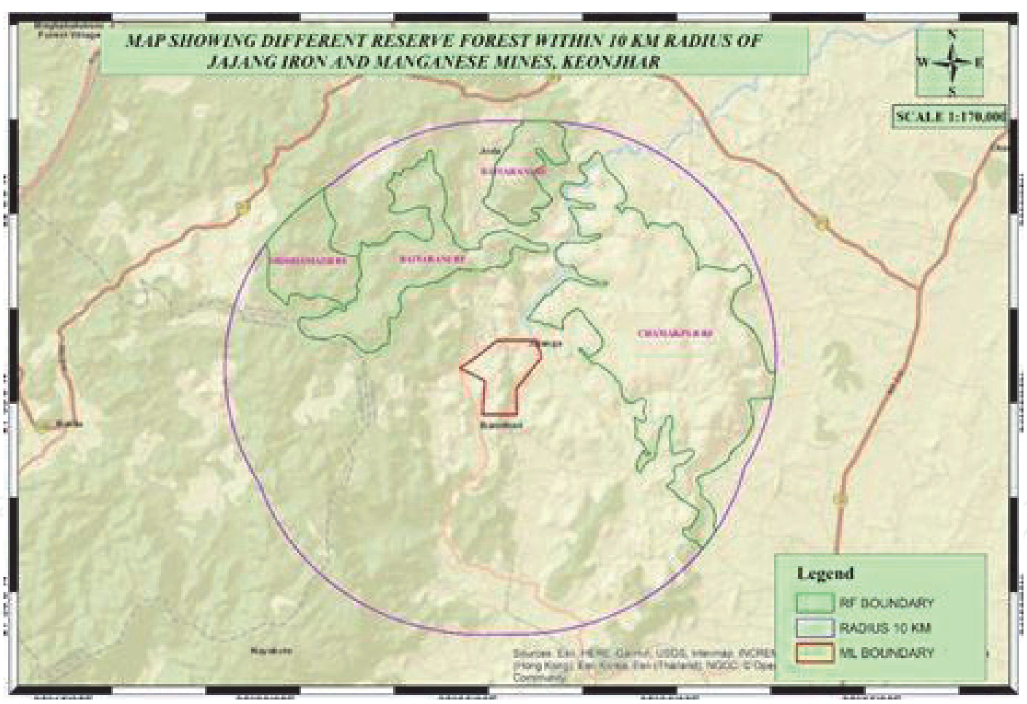

Figure 2.
Outline map within 10 km radius of Jajanga iron and manganese ore mine at Keonjhar. RF: Reserve Forest, ML: Mining lease.

i. Forest area (FA): 247 ha, where mining activities have not yet been taken up and have natural vegetation in some parts (**Figure 3**).

ii. Dump Area (DA): 41.967 ha i.e. equal to 42 ha, where the waste and topsoil were dumped in the past (**Figure 4**).

iii. Mining Area (MA): 377.18 ha, where mining has been done (**Figure 5**).

Figure 3.
Forest area (FA) of JIMOM.

Figure 4.
Dump area (DA) of JIMOM.

Soil analytic report comprises of some physical and chemical parameters are used to validate the fertility and health status of soil in this area is presented in **Table 1**. Physical parameters (sand, silt and clay percentage) related to the development of soil structure indicated that the soil of the area is loamy with some proportions of silt and clay. The depth varies from shallow (0-30 cm) and medium (31–50 cm) to moderately deep (51-80 cm). Most areas have medium-depth soil. More than half of the area has moderate to good water holding capacity. Chemical parameters encompass pH, nitrogen, phosphorus, potassium and organic carbon mostly related to soil fertility inferred that the soil is slightly acidic and adequate in the required nutrient parameters (potassium, phosphorus and nitrogen) to afford plant growth [23].

Figure 5.
Mining activity at JIMOM.

Parameters	Values (Mean ± SD)
Sand (%)	68.5 ± 3.18
Silt (%)	15.3 ± 0.76
Clay (%)	16.2 ± 1.32
Bulk density (g/cm^3)	1.18 ± 0.065
Soil Moisture (%)	16.73 ± 1.17
WHC (%)	48.3 ± 3.6
pH	6.42 ± 0.46
Nitrogen (kg/ha)	163.07 ± 18.62
Phosphorus (kg/ha)	4.25 ± 0.66
Potassium (kg/ha)	279.92 ± 24.3
Organic Carbon (%)	3.8 ± 0.12

Source: Soil analysis report of Jajang iron and manganese ore mine (JIMOM); WHC: Water Holding Capacity.

Table 1.
Soil physico -chemical characters (mean ± SD) of the study site.

3. Methods

A field survey was carried out from June, 2015 to May, 2017 in FA, DA and plantation (P). One hundred and fifty quadrats of 20 m × 20 m in sizes were laid down randomly at FA to obtain data on the composition and phytosociological attributes of tree species. In each quadrat, trees (≥ 30 cm GBH) such as girth at breast height (137 cm above ground), height, canopy height, canopy width and regeneration (plants <10 cm GBH) were recorded [24]. Tree height and canopy height were measured from the ground to the tree tip and up to the height from where the branching of canopy starts, respectively using a height-measuring rod.

To measure the canopy width each tree was viewed below from all sides to identify the longest axis. The diameter 'd_1' or length of the longest axis passing through the center of the canopy/crown was measured followed by the length of the shortest axis or diameter 'd_2' perpendicular to the longest (first) axis. The two diameters were then averaged to determine the canopy width (in meter) as:

$$CW = d_1 + d_2/2 \tag{1}$$

Where, d_1 = length of the longest axis of each tree canopy and d_2 = Length of the shortest axis of each tree canopy perpendicular to the longest axis.

Shrub species from the FA were analyzed by placing two quadrats of 5 m × 5 m sizes nested within each quadrat laid down for tree species. The density and frequency of each shrub species enumerated from the FA were calculated as:

$$\text{Density} = \text{Total number of individuals of a species/Total number of quadrats studied} \tag{2}$$

$$\text{Frequency} = \text{Number of quadrats in which species occur/} \\ \text{Total number of quadrats studied} \tag{3}$$

The selection of shrub species from FA for restoration practice was recognized using relative index (RI) calculated as a sum of relative density (RD) and relative frequency (RF) [14]. Relative density (RD) is the study of the numerical strength of a species to the total number of individuals of all species and calculated as:

$$\text{Relative Density (RD)} = (\text{Number of individuals of a species/} \\ \text{Number of individuals of all species}) \times 100 \tag{4}$$

Formulae to calculate the relative frequency (RF) as:

$$\text{Relative Frequency (RF)} = (\text{Frequency of a species/Frequency of all species}) \times 100 \tag{5}$$

Unlike shrub and tree species, herbaceous species were analyzed by placing 300 numbers of 1 m × 1 m size quadrats each at FA and DA. Only abundance (A) was calculated for herbaceous species. The abundance which is an appreciation of the number of individuals of different species in a community is calculated as [25]:

$$\text{Abundance (A)} = \text{Total number of individuals of a species/} \\ \text{Total number of quadrats in which the species occurred} \tag{6}$$

In both FA and DA abundance of herbaceous species was estimated at regular intervals and categorized as rare, common and abundant. Further abundance rating (AR) was given to each herbaceous species. The rare species were rated as 1, while the common and abundant species were given a score of 2 and 3, respectively [26].

3.1 Species selection from forest

Tree species for restoration were selected in two phases. In the first phase, the top 15 species were selected based on the Importance Value Index (IVI). Remarking was given to each species based on the IVI. IVI was calculated as a sum of relative density (RD), relative frequency (RF), and relative dominance (RDo) [27, 28]. Formulae for measurement of RD and RF of tree species is similar to that of RD and RF of shrub species, but the relative dominance (RDo) of tree species was calculated as:

$$\text{Relative Dominance (RDo)} = (\text{Basal area of a species}/\text{Basal area of all the species}) \times 100 \tag{7}$$

The basal area which is regarded as an index of dominance of a species was calculated as:

$$\text{Basal area (BA)} = \pi r^2 \left(m^2\right) \tag{8}$$

$$\text{Importance Value Index (IVI)} = \text{RD} + \text{RF} + \text{RDo} \tag{9}$$

During the second phase of selection, regeneration potential was included. Tree species represented by more than 15 individuals per m^2 in the regeneration (seedling) stage (GBH $\leq$ 10 cm) were ranked 1, species having less than five number of individuals in the regeneration stage were ranked 3 and species having individuals in between 5 and 15 in the regeneration stage were ranked 2 [29]. Adding IVI and regeneration ranks, the top twelve tree species were selected for restoration. Shrub species were selected using relative index (RI) and herbaceous species on abundance ranking (AR).

3.2 Species selection from plantation

Tree species in "P" were selected based on their growth, productivity and adaptation. The growth was estimated using the size index [14] as:

$$\text{Size Index (SI)} = \text{Tree height (cm)} \times \text{gbh (cm)}. \tag{10}$$

Productivity potential of tree species was estimated using canopy index [14] as:

$$\text{Canopy Index (CI)} = \left(\text{Average canopy height} + \text{Average canopy width}\right) \times \text{no.of sample trees}. \tag{11}$$

Adaptation potential of species was evaluated as; species grown on the slopes were ranked 1, species grown on flat terrain were ranked 2, while those species are grown in valleys, stream bed or river bed were ranked 3 and 4, respectively. The species growing on shallow soils were ranked 1, while those on medium and deep soil were ranked 2 and 3, respectively. Adding the ranks for growth, productivity, terrain and soil, the top ten species were selected. Some species were included based on their properties to enrich the soil.

3.3 Economic rank (ER) of tree species selected for plantation

The economic rank of tree species was considered as an additional criterion to strengthen the process of tree species selection from mining forest areas and plantation for plantation in the mining waste site of JIMOM. To analyze the economic rank of tree species selected from FA and P for plantation the local people and forest officials were consulted and interviewed during the field visit days. Based on local use types (food, animal feed, timber, gum, edible fruit, ethnomedicine, edible oil, etc.) of such plant species for livelihood subsistence of the local community and industrial purposes their economic rank was calculated. As ER was an ordinal variable, it took values >0 and varied from 1 to 3. Species having a maximum number of economic uses were ranked as 1 and those having a minimum number of economic uses were ranked as 3. The other ones of economic uses intermediate between maximum and minimum were ranked as 2.

4. Results and discussion

4.1 Species richness and abundance

The study explored the presence of 67 plant species of 26 angiospermic families and 51 genera belonging to different strata i.e. tree, shrub and herb from FA, P and DA of Jajang Iron and Manganese Ore Mine (JIMOM) (**Tables 2–4**). From FA 62 plant species were recorded which includes 34 trees, 6 shrubs and 22 herbaceous species (**Tables 2–4**). However, in plantation only12 tree species were recorded. The number of tree species enumerated in FA was more or less 3 times of P. Tree species found similar to both FA and P are *Acacia nilotica*, *Samanea saman*, *Albizia lebbeck*, *Dalbergia sissoo*, *Madhuca indica*, *Gmelina arborea* and *Xylia xylocarpa*. Of these, *Samanea saman*, *Dalbergia sissoo*, *Albizia lebbeck* and *Gmelina arborea* performed better in “P” only. On the other hand, *Xylia xylocarpa* performed well in both. Compared to tree and herb layers, the diversity of the shrub layer in terms of the number of species was too low. Only six species of shrubs from families Lythraceae, Sterculiaceae, Oleaceae, Rubiaceae, Flacourtiaceae and Fabaceae were recorded from FA (**Table 3**). In the herb layer, all the 22 species were enumerated both from FA and DA and included under 3 families namely Caryophyllaceae, Cyperaceae and Poaceae. Based on species dominancy family Poaceae was species rich followed by Cyperaceae and Caryophyllaceae (**Table 4**). High species richness of trees in FA as compared to plantation may likely due to the high level of structural complexity and stratification of vegetation to attract wild animals which acts as the seed dispersers required for seed germination. Dispersal of seeds spatially by the dispersers to a greater extent and germination of seeds in newly arrived areas may one of the ways to maintain high species richness in FA. Inversely low species richness of trees in plantations may be due to lack of seed source and litter deposition and decomposition on the soil surface of plantation [30]. Further Plantations are mostly monocultures or include few species of interest leads to low species richness [4, 29].

4.2 Tree species selection from FA and “P”

Species selection from different vegetation layers of FA for plantation at mine waste sites (DA) through the use of some phytosociological parameters (abundance, frequency, IVI, etc.) is vital as a first step and was amplified by studying the economic use and regeneration status of trees, RI of shrubs and AR for herbs, respectively to reveal the suitability of species to survive in the existing edaphic and environmental conditions of mine waste sites. In the tree layer *Holarrhena antidysentrica* had maximum IVI followed by *Mitragyna parviflora, Anogeissus latifolia, Adina cordifolia, Buchnania lanzan, Lannea coromandelica, Miliusa velutina, Xylia xylocarpa* and *Bridelia retusa.* These tree species had IVI greater than 7. The rest of the species had IVI ranged from 0.31 to 5.78. The top 15 species with higher

Name of species	Family	IVI	Rank
Holarrhena antidysentrica (L.) Wall. Ex A. DC.	Apocynaceae	15.75	1*
Mitragyna parviflora (Roxb.) Koth.	Rubiaceae	15.40	2*
Anogeissus latifolia (Roxb. ex DC.) Wall. ex Bedome	Combretaceae	12.12	3*
Adina cordifolia (Roxb.) Brandis	Rubiaceae	10.96	4*
Buchnania lanzan Spreng.	Anacardiaceae	10.46	5*
Lannea coromandelica (Houtt.)Merr.	Anacardiaceae	10.44	6*
Miliusa velutina (Dunal) Hook. f. &Thomas	Annonaceae	9.91	7*
Xylia xylocarpa (Roxb.)Taub.	Mimosaceae	9.36	8*
Bridelia retusa (L.) Spreng.	Euphorbiaceae	7.19	9*
Schleichera oleosa (Lour.) Oken	Sapindaceae	5.78	10*
Syzygium cumini (L.) Skeels	Myrtaceae	4.89	11*
Garuga pinnata (Roxb.)	Burseraceae	4.65	12*
Wendlandia tinctoria (Roxb.) DC.	Rubiaceae	4.34	13*
Shorea robusta Gaertn. f.	Dipterocarpaceae	4.23	14*
Terminalia bellirica (Gaertn) Roxb.	Combretaceae	2.73	15*
Terminalia alata Heyne ex Roth.	Combretaceae	2.50	16
Dalbergia sissoo Roxb.	Mimosaceae	2.41	17
Elaeodendron glauca (Rottb) Pers.	Celastraceae	2.21	18
Morinda pubescens Sm.	Rubiaceae	2.13	19
Cassia fistula L.	Caesalpiniaceae	1.86	20
Madhuca indica Gmel.	Sapotaceae	1.55	21
Samanea saman (Jacq.) Merr.	Mimosaceae	1.43	22
Lagerstroemia parviflora Roxb.	Lythraceae	1.37	23
Butea monosperma (Lam.) Taub.	Fabaceae	1.22	24
Terminalia arjuna (Roxb. Ex DC.) Wight &Arn.	Combretaceae	1.2	25
Trema orientalis Linn. Blume	Ulmaceae	1.18	26
Albizia lebbeck (L.) Benth.	Mimosaceae	1.15	27
Acacia nilotica (Linn.) Willd. Ex Del.	Leguminosae	1.11	28
Pongamia pinnata (L.) Pierre	Leguminosae	1.08	29
Phyllanthus emblica L.	Euphorbiaceae	1.05	30
Hymenodictyon excelsum (Roxb.) Wall	Rubiaceae	0.58	31
Bauhinia racemosa Lam.	Caesalpiniaceae	0.46	32
Terminalia chebula Retz.	Combretaceae	0.41	33
Gmelina arborea Roxb.	Simaroubaceae	0.31	34

**Species selected for restoration.*

Table 2.
Importance value index (IVI) of tree species recorded in forest area (FA) of Jajang iron and manganese ore mine.

IVI values were selected from FA for economic use and regeneration studies. Considering all the criteria (IVI, economic rank (ER) and regeneration rank) of species selection, tree species selected from FA for plantation are presented in **Table 5**. To

Name of the species	Family	RI	Rank
Woodfordia fruticosa (L.) Kutz.	Lythraceae	23.71	1
Helicteres isora L.	Malvaceae	20.81	2
Nyctanthes arbortristis L.	Oleaceae	17.31	3
Wendlandia exerta (Roxb.) DC.	Rubiaceae	15.29	4
Flacourtia indica (Burm. f.) Merr.	Flacourtiaceae	13.17	5
Cassia auriculata L. (Roxb.)	Fabaceae	11.87	6

Table 3.
Relative index (R.I.) of shrub species at Jajang iron and manganese ore mine.

Name of the species	Family	Abundance	Rank
Apluda mutica L.	Poaceae	4	6*
Aristida setacea Retz.	Poaceae	6	4*
Cynodon dactylon (L.) Pers.	Poaceae	3	7*
Chloris barbata Sw.	Poaceae	6	4*
Chloris virgata Sw.	Poaceae	8	2*
Cryperus compressus L.	Cyperaceae	9	1*
Cyperus difformis L.	Cyperaceae	4	6*
Cyperus eleusiniodes (Lunth.) Haines	Cyperaceae	3	7*
Cyperus iria L.	Cyperaceae	3	7*
Cyperus sp.	Cyperaceae	2	8
Dactyloctenium aegyptium (L.) Beauv.	Poaceae	7	3*
Digitaria marginata Linn.	Poaceae	7	3*
Oplismenus burmannii (Retz.) Beauv.	Poaceae	2	8
Isellema laxum Hack.	Poaceae	5	5*
Dianthus sp.	Caryophyllaceae	2	8
Dichanthium annulatum Forsk.	Poaceae	4	6*
Paspalidium punctatum (Burm.) *A. Camus*	Poaceae	3	7*
Pennisetum sp.	Poaceae	1	9
Setaria verticillata (L.) Beauv.	Poaceae	5	5*
Sporobolus indicus (Linn.) Chase	Poaceae	2	8
Sporobolus sp.	Poaceae	2	8
Themeda arundinaceae (Roxb.) A. Camus	Poaceae	3	7*

**Species selected for restoration.*

Table 4.
Abundance rating (AR) of herbaceous species at Jajang iron and manganese ore mine.

rehabilitate the mine waste sites tree species selected as the planting material may not only act as one of the successful methods of ecorestoration but also establish an ecological condition for nutrient cycling in soil nutrient amelioration as well as create an ecological avenue for attracting avifauna and other wildlife to congregate in this area. Further, in the future, this ecologically restored area should be used

Name of the species	IVI		Regeneration rank	Multiple economic uses	Economic Rank (ER)	Total rank
	Value	Rank				
Holarrhena antidysentrica	15.75	1*	1	WS, AI,D, CM, P,M	1	3
Mitragyna parviflora	15.40	2*	1	HC, F, AI, M	2	5
Anogeissus latifolia	12.12	3*	1	HC, BF, FW, AI, M	2	6
Adina cordifolia	10.96	4*	2	FW,AF, M, AI	2	8
Buchnania lanzan	10.46	5*	2	BF, EF, M, FW	2	9
Lannea coromandelica	10.44	6*	2	AF, FW,G,M	2	10
Miliusa velutina	9.91	7*	1	FW, M	3	11
Xylia xylocarpa	9.36	8*	2	HC, BF, AF, EF, M	2	12
Bridelia retusa	7.19	9*	1	F, FW, HC, AI, M	2	12
Schleichera oleosa	5.75	10*	1	F, MO, EO, EF, FW, M	1	12
Syzygium cumini	4.89	11*	3	FO, CL,F, AI, EF, M	1	15
Garuga pinnata	4.65	12*	2	EF, F, G, FW	2	16
Wendlandia tinctoria	4.34	13*	1	M, AT	3	17
Shorea robusta	4.23	14*	3	W, AI, T, EO, M	2	19
Terminalia bellirica	2.73	15*	2	G, M	3	20

HC, House Construction; F, Furniture; AI, Agricultural Impliments; BF, Bio Fencing; P, Paper; AT, Arrack & Toddy; WS, Walking Stick;FW, Fuel Wood; M, Medicine; G, Gum; CL, Country Liquor; EF, Edible Fruit; CM, Carved Material;D, Dye; AF, Animal Feed; MO, Message Oil;EO, Edible Oil; W, Wood; T, Toothbrush.

Table 5.
Multiple economic uses, importance value index, regeneration and economic ranks of tree species in mine forest at Jajang iron and manganese ore mine.

to maintain socioeconomic goals (productivity) and to fulfill the biodiversity objectives.

Unlike FA, instead of IVI and regeneration rank important growth related parameters like growth rate and productivity of tree species at "P" was considered along with ER, terrain and soil depth to select species for plantation at mine waste sites. The age of tree species years after the plantation was ranged from 3 to 6 years. *Gmelina arborea* was the fast-growing species with a maximum growth rate (3867 cm^2/year) with minimum ER while *Xylia xylocarpa* gained maximum productivity (48 cm^2/year) and ER (**Table 6**). When adaptation to terrain and soil depth was included in the selection parameter, *Samanea saman* shared the top rank followed by *Flindersia australis*, *Dalbergia sissoo*, *Xylia xylocarpa*, *Albizia lebbeck* = *Peltophorum pterocarpum*, *Gmelina arborea*, etc.

Parameters used for the choice of species were to assess their ability to adapt and thrive in challenging environmental conditions. The inclusion of more than one parameter ensures that even if two species scored the same on one parameter, the difference in scores on other parameters assisted in deciding which species was the best. Aside from parameter selection, selecting species for plantation from several sampling locations (FA and P) aided in the development of a comprehensive list of species based on their performance in a variety of habitats. Only 12 tree species were grown in plantations, out of which 7 species did occur in FA and most of the species were native to the area. On the other hand, the FAs' comparatively large number of species contributed to more options for the selection of species. The top-performing native species in the neighborhood from a cumulative list of 21 tree

Tree species	Age	Growth rate GR/Y	Growth rate Rank	Productivity rate P/Y	Productivity rate Rank	T Rank	S Rank	Multiple economic uses	Economic Rank (ER)	Total Rank
Acacia auriculiformis	5	1862	11	28	11	2	1	D, FW, M	2	27
Acacia nilotica	4	1973	10	26	12	2	1	D, AF, FW, M	2	27
Samanea saman	6	3567	2	36	4	2	1	AF,FW,G	2	11
Albizia lebbeck	4	2963	5	32	7	2	1	HC, F, AI, M	2	17
Casia siamea	4	1435	12	31	8	1	1	D, FW	3	25
Dalbergia sissoo	4	2595	7	44	2	1	2	F, HC, M	2	14
Delonix regia	6	2147	9	35	5	2	3	D, FW	3	23
Flindersia australis	3	3279	3	42	3	2	1	F, HC	3	12
Madhuca indica	4	2888	6	29	10	1	1	CL, EO, M	2	20
Gmelina arborea	6	3867	1	30	9	2	3	F, AI, M	2	17
Peltophorum pterocarpum	4	3215	4	33	6	2	3	D, FW, M	2	17
Xylia xylocarpa	4	2583	8	48	1	2	3	HC, BF, AF, EF, M	1	15

GR/Y, growth rate/year; P/Y, Productivity/year; T, Terrain; S, Soil.
HC, House Construction; F, Furniture; AI, Agricultural Impliments; BF, Bio Fencing; FW, Fuel Wood; M, Medicine; G, Gum; CL, Country Liquor; EF, Edible Fruit; D, Dye; AF, Animal Feed; EO, Edible Oil.

Table 6.
Growth (cm²/year), productivity (cm²/year), terrain, soil and economic ranks of tree species at Jajang iron and manganese ore plantation area.

species, 11 from FA, 9 from plantations and one species common to both i.e. *Xylia xylocarpa* to encourage natural colonization (**Table 7**).

Furthermore, the study suggests that growing leguminous plants, which give nitrogen to the root zone in mine spoil, would be more beneficial in increasing mining wasteland fertility [19]; [33]. A*lbizia lebbeck, Acacia auriculiformis* and *Acacia nilotica* are the species with strong nitrogenous activity in root nodules [6]; [34]. As a result, these tree species are recommended for planting on dumps and in degraded environments. In addition to these *Pongamia pinnata* is regarded as one of the most promising plants for mining overburden [35, 36] and should be planted on the mining waste site to enrich the soil. Critical analysis of the study envisages that tree species like *Samanea saman*, *Flindersia australis, Gmelina arborea* and *Peltophorum pterocarpum* are the topmost selected ones from "P" may do well when planted on dumps, as suggested. The list of tree species that have been suggested for plantation or revegetation both from mining forest and plantation based on the results of the present investigation and their unique ecological features to ameliorate the degraded conditions is presented in **Table 7**.

4.3 Shrub and herbaceous species selection

The relative index (RI) of shrub species in the FA ranged from 11.87 to 23.71. *Woodfordia fruticosa* had the highest RI followed by *Helicteres isora*, *Nyctanthes*

Species	Characteristics*	From mining forest area	From plantations
Holarrhena antidysentrica	Drought tolerant, light demander, fire tolerant and pioneer species	√	
Mitragyna parviflora	Esthetic, easy to grow, industrial woodware and wind breaker	√	
Anogeissus latifolia	Drought resistant, grow in well drained and low fertility soil and acts as soil stabilizer	√	
Adina cordifolia	Prefers moist and well drained soil,soil binder and drought resistant	√	
Buchnania lanzan	Light demander, prefers dry soil and grow in hill slopes	√	
Lannea coromandelica	Grow in poor soil condition and fire resistant	√	
Miliusa velutina	Grow in dry soil and drought resistant	√	
Xylia xylocarpa	Grow in adverse environmental conditions and nitrogen fixer	√	√
Bridelia retusa	Fast growing and fire resistant	√	
Schleichera oleosa	Slow growing, fire resistant grow in well drained and acidic soil, and light demander	√	
Syzygium cumini	Fast growing, drought tolerant and grow in shallow and rocky soils	√	
Garuga pinnata	Grow in well drained soil having moderate fertility and prefers acidic to neutral soil pH	√	
Samanea saman	Fast growing, prefers moderately to acidic soil, drought tolerant and nitrogen fixer		√
Flindersia australis	Fast growing, light demanding and grow in wide range of soil		√
Dalbergia sissoo	Leguminous, dust resistant and nitrogen fixer		√
Albizia lebbeck	Leguminous, Nitrogen fixer and soil binder		√
Peltophorum pterocarpum	Fast growing, nitrogen fixer and used as shelter belts		√
Madhuca latifolia	Grow in loamy and sandy loam soil and drought resistant		√
Gmelina arborea	Nitrogen fixer		√
Delonix regia	Fast growing, drought resistant and nitrogen fixer		√
Cassia siamea	Easy to grow, fast growing and nitrogen fixer		√

Source: [31, 32].

Table 7.
Tree species suggested for plantation on dumps.

arbor-tristis, *Wendlandia exerta* and *Flacourtia indica* while C*assia auriculata* had the lowest RI (**Table 3**). All six species enumerated were suggested for use in rehabilitation efforts. In the understorey in addition to shrubs the floristic inventory of herbaceous species of the study area revealed that Poaceae had the maximum number of species indicating that members of this family had the greatest potential to colonize adverse iron and manganese mine spoil habitat. The ability of herbaceous species, particularly grass species to withstand drought, poor soil nutrients and climatic conditions [37] may play a role in their colonization on mine spoils. Many researchers have emphasized the significance of grasses as the first colonizers during the restoration of mine land [38–40]; [29]. Grassroots with their fibrous root systems, are said to help limit erosion, stabilize soil and conserve moisture [37]. Furthermore, the importance of grass species cover as nurse crops for later colonizers has been extensively documented [29, 40, 41]. Aside from the importance of species rich families of herbaceous species for restoration, measuring one of the key phytosociological attributes i.e. abundance of such species was considered as a tool or criteria to select the key species from the group of this plantlife form that can be successfully applied to the development of mining waste site restoration strategies. Analytical results on herbaceous species abundance in the mining forest area ranged from 1 to 9 with *Cyperus compressus* being the most abundant followed by *Chloris virgata*, *Dactyloctenium aegypticum* = *Digitaria marginata*, *Chloris barbata* = *Aristida setacea*, *Setaria verticillata* = *Isellema laxum* and so on. *Pennisetum* sp. on the other hand had the minimum (**Table 4**). Based on the abundance value and its rating the top sixteen herbaceous species from the mining forest region were selected for restoration activity (**Table 4**). As reported by [12]; [42] planting selected native herb species on the periphery of dumps or mine waste sites and streambeds can operate as a vegetative filter to reduce soil and water pollution in the surrounding areas. Herbs are preferably more successful than agroforestry crops at preventing runoff and erosion [34, 43]. As a result native herb species are recommended for the mine wast sites at the initial phase of restoration in this study. The slope gradient was one of the factors considered when selecting plant species for restoration. On the slopes, the herbaceous species named *Setaria verticillata*, *Themeda arundinaceae* and *Dactyloctenium aegyptium* were found abundant. Therefore, these plant species should be grown on mine waste slopes. As the soil physicochemical characters of mine waste sites were comparable to those of FA and P, and 70 cm of top soil was stored separately for spreading over dumps during resolution, the selected plant species will grow successfully on the mine waste sites or slag hips. These herbaceous species selected based on taxonomic and phytosociological attributes for the eco-restoration program may not only grow and spread in these locations but also provide food sources for local fauna and help to recover ecosystem services for local communities.

5. Conclusion

To restore the biological quality of the degraded areas of Jajang Iron and Manganese Ore Mine (JIMOM), revegetation with native or indigenous plant species selected from the mine forest area (FA) and plantation (P) constitutes the most effective, useful, and widely accepted way of ecological restoration of mining degraded lands to reduce soil erosion and protect the soils against degradation. Before revegetation, plant selection is very important for an effective restoration strategy. Plants need to be selected for restoration based on the study of their IVI, regeneration potential, economic rank, growth rate, productivity, relative index, abundance rank and their ability to survive and regenerate in the local, specific environment, and to stabilize the soil structure. Inhabitation of the land with different native or indigenous plant species enables the association of microorganisms which are fundamental to maintain soil quality through the decomposition of organic matter and nutrient cycle. The results of the study signify that the selective species of three different plant life forms such as trees (*Holarrhena antidysentrica, Mitragyna parviflora, Anogeissus latifolia, Adina cordifolia, Buchnania lanzan, Lannea coromandelica, Miliusa velutina, Xylia xylocarpa, Bridelia retusa,* etc. from mining forest area and *Samanea saman, Flindersia australis, Dalbergia sissoo, Albizia lebbeck, Peltophorum pterocarpum, Madhuca latifolia, Gmelina arborea, Delonix regia, Cassia siamea* from plantation), shrubs (*Woodfordia fruticosa, Helicteres isora, Nyctanthes arbor-tristis*, *Wendlandia exerta, Flacourtia indica* and *Cassia auriculata*) and herbs (*Cyperus compressus, Chloris virgata*, *Dactyloctenium aegypticum*, *Digitaria marginata*, *Chloris barbata*, *Aristida setacea*, *Setaria verticillata*, *Isellema laxum*, etc.) for plantation or afforestation can potentially enhance the recovery of mine degraded lands. This study not only provides an insight to restore the mining degraded lands of JIMOM but also facilitates the natural process of speciation and becomes a source of germplasm of various species. It improves all environmental conditions esthetically including economical aspects. Further, the ecorestoration approach described in this paper is also to be recommended for the environmental management of degraded mining lands. From a future restoration point of view and to strengthen the restoration practice in revegetated degraded mining lands of JIMOM monitoring of soil physicochemical parameters will be made at regular intervals to indicate the change in soil nutrient status of the restored area. In addition to this monitoring of vertebrate faunal communities and their association with plant life forms in restored areas may also be important in understanding the overall effects of restoration work and maintaining the biological diversity of the area for future prospects. Such scientific investigations will boost further restoration practice and also useful in a way to reduce high rates of forest destruction, energy shortages, and steps towards conservation of biological resources.

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