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Original Research Article

Species Diversity and Vegetation Structure of Gorumahisani Iron Ore Mines, Mayurbhanj, Odisha

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Abstract: The human influences on biodiversity and ecosystem functioning have deleterious impacts resulting in significant changes in land and resource sustainability. An understanding of the impact of mining on the environment particularly on vegetation characteristics is a prerequisite for further management of these mining sites, especially in the selection of species for reclamation works. The present paper deals with the study of the angiosperm flora composition of the iron mining area of Gorumahisani forest, at both core and buffer zone. The vegetation sampling and data analysis were done following standard procedures. A total of 106 plant species were encountered in Gorumahisani iron ore mines. Thirty-eight species were recorded in the core zone and include 13 trees, 16 shrubs and 9 herbaceous species. Ninety-four plant species were documented in the buffer zone and include 57 trees, 22 shrubs, and 15 herbs. Different diversity indices (Shannon-Weiner, Simpson dominance, and Evenness Index) reveal variation among the tree, shrub, and herb species. Vegetation analysis showed a drastic reduction of plant species in the core zone compared to that of the buffer zone. It is evident from the study that there are few plant species present in the buffer zone of Gorumahisani. These species are likely to be affected by mining projects and other related activities like road construction, blasting, excavation for mining, and dumping of excavated material. The present study led to the conclusion that phytosociological analysis can be used as an important tool for predicting the suitability of mined habitats for plant growth.

Key words: Biodiversity, buffer zone, core zone, diversity indices, floristic composition, phytosociological study

Introduction

The diverse resources of the earth are extensively exploited to improve the quality of human life. Mining is one such resource that involves the extraction of minerals from the earth's crust. Metals such as iron have been mined for a long time, while others such as aluminum is recently mined (Reardon, 2011). Global trends in iron and steel consumption show higher consumption of metals in America, the European Union, China, and India than extraction which relates to the economic growth of these countries. The reserves of these metals (e.g. Fe is 5% of Earth crust) largely exceed the amounts already extracted and will ensure the availability of these resources for a long time (USGS, 2017). Demand for minerals also poses significant risks (Murguía, 2016), particularly where mineral resources and biodiverse old-growth forests co-exist in developing countries that seek revenue from mining but lack regulatory oversight and enforcement capability (Laurance *et al.,* 2012). Mining affects biodiversity at multiple spatial scales (site, landscape, regional and global) through direct (i.e.

mineral extraction) and indirect processes (via industries supporting mining operations, and external stakeholders who gain access to biodiversity-rich areas as the result of mining), and in some cases singlehandedly causing region-wide declines in rare and threatened species and ecosystems (Jacobi *et al.,* 2007). Mining causes deforestation both within and beyond the lease boundaries. Within leases, forests are cleared for mineral extraction, processing, and infrastructure development (Sonter *et al.,* 2014). However, off-lease impacts are potentially more extensive and their pathways more complex, (Duran *et al.,* 2013; Ferreira *et al.,* 2014; Sonter *et al.,* 2014). Deforestation may extend substantial distances (> 10 km) beyond lease boundaries (Duran *et al.,* 2013; Sonter *et al.,* 2014), due to the combined effects of land use displacement (Schueler *et al.,* 2011), urban expansion (Mwitwa *et al.,* 2012), development of commodity supply chains (Sonter *et al.,* 2015), and concerns over mine waste discharge (Edwards *et al.,* 2014) and spills (Edwards and Laurance, 2015). It is essential to understand and mitigate mining-induced deforestation if tropical forests are to be conserved (Sonter *et al.,* 2014).

India is one of the countries endowed with the richest iron ore deposits in the world and ranks 5^{th} position in the production of iron ore accounting for about 8 percent of the global output. Odisha, one of the eastern states of India is known as one of the most mineral-rich states of India having more than 35% of the country's iron ore resources with 5231 million tonnes of iron ore. The mineral resources of the state are widely distributed covering 25 districts out of 30 districts. But the mining activities are being undertaken wildly in six districts i.e. Keonjhar (31.28%), Sundergarh (20.03%), Angul (10.24%) followed by Jharsuguda (8.87), Koraput (6.3%) and Mayurbhanj. The iron ore deposits of Orissa are found in five distinct geographic zones; (1) Bonai-Keonjhar,(2) Gandhamardhan, (3) Tomka-Daitari, (4) Hirapur and (5) Gorumahisani-Badampahar. Most of Orissa's mineral deposits are in forests that are inhabited by tribal populations and harbor rich biodiversity. Mineral extraction, therefore, has disproportionately affected forest ecosystems and the forest-dwelling population. The impact of mining on natural ecosystems, biodiversity, and tribal livelihoods has become a key concern and source of conflict in Odisha. The exploration and exploitation phases of metal mining decrease biodiversity primarily through deforestation, disturbance from road construction, and associated river sedimentation (Gross, 2017; Sonter *et al.,* 2017). Restoration of biodiversity and ecosystem services in post-mining and post-industrial sites has received wide attention among restoration scientists. An understanding of the impact of mining on the environment particularly on vegetation characteristics is a prerequisite. Although reports related to the floristic composition of the mining areas are available in different parts of the country (Dubey and Dubey, 2011; Kumar, 2013; Jhariya *et al.,* 2016) including Odisha (Chaturvedi and Patra, 2016; Mishra and Patra, 2017) but no work has been done in Gorumahisani iron ore mining of Mayurbhanj district, Odisha, India. We focus here primarily on the impact of mining over existing plant biodiversity and to recommend the proper strategies for its conservation.

Materials and Methods

Study Area

The Gorumahisani iron ore mines (860 14' 40.74521" to 860 17' 21.67649 E and 220 18' 12.05986" to 220 20' 28" N) cover an area of 349.50 ha is located in Mayurbhanj district of Odisha (Fig. 1). This is one of the major deposits of iron ore Gorumahisani, Badampahar, Suleipat hill range. The mine falls in the survey of India Toposheet No 73 J/7. The mine is located in the village Kuleisila, Badamounda, Sanamounda, Sundhal, Balitangi, Nodhabani and Gorumahisani R.F. The lease area is 349.50 ha out of which 90.5 ha belongs to the reserve forest category, 81 ha has been diverted by the lessee for mining purposes. The eastern part of the lease area represents rugged topography. The altitude varies from 480m to 906 m above MSL. The western part is mostly plain land. In the western part, altitudes vary from 290 m to 350m. Most of the area in this region has been degraded/utilizes for quarrying, dumping, etc. The climate of the area is subtropical with an annual rainfall of 1100 mm. The range of temperature is found to be 9^{0}C to 45.5^{0} C. Relative humidity varies from 20

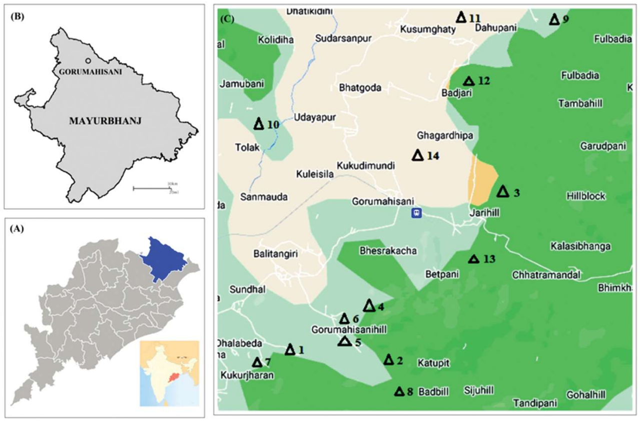

Fig. 1. (A) Map of Odisha state showing Mayurbhanj district (B) Map of Mayurbhanj district showing Gorumahisani region (C) study area (Δ) of core and buffer zone 1. Rajpal Dumping Site (22°18'48.35"N and 86°16'24.94"E) 2. Back side of Katupit (22°18'11.01"N and 86°17'13.39" E) 3.Hill Block (22°18'32.26"Nand86°17'08.16"E) 4. Kachar west(22°18'19.03"N and 86°16'57.02"E) 5. Near Shiva Temple (22°18'56.87"N and 86°16'52.86"E) 6. L- Level (22° 19'11.49"N and 86°16'49.93"E)7. Near Hickeysahi Primary School (22°18'19.57"N and 86°15'54.11" E) 8. Badbil village (22°18'15.96"N and 86°18'20.83"E) 9. Kautika village (22° 23'13.79"N and 86°18'55.53"E) 10. Kapili village (22°21'20.47"N and 86°14'24.62"E) 11. Kusumghati (22°22'48.12"N and 86°18'23.75"E) 12. Badjari village (22°21'25.55"N and86°18'20.44"E)13. Betpani village (22°19'12.89"N and86°18'33.55" E) and 14. Kukudamundi village (22°21'03.57"N and 86°18'20.44"E)

Fig. 2. Core zone of Gorumahisani mining area

to 96 %. Various mining operations such as drilling, blasting, excavation transportation are being adopted.

Methods

Two sites (Core zone and buffer zone) of about hundred hectares each were selected for the present investigation. Core zone was the disturbed sites (mined sites) where active mining operation is going on (Fig. 2). Adjacent to core area where

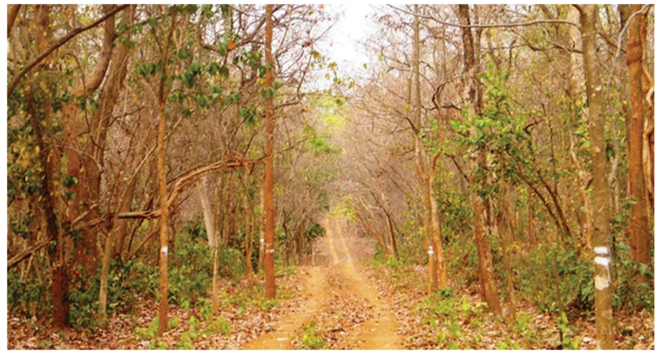

Fig. 3. Buffer zone of Gorumahisani mining area.

mining activities was less represent the buffer zone (Fig. 3). In order to assess the baseline status of the flora of the core and the buffer zones, a detailed survey of the flora of the mine lease area (MLA) and its environment extending up to a radius of 10 km was carried out from June 2017 to May 2019 (Table 1). The phytosociological study was carried out following the random quadrate sampling method (Misra, 1968). Ten quadrates were taken in both cases covering rainy and winter season i.e. from September to December. In order to accommodate the maximum representation of different types of plant species, sample plots were laid in selected places in different parts of the mining area that contain natural vegetation. For this purpose the entire area of 100 ha. was divided into 10 segments. In each segment a sampling area of 400 m^2 with length and breadth of 20m and 20m respectively were measured. All plants above 3m tall were recorded by measuring girth at breast height (GBH) species wise. For bushes, shrubs (less than 3m tall) a sampling area of 25 m^2 (5m × 5m) was nested inside the aforementioned 400m^2 plot. The sampling plot of 1 m^2 (1m × 1m) area was also nested inside the 25m^2 plots to make an inventory of all herbaceous vegetation.

The vegetation data were quantitatively analyzed following standard procedures (Curtis and McIntosh, 1950, Mishra, 1968). The girth was measured using 2m tape. The height of small trees and shrubs was measured using a 5 m graded pole. When the height exceeded 5 m it was estimated visually. For calculating the basal area of multi-stemmed trees, the girth of each stem was measured individually and added up. The economic uses of plant species if any were discussed

Table 1. List of study sites with zone, number of quadrates, elevation, latitude and longitude.

Sl. No.	Name of the Site	Zone	No. of Quadrates	Elevation	Latitude	Longitude
			Latitude & Longitude for quadrate study			
1.	Rajpal Dumping Site	Core zone	02	622 mt.	22° 18'48.35" N	86°16'24.94" E
2.	Back side of Katupit	Core zone	02	719 mt.	22° 18'11.01" N	86°17'13.39" E
3.	Hill Block	Core zone	02	899 mt.	22° 18'32.26" N	86°17'08.16" E
4.	Kachar west	Buffer zone	01	722 mt.	22° 18'19.03" N	86°16'57.02" E
5.	Near Shiva Temple	Core zone	02	600 mt.	22° 18'56.87" N	86°16'52.86" E
6.	L- Level	Core zone	02	535 mt	22° 19'11.49" N	86°16'49.93" E
7.	Near Hickeysahi Primary School	Buffer zone	01	355 mt	22° 18'19.57" N	86°15'54.11" E
8.	Badbil village	Buffer zone	01	566 mt.	22° 18'15.96" N	86°18'20.83"E
9.	Kautika village	Buffer zone	01	355 mt.	22° 23'13.79" N	86°18'55.53" E
10.	Kapili village	Buffer zone	01	299 mt.	22° 21'20.47" N	86°14'24.62" E
11.	Kusumghati	Buffer zone	02	325 mt.	22° 22'48.12" N	86°18'23.75" E
12.	Badjari village	Buffer zone	01	364 mt.	22° 21'25.55" N	86°18'20.44" E
13.	Betpani village	Buffer zone	01	412 mt.	22° 19'12.89" N	86°18'33.55" E
14.	Kukudamundi village	Buffer zone	01	329 mt.	22° 21'03.57" N	86°18'20.44" E

with the local people. Plant samples were identified or confirmed with available regional floras (Saxena and Brahmam, 1996). Phytosociological parameters indicated below were analyzed by the following methods and formulas (Curtis, 1959, Mishra, 1968).Species diversity indices like Shannon-Wiener Index (H'), Simpson's Index (D) and evenness index (E) were calculated as per Magurran (1988). Formulae used for various calculations are as given below:

Formulae used for various calculations are:

Density = Total number of individuals of a species in all quadrates/Total number of quadrates studied

Frequency (%) = Number of quadrates in which the species occurred/Total number of quadrates studied x100

Abundance = Total number of individuals of a species in all quadrates/Total number of quadrates in which the species occurred

Relative Density = (Density of the species)/(Total density of all the species) x 100

Relative Frequency = (Number of sample plots with a sighting of a species) /(Total number of sample plots) x 100

Relative Dominance = (Total basal area of a species) / (Total basal area for all species) x 100

IVI = Relative Density + Relative Frequency + Relative Dominance

Species diversity indices like Shannon-Wiener Index (H) Simpson Index (D) and evenness index were calculated as per Magurran (1988) using following formulae:-

Shannon –Wiener index $H = -\Sigma_{i=0}^{s} Pi ln Pi$

where Pi is the proportion of the individual found in the i[th] species, ln denotes natural logarithm and H is the Shannon –Wiener index .

Simpson's index $D = \Sigma_{i=0}^{s} (Pi)^2$

Where is the proportion of the individual found in the i[th] species and D Simpson's index

Evenness index (E) = H/S

Where H is the Shannon –Wiener index of diversity, S total number of species and is the natural logarithm.

Results

A total of 106 plant species were encountered in Gorumahisani iron ore mines. Thirty-eight species were recorded in the core zone and include 13 trees, 16 shrubs, and 9 herbaceous species (Table 2-4). The relative density of tree species varied from 2.26 to 19.77, relative frequency 4.65 to 11.62, relative dominance

Table 2. Frequency (F), density(D), quadrate (q), abundance (A), relative frequency (RF), relative density (RD), relative dominance (RDo) and importance value index (IVI) of tree species in core zone of Gorumahisani mining area.

Sl. No.	Botanical name	F (%)	D/q	A	RF	RD	RDo	IVI
1	*Acacia aurculiformis* Benth.	50.00	4.00	8.00	6.97	13.56	15.55	36.08
2	*Aphanamixis polystachya* (Wall.) Parker	33.33	0.67	2.00	4.65	2.26	3.89	10.8
3	*Buchanania lanzan* Spreng.	50.00	3.50	7.00	6.97	11.86	13.61	32.44
4	*Casearia tomentosa* Roxb.	50.00	1.00	2.00	6.97	3.39	3.89	14.25
5	*Cassia fistula* L.	66.67	2.67	4.00	9.30	9.04	7.77	26.11
6	*Haldina cordifolia* (Roxb.) Ridsd.	66.67	1.17	1.75	9.30	3.95	3.40	16.65
7	*Holarrhena antidysenterica* Wall. ex. A.DC.	50.00	2.00	4.00	6.97	6.78	7.77	21.53
8	*Holoptella integrifolia* (Roxb.) Planch.	33.33	0.83	2.50	4.65	2.82	4.86	12.33
9	*Lannea coromandelica* (Houtt.) Merr.	83.33	4.33	5.20	11.62	14.69	10.11	36.42
10	*Madhuca indica* Gmel.	66.67	1.50	2.25	9.30	5.08	4.37	18.76
11	*Pterocarpus marsupium* Roxb.	50.00	1.00	2.00	6.97	3.39	3.89	14.25
12	*Shorea robusta* Gaertn.f.	66.67	5.83	8.75	9.30	19.77	17.01	46.08
13	*Terminalia tomentosa* (Roxb. ex. DC.) Wight & Arn.	50.00	1.00	2.00	6.97	3.39	3.89	14.25

Table 3. Frequency (F), density (D), quadrate (q), abundance (A), relative frequency (RF), relative density (RD), relative dominance (RDo) and importance value index (IVI) of shrub species in core zone of Gorumahisani mining area.

Sl. No.	Botanical name	F (%)	D/q	A	RF	RD	RDo	IVI
1	*Adhatoda vasica* Nees	66.67	1.17	1.75	9.10	5.15	4.06	18.30
2	*Abrus precatorius* L.	33.33	0.50	1.50	4.55	2.21	3.48	10.23
3	*Ageratum conyzoides* L.	50.00	0.83	1.67	6.82	3.68	3.87	14.37
4	*Barleria cristata* L.	50.00	1.83	3.67	6.82	8.09	8.51	23.42
5	*Barleria montana* Nees	50.00	0.83	1.67	6.82	3.68	3.87	14.37
6	*Calotropis procera* (Aiton)W.T. Aiton	50.00	0.83	1.67	6.82	3.68	3.87	14.37
7	*Crotalaria juncea* L.	33.33	1.67	5.00	4.55	7.35	11.61	23.51
8	*Cassia tora* L.	50.00	0.83	1.67	6.82	3.68	3.87	14.37
9	*Dioscorea pentaphylla* L.	50.00	0.67	1.33	6.82	2.94	3.10	12.86
10	*Jatropha curcas* L.	50.00	1.00	2.00	6.82	4.41	4.64	15.87
11	*Lantana camara* L.	66.67	8.00	12.00	9.10	35.29	27.86	72.24
12	*Sida acuta* Burm. f.	33.33	0.33	1.00	4.55	1.47	2.32	8.34
13	*Sida cordifolia* L.	50.00	1.33	2.67	6.82	5.88	6.19	18.89
14	*Tephrosia sps.*	33.33	0.83	2.50	4.55	3.68	5.80	14.03
15	*Urena lobata* L.	66.67	2.00	3.00	9.10	8.82	6.96	24.88
16	*Vitex negundo* L.	50.00	2.17	4.33	1.68	2.37	2.39	6.44

Table 4. Frequency (F), density (D), quadrate (q), abundance (A), relative frequency (RF), relative density (RD), relative dominance (RDo) and importance value index (IVI) of herb species in core zone of Gorumahisani mining area

Sl. No.	Botanical name	F (%)	D/q	A	RF	RD	RDo	IVI
1	*Argemone mexicana* L.	50.00	2.17	4.33	10.35	14.94	16.68	41.97
2	*Cynodon dactylon* (L.) Pers.	83.33	3.67	4.40	17.25	25.29	16.94	59.48
3	*Dicliptera sps*	66.67	2.50	3.75	13.80	17.24	14.43	45.48
4	*Eclipta prostrata* (L.) L.	33.33	1.00	3.00	6.90	6.90	11.55	25.35
5	*Justicia betonica* L.	50.00	1.67	3.33	10.35	11.49	12.83	34.68
6	*Limnophila indica* (L.) Druce	33.33	0.83	2.50	6.90	5.75	9.62	22.27
7	*Mimosa pudica* L.	50.00	0.67	1.33	10.35	4.60	5.13	20.08
8	*Phyllanthus niruri* L.	50.00	0.67	1.33	10.35	4.60	5.13	20.08
9	*Tephrosia tinctoria* Pers.	66.67	1.33	2.00	13.80	9.20	7.70	30.70

Table 5. Frequency (F), density (D), quadrate (q), abundance (A), relative frequency (RF), relative density (RD), relative dominance (RDo) and importance value index (IVI) of tree species in buffer zone of Gorumahisani mining area

Sl. No.	Botanical name	F (%)	D/q	A	RF	RD	RDo	IVI
1	*Acacia catechu* (L.) Willd.	33.33	0.83	2.50	1.12	0.91	1.38	3.41
2	*Aegle marmelos* (L.) Correa	50.00	1.67	3.33	1.68	1.82	1.84	5.34
3	*Albizia lebbeck* (L.) Benth.	66.67	2.50	3.75	2.23	2.74	2.07	7.04
4	*Alstonia scholaris* (L.) R. Br.	33.33	1.00	3.00	1.12	1.09	1.66	3.87
5	*Annona squamosa* L.	66.67	1.33	2.00	2.23	1.46	1.10	4.80
6	*Anogeissus acuminata* (Roxb. ex DC.) Guillaum. & Perr.	50.00	0.67	1.33	1.68	0.73	0.74	3.14
7	*Artocarpus heterophyllus* Lam.	50.00	2.17	4.33	1.68	2.37	2.39	6.44
8	*Bauhinia racemosa* Lam.	50.00	0.67	1.33	1.68	0.73	0.74	3.14
9	*Bauhinia variegata* (L.) Benth.	16.67	0.17	1.00	0.56	0.18	0.55	1.29
10	*Bixa orellana* L.	33.33	0.50	1.50	1.12	0.55	0.83	2.49
11	*Bombax ceiba* L.	66.67	3.17	4.75	2.23	3.47	2.62	8.32
12	*Buchanania lanzan* Spreng.	83.33	5.83	7.00	2.79	6.39	3.86	13.04
13	*Butea monosperma* (Lam.)Taub.	50.00	4.00	8.00	1.68	4.38	4.42	10.47
14	*Careya arborea* Roxb.	50.00	3.50	7.00	1.68	3.83	3.86	9.37
15	*Casearia tomentosa* Roxb.	66.67	1.50	2.25	2.23	1.64	1.24	5.12
16	*Cassia fistula* L.	66.67	4.33	6.50	2.23	4.74	3.59	10.57
17	*Chloroxylon swietenia* (Roxb.) DC.	33.33	0.67	2.00	1.12	0.73	1.10	2.95
18	*Choclospermum gossypium* DC.	50.00	1.00	2.00	1.68	1.09	1.10	3.88
19	*Dalbergia paniculata* Roxb.	33.33	2.00	6.00	1.12	2.19	3.31	6.62
20	*Dalbergia sisoo* Roxb.	33.33	2.67	8.00	1.12	2.92	4.42	8.45
21	*Diospyros melanoxylon* Roxb.	50.00	1.00	2.00	1.68	1.09	1.10	3.88
22	*Diospyros montana* Roxb.	16.67	0.83	5.00	0.56	0.91	2.76	4.23
23	*Ficus beneghalensis* L.	33.33	1.00	3.00	1.12	1.09	1.66	3.87
24	*Ficus glormerata* Roxb.	50.00	1.17	2.33	1.68	1.28	1.29	4.24
25	*Oroxylon indicum* (L.) Benth. ex Kurz	33.33	0.50	1.50	1.12	0.55	0.83	2.49
26	*Flacourtia indica* (Burm.f.) Merr.	50.00	1.83	3.67	1.68	2.01	2.02	5.71
27	*Garuga pinnata* Roxb.	50.00	0.83	1.67	1.68	0.91	0.92	3.51
28	*Haldina cordifolia* (Roxb.) Ridsd.	50.00	0.83	1.67	1.68	0.91	0.92	3.51
29	*Holarrhena antidysenterica* Wall. ex. A.DC.	50.00	0.83	1.67	1.68	0.91	0.92	3.51
30	*Kydia calycina* Roxb.	50.00	1.00	2.00	1.68	1.09	1.10	3.88
31	*Lagerstroemia parviflora* Roxb.	33.33	1.67	5.00	1.12	1.82	2.76	5.70
32	*Lannea coromandelica* (Houtt.) Merr.	33.33	0.83	2.50	1.12	0.91	1.38	3.41
33	*Madhuca indica* Gmel.	33.33	0.33	1.00	1.12	0.36	0.55	2.03
34	*Mangifera indica* L.	66.67	1.33	2.00	2.23	1.46	1.10	4.80
35	*Miliusa velutina* (Dunal) Hook. f. & Thomas	50.00	2.00	4.00	1.68	2.19	2.21	6.07
36	*Mitragyna parvifolia* (Roxb.) Korth	33.33	0.50	1.50	1.12	0.55	0.83	2.49
37	*Morinda tinctoria* Roxb.	50.00	1.83	3.67	1.68	2.01	2.02	5.71
38	*Ougeinia oojeinensis* (Roxb.) Hochr.	50.00	0.83	1.67	1.68	0.91	0.92	3.51
39	*Phoenix sylvestris* (L.) Roxb.	50.00	0.83	1.67	1.68	0.91	0.92	3.51
40	*Polyalthia cerasoides* (Roxb.)Bedd.	50.00	0.83	1.67	1.68	0.91	0.92	3.51
41	*Pongamia pinnata* (L.) Pierre	50.00	1.00	2.00	1.68	1.09	1.10	3.88
42	*Randia dumetorum* (Retz.) Poir.	50.00	0.83	1.67	1.68	0.91	0.92	3.51
43	*Schleichera oleosa* (Lour.) Oken	50.00	0.67	1.33	1.68	0.73	0.74	3.14
44	*Semecarpus anacardium* L.	33.33	1.67	5.00	1.12	1.82	2.76	5.70
45	*Shorea robusta* Gaertn. f.	83.33	4.50	5.40	2.79	4.93	2.98	10.70
46	*Sterculia urens* Roxb.	33.33	0.33	1.00	1.12	0.36	0.55	2.03

47	*Syzigium cumini* (L.) Skeels	50.00	1.33	2.67	1.68	1.46	1.47	4.61
48	*Tamarindus indica* L.	66.67	2.00	3.00	2.23	2.19	1.66	6.08
49	*Tectona grandis* L. f.	83.33	3.67	4.40	2.79	4.01	2.43	9.24
50	*Terminalia arjuna* (Roxb. ex. DC.) Wight & Arn.	50.00	1.67	3.33	1.68	1.82	1.84	5.34
51	*Terminalia alata* Heyne ex. Roth	66.67	2.50	3.75	2.23	2.74	2.07	7.04
52	*Terminalia bellerica* (Gaertn.) Roxb.	33.33	1.00	3.00	1.12	1.09	1.66	3.87
53	*Terminalia chebula* Retz.	66.67	1.33	2.00	2.23	1.46	1.10	4.80
54	*Terminalia tomentosa* (Roxb. ex. DC.) Wight & Arn.	50.00	0.83	1.67	1.68	0.91	0.92	3.51
55	*Xylia xylocarpa* (Roxb.) Taub.	50.00	0.67	1.33	1.68	0.73	0.74	3.14
56	*Zizyphus jujuba* (L.)Gaertn.	66.67	1.33	2.00	2.23	1.46	1.10	4.80
57	*Zizyphus rugosa* Lam.	50.00	0.67	1.33	1.68	0.73	0.74	3.14

Table 6. Frequency (F), density (D), quadrate (q), abundance (A), relative frequency (RF), relative density (RD), relative dominance (RDo) and Importance Value Index (IVI) of shrub species in buffer zone of Gorumahisani mining area

Sl. No.	Botanical name	F (%)	D/q	A	RF	RD	RDo	IVI
1	*Adhatoda vasica* Nees	83.33	3.67	4.40	5.49	9.65	7.43	22.57
2	*Ageratum conyzoides* L.	50.00	0.83	1.67	3.30	2.19	2.81	8.30
3	*Barleria cristata* L.	66.67	0.50	0.75	4.40	1.32	1.27	6.98
4	*Barleria montana* Nees	66.67	1.00	1.50	4.40	2.63	2.53	9.56
5	*Calotropis procera* (Aiton)W.T. Aiton	66.67	0.50	0.75	4.40	1.32	1.27	6.98
6	*Crotalaria juncea* L.	66.67	1.17	1.75	4.40	3.07	2.96	10.42
7	*Croton roxburghi* Balakr.	50.00	4.00	8.00	3.30	10.53	13.51	27.33
8	*Cassia tora* L.	83.33	1.17	1.40	5.49	3.07	2.36	10.93
9	*Jatropha curcas* L.	66.67	0.83	1.25	4.40	2.19	2.11	8.70
10	*Helicteres isora* L.	66.67	4.33	6.50	4.40	11.4	10.98	26.78
11	*Hyptis suaveolens* (L.) Poit	66.67	1.00	1.50	4.40	2.63	2.53	9.56
12	*Indigofera cassioides* DC.	66.67	0.50	0.75	4.40	1.32	1.27	6.98
13	*Lantana camara* L.	66.67	1.50	2.25	4.40	3.95	3.80	12.14
14	*Leea asiatica* (L.) Ridsdale	83.33	1.17	1.40	5.49	3.07	2.36	10.93
15	*Leea indica* (Burm. f.) Merr.	50.00	3.50	7.00	3.30	9.21	11.82	24.33
16	*Rouvolfia serpentina* (L.) Benth. ex Kurz	66.67	1.00	1.50	4.40	2.63	2.53	9.56
17	*Sida acuta* Burm. f	83.33	2.17	2.60	5.49	5.70	4.39	15.59
18	*Sida cordifolia* L.	50.00	4.00	8.00	5.77	9.92	11.66	27.35
19	*Tephrosia sps.*	83.33	1.50	1.80	5.49	3.95	3.04	12.48
20	*Urena lobata* L.	50.00	3.50	7.00	3.30	9.21	11.82	24.33
21	*Vitex negundo* L.	66.67	1.50	2.25	4.40	3.95	3.80	12.14
22	*Woodfordia floribunda* Salisb.	83.33	1.17	1.40	5.49	3.07	2.36	10.93

Table 7. Frequency (F), density (D), quadrate (q), abundance (A), relative frequency (RF), relative density (RD), relative dominance (RDo) and Importance Value Index (IVI) of herb species in buffer zone of Gorumahisani mining area

Sl. No.	Botanical name	F (%)	D/q	A	RF	RD	RDo	IVI
1	*Alternanthera sessilis* (L.) R.Br. ex DC.	50.00	0.67	1.33	5.77	1.65	1.94	9.37
2	*Achyranthes aspera* L.	83.33	5.83	7.00	9.62	14.46	10.21	34.29
4	*Amaranthus spinosus* L.	66.67	3.17	4.75	7.69	7.85	6.93	22.47
5	*Andrographis paniculata* (Burm.f.) Nees	16.67	0.17	1.00	1.92	0.41	1.46	3.79
6	*Argemone mexicana* L.	50.00	4.00	8.00	5.77	9.92	11.66	27.35
7	*Boerhavia diffusa* L.	50.00	3.50	7.00	5.77	8.68	10.21	24.65
8	*Cleome viscosa* L.	66.67	1.50	2.25	7.69	3.72	3.28	14.69
9	*Commelina benghalensis* L.	66.67	4.33	6.50	7.69	10.74	9.48	27.91

10	*Cyperus rotundus* L.	33.33	0.67	2.00	3.85	1.65	2.92	8.42
11	*Elephantous scaber* L.	16.67	0.17	1.00	1.92	0.41	1.46	3.79
12	*Hygrophila auriculata* Schumach.	33.33	0.50	1.50	3.85	1.24	2.19	7.27
13	*Mimosa pudica* L.	66.67	3.17	4.75	7.69	7.85	6.93	22.47
14	*Tephrosia purpurea* (L.) Pers.	33.33	1.00	3.00	3.85	2.48	4.37	10.70
15	*Tridax procumbens* L.	66.67	1.33	2.00	7.69	3.31	2.92	13.91

3.4 to 17.01, and important value index (IVI) 10.8 to 46.08. The highest density was shown by *Shorea robusta* whereas the lowest density was revealed by *Aphanamixis polystachya*. The relative density of shrub species ranged from 1.47 to 35.29, relative frequency 1.68 to 9.10, relative dominance 2.39 to 27.86, and important value index (IVI) 6.44 to 72.24. The highest density was shown by *Lantana camara* whereas the lowest density was revealed by *Sida acuta*. The relative density of herbs varied from 4.6 to 25.29, relative frequency 6.9 to 17.25, relative dominance 5.13 to 16.94, and important value index (IVI) 20.08 to 59.48. The most dominant species in terms of density was *Cynodon datylon* whereas the lowest density was shown by *Mimosa pudica*. Ninety-four plant species were documented in the buffer zone and includes 57 trees, 22 shrubs, and 15 herbs (Table 5-7). The relative density of tree species varied from 0.36 to 6.39, relative frequency 0.56 to 2.79, relative dominance 0.55 to 4.42, and important value index (IVI) 1.29 to 13.04. The highest density was shown by *Buchanania lanzan* whereas the lowest density was revealed by *Madhuca indica*. The relative density of shrub species ranged from 1.32 to 11.4, relative frequency 3.3 to 5.77 relative dominance 1.27 to 13.51, and important value index (IVI) 6.98 to 27.35. The highest density was shown by *Helicteres isora* whereas the lowest density was revealed by *Barleria cristata*. The relative density of herbs varied from 0.41 to 14.46., relative frequency 1.92 to 9.62, relative dominance 1.46 to 11.66, and important value index (IVI) 3.79 to 34.29. The most dominant species in terms of density was *Achyranthes aspera* whereas the lowest density was shown by *Andrographis paniculata*. The analysis of the recorded plant species based on growth habits showed highest proportion of trees followed by shrubs, and herbs (Fig. 4). A clear-cut variation of life form is observed between the two sites. Species diversity

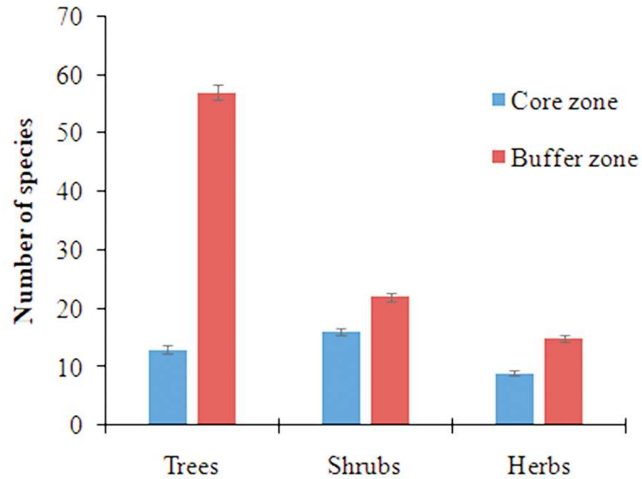

Fig. 4. Trees, shrubs and herbs (mean + SE) in core zone and buffer zone of the study sites.

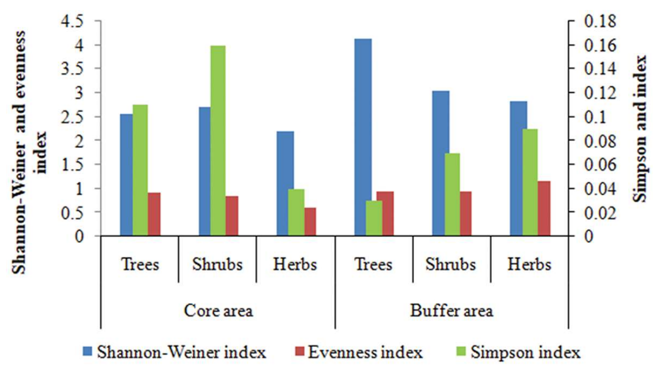

Fig. 5. Species diversity indices of trees, shrubs and herbs in core zone and buffer zone of the study sites.

indices (Shannon-Weiner) revealed variation among the tree, shrub, and herb species (Fig. 5). The diversity index in the tree level (4.13) is much more in the buffer zone in comparison to core zone (2.56). Similarly, diversity index of shrub and herb was higher in buffer zone than the core zone. The Evenness index of trees, shrubs and herbs followed the same trend of Shannon-Weaver index of diversity in both zones (Fig. 5). The concentration of dominance or Simpson Dominance Index also exhibited variation among the vegetation layers. Dominance index in the tree level of the buffer zone is only 0.03 which is much lower to 0.11 in comparison to core zone (Fig. 5).

Discussion

The number of species documented in the present study is comparable to 57 species recorded from Mylodai forest of Courtallum (Parthasarathy and Karthieyan, 1997), 185 species from the tropical forest of Similipal Biosphere reserve (Reddy *et al.,* 2007), 52-110 species from tropical forest in the Eastern Ghats of Northern Andhra Pradesh (Reddy *et al.,* 2011), 96 species from Bhiwani open cast mining zones-Haryana, India (Kumar, 2013) and 58 species from Raikela Iron Ore Mines Sundergarh, Odisha (Mishra and Patra, 2017). The present finding on species diversity indices is in conformity with the observation of Parthasarathy and Karthieyan (1997), Reddy *et al.* (2007), Reddy *et al.* (2011), Ganguli *et al.* (2016) and *Mondal et al. (2019).* The growth forms found are trees, shrubs, and herbs, with the trees component representing the largest number of species. A marked variation in vegetation structure is observed between the sites due to mining activities. Mining directly caused more extensive deforestation as a result a lesser number of species is observed within the core area. Mining–induced deforestation is also reported elsewhere (Duran *et al.* 2013; Sonter *et al.* 2017). Higher number of species in buffer zone in comparison to core zone indicates a precise pattern of vegetation change. Such findings indicate that mining is an important determinant, and therefore could influence the vegetation of the locality. Extraction of minerals grew at an unprecedented pace in the past decades, causing a wide range of social and environmental impacts around the world (Krausmann *et al.,* 2017). The direct land used by mining is a crucial indicator of environmental pressure, which is closely associated with a range of negative impacts, including fragmentation and degradation of ecosystems and biodiversity loss (Kobayashi *et al.,* 2014; Boadi *et al.,* 2016; Murguia *et al.,* 2016; Sonter *et al.,* 2018; Haddaway *et al.,* 2019; *Mabey et al., 2020*). It is also observed that within the buffer zone there are few important species like *Albizia lebbeck, Artocarpus heterophyllus, Bombax ceiba, Buchanania lanzan, Butea monosperma, Careya arborea, Cassia fistula, Dalbergia sisoo, Shorea robusta, Tamarindus indica, and Tectona grandis* which are considered to be prominent forest species of Odisha. The availability of some of these species is not very frequent in the core zone. Diversity in the tree level in the non-forest areas is further enhanced by the availability of non-forest species like *Mangifera indica*. Shrub species like *Lantana camara* and *Ageratum conyzoides* are also available in this region which is considered to be the invasive species in Indian forests as well as non-forest areas (Panda *et al.,* 2018). These invasive species are also very frequently available in the core area. The availability of these species in the buffer zone signifies that there is considerable anthropogenic intervention in the ecosystem which has resulted in alteration of species composition of the core as well as buffer zone which is similar to the studies on the impact of invasive species on forests (Charles and Dukes, 2007; Devine and Fei, 2011; Priyanka and Joshi, 2013). There may be less extraction of forest resources from the buffer zone due to its remoteness.

Shannon-Weaver index of diversity for tree species was much lower in the core area compare to buffer area representing that the diversity was drastically reduced in the core areas and also suggests the dominance of one or two species in the core area. Similar findings were reported by Raizada and Samra (2000). They reported that diversity (H') of tree species in the natural forest was higher than the rehabilitated area. Concentration of dominance or Simpson Dominance Index, as expected, showed inverse relationship with the diversity index and had a higher value for core area in comparison to that of buffer area. *The* dominance index in the tree level of the buffer zone is only 0.03 which is much lower than 0.11 in comparison to the core zone. This signifies that the tree layer in the buffer zone is shared by many species rather than a few ones which is a tendency towards mixed forest type rather than the dominance of few tree species. Dominance of single species is often attributed to niche diversification, disease, species competition, and grazing (Harper, 1977; Whittaker & Levin, 1977).The Evenness Index did not show much variation with respect to the trees and shrubs of the both core and buffer area. This is in concurrence with the finding of Sonakar et al. (2005). They reported a higher diversity index, and lower concentration of dominance for the ground flora under plantation than that of unplanted barren land.

In effort to restore the sites disturbed by mining activities, the analysis of natural vegetation processes represents valuable starting point for the selection of suitable species to be used. The development of tree species is important to maintain the environment and ecosystem safely. The resultant tree species viz., *Albizia lebbeck, Artocarpus heterophyllus, Bombax ceiba, Buchanania lanzan, Butea monosperma, Careya arborea, Cassia fistula, Dalbergia sisoo, Madhuca indica, Pterocarpus marsupium, Shorea robusta, Tamarindus indica, and Tectona grandis* which are suitable to local environmental and habitat conditions can be used for revegetating the mined areas. In achieving better growth of planted species on mined area certain steps should be followed which includes water management to promote growth of perennial species, protection from anthropogenic disturbances i.e. grazing and cutting. In addition, ecological study at regular intervals is needed to monitor the survival and growth of plant species and to find out the effects of various plant species on the habitat conditions.

Conclusion

Relationships between mining and biodiversity are complex and interact with other threatening processes over multiple scales. The vegetation potential of any area is dependent upon physical environmental limitations and edaphic-biotic components and their interaction, soil surface characteristics, climate, and vegetation after open-cast mining. Individual species success and community composition are governed by local site variables. In the present study, due to extensive iron mining, large areas of the Gorumahisani area have been turned into degraded forest, creating unfavorable habitat conditions for plants. The unfavorable habitat conditions prevailing in the mined areas have reduced the chances of regeneration of many a species, thereby, leading to reducing the number of species in the mined areas. It is evident from the study that there is few plant species present in the buffer zone of Gorumahisani. These species are likely to be affected by mining projects and other related activities like road construction, blasting, excavation for mining, and dumping of excavated material. The present study shows that phytosociological analysis can be used as an important tool for predicting the suitability of mined habitats for plant growth. It is concluded that current mining practices need to change and contribute to community development with more equity, and to protect better natural resources and ecosystems in order to be environmentally acceptable and compliant with sustainable development objectives. To conserve forests and mitigate the adverse impacts of mining, assessment, and environmental licensing processes must consider both on- and off-lease sources of deforestation.

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