Research Article

Assessment of Soil Microbes and Enzyme Activities in the Degraded Soils Adjacent to Industries and Mines and its Relation with Heavy Metal Contaminants

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Abstract

A study was undertaken to assess the microbial diversity and enzyme activities and their relationship with soil properties in the soils adjacent to chromium, iron and coal mining areas of Jajpur, Keonjhar and Jharsuguda districts and adjacent to industrial areas as well as ash ponds of thermal power plant and aluminium refinery of Angul, Koraput, Rayagada, Jagatsinghpur, Sundargarh, Bhadrak, Balasore, Mayurbhanj, Cuttack, and Ganjam districts of Odisha, India. The effluents from the mines are discharged to nearby arable lands and water bodies causing acid mine drainage. The soils of the study area are strongly acidic to slightly alkaline in reaction (pH 4.23 - 7.85), non saline, and having very low to high organic carbon (0.15 - 1.88%), low to medium in available nitrogen (N), low to high in available phosphorus (P) and potassium (K). The soils contain toxic levels of iron (Fe), manganese (Mn), chromium (Cr), nickel (Ni), lead (Pb) and relatively higher status of available zinc (Zn). Highest available Fe (240.8 mg kg^{-1}) was observed in the soils adjacent to sugar factory of Ganjam district, Mn in the soils of coal mining areas of Jharsuguda (146.0 mg kg^{-1}), highest Cr (178.4 mg kg^{-1}) and Ni (12.4 mg kg^{-1}) in the soils of chromium mining areas of Jajpur and highest Pb (18.9 mg kg^{-1}) in the bauxite mining areas of Koraput district of Odisha. However, highest available Cu (9.02 mg kg^{-1}) and Zn (6.36 mg kg^{-1}) contents were recorded adjacent to Rourkela steel plant areas of Sundargarh district. Toxicity of heavy metals in the soils of Jagatsinghpur district led to very low biological activities in terms of dehydrogenase (0.186 µg TPF hr^{-1}g^{-1}), fluorescein diacetate (0.152 µg g^{-1} hr^{-1}) and alkaline phosphatase (9.68 µg PNP g^{-1} hr^{-1}). The study emphasized that toxic levels of heavy metals in these mining and industrial areas and consequently their uptake in to the plant system is very much harmful to the livestock and human beings and there is an urgent need to advocate the people in these areas to adopt proper remedial measures so as to minimize the levels of these elements in the soil-plant-animal-human chain.

Keywords: Heavy Metals; Pollutants; Mining and Industrial Areas; Microbial Diversity; Enzyme Activities; Soil Properties; Correlations

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Introduction

The state of Odisha is rich in natural resources, endowed with an abundance of mineral, forest, marine and water resources and it is India's main supplier of valuable minerals such as chromites, nickel ore, coal, bauxite, iron ore and manganese. The state accounted for 38 and 98% of India's total production of iron and chromium ore, respectively. Sukinda valley of Odisha has the major production of chromium and is under serious threat due to the production of chromium and chromates which are known as the potential carcinogenic substances for lungs and nose cancer. Heavy metals are potentially toxic to crop plants, animals and human beings when the contaminated soils are used for crop production. Pollution of the biosphere with heavy metals due to intensive agricultural and other anthropogenic activities poses serious problems to the farming land [1]. Organic materials such as farm manures, bio-solids or composts contain higher concentration of trace elements and its usage increases the total amount of copper (Cu), zinc (Zn), lead (Pb), cadmium (Cd), iron (Fe) and manganese (Mn) in soils [2].

Chemical compounds, entering the ecosystem as a result of different human activities, may accumulate in soil and water environments. Therefore, soil may be regarded as a long-term reservoir of pollutants, from which these compounds may be introduced to food chains or groundwater. Inappropriate and careless disposal of industrial waste often results in environmental pollution. The pollution includes point sources such as emission, effluents and solid discharge from industry, vehicle exhaustion and metal smelting or mining as well as nonpoint sources like pesticide residues or excessive use of fertilizers [3]. Each of the sources have their own damaging effects on plant, animal and human health, but those that add heavy metals to soils are of serious concern due to the persistence of these elements in the environment. They cannot be destroyed, but are only transformed from one state to another [4].

Heavy metal pollution of surface soils due to intense industrialization and urbanization has become a serious concern and accumulation of heavy metals in surface soils is affected by many environmental variables, including parent material and soil properties, as well as by human activities, such as industrial production, traffic, farming, and irrigation. Most common heavy metals produced by industrial activities are lead (Pb), mercury (Hg), cadmium (Cd), arsenic (As), chromium (Cr), manganese (Mn), iron (Fe), and zinc (Zn), and accumulated slowly in the surrounding water and arable lands. Heavy metal toxicity has an inhibitory effect on plant growth, stomata function, photosynthesis activity and accumulation of high density elements damages the root system and severely affects the microbial activities [5]. Sites near coal mining areas were heavily contaminated with heavy metals like Fe, Mn, Zn, Pb, Cu, Ni, Cd and Cr compared to the critical soil concentrations [6].

Microorganisms are the first biota that undergoes direct and indirect impacts of heavy metals. Some metals (Fe, Zn, Cu, Ni, Co) are of vital importance for many microbial activities when occur at low concentrations and are often involved in the metabolism and redox processes. Some heavy metals such as Co, Cu, Fe, Mn, Mo, Ni, V and Zn are required in minute quantities by organisms, however, excessive amounts of these elements can become harmful to organisms. Other heavy metals such as Pb, Cd, and Hg do not have any beneficial effect on organisms and they are very harmful to both plants and animals. Soil bacteria immobilize heavy metals and contribute higher mobility to heavy metals, whereas Pb and Hg are more readily accumulated by fungi and actinomycetes in comparison to Zn, Mn, Cd, Ni, and Co which make selective accumulation of heavy metals by fungi different from many bacteria and yeast. Soil fungi are sensitive to a wide variety of organic and inorganic pollutants and environmental changes. Actinomycetes are important in forming stable humus, which enhances soil structure, improves retention of soil water and nutrients. Bacteria facilitate a number of physical and biochemical alterations or reactions in soils and thereby directly or indirectly support the development of higher plants.

Soil biological activities depends on the metabolic state of soil microorganisms and the microbial activity is affected by numerous factors such as soil type, pH etc [7]. The activities of certain enzymes such as dehydrogenase, urease, aryl sulfatase and phosphatase have been reported as available indicators of heavy metal contamination in soil ecosystems [8]. Karaca., *et al*. [9] explained that activities of aryl sulphatase, galactosidase, and alkaline phosphomonoesterase in soil negatively correlated with Cd. Hinojosa., *et al*. [10] reported that phosphatase, aryl sulfatase, β-glucosidase, urease, and dehydrogenase activities in soils polluted with heavy metals were less active in soils contaminated with Cd, Cu, Pb, and Zn than in non-contaminated soils. The present investigation was undertaken to assess the spatial distribution of heavy metals and their relationship with microbial activities in the mining and in-

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dustrial areas in some parts of Odisha, India so as to advocate proper remedial measures for minimizing their accumulation in soil-plant-human beings.

Materials and Methods

A total of 55 surface (0 - 30 cm) soil samples were collected during 2015-18 adjacent to mines and industrial areas representing from 13 districts (Jajpur-3, Keonjhar-5, Angul-3, Koraput-2, Rayagada-3, Jagatsinghpur-6, Sundargarh-12, Jharsuguda-4, Bhadrak-2, Balasore-6, Mayurbhanj-2, Cuttack-5, and Ganjam-2) of Odisha, India. Fresh soil samples were collected from all the locations and the soil samples were sieved with 0.5 mm sieve by removing gravels and other waste materials, stored up to 3 weeks at 4ºC and used for enumeration of microbes and estimation of enzyme activities. Nutrient Agar media was used for isolation of bacteria, Potato Dextrose Agar for fungi and Starch Casein Agar for actinomycetes. Soil dilution plates were prepared from fresh soil on the day of sampling. After the serial dilution, 1.0 ml of required dilution (10^{-4} for fungi and actinomycetes and 10^{-5} for bacteria) was inoculated into the respective petri plates. The sample was spread over the media via a flame sterilized bent glass rod and all plates were incubated in the dark at 20°C. After microbial colonies are readily visible (2 - 7 days for bacteria and fungi and 7 - 14 days for actinomycetes), the number of colonies on each plate are counted and calculated. The number of cfu g^{-1} dry soil was estimated by taking the soil dilution factor and soil moisture content into account. Enumeration of these colonies which develop on a specific growth medium, the number of viable cells of a particular group of microbes present in the soil can be ascertained.

Soil dehydrogenase activity (DHA) is determined by the method as described by Casida., *et al* [7]. The fluorescein diacetate hydrolysis assay (FDA) was determined in the fresh soils by the method as described by Green., *et al* [11]. Phosphatase activity was determined by the method described by Tabatabai and Bremner [12]. The air dried soils were analyzed for physico-chemical properties (pH, EC, organic C, available N, P and K) as per the standard methods described by Jackson [13]. Heavy metals (Fe, Cu, Mn, Zn, Cr, Ni and Pb) in the soils were estimated by using the respective electrodeless discharge lamps in Atomic Absorption Spectrophotometer [13]. Correlation coefficients were derived to establish the relationship between soil properties and microbial variables with heavy metals.

Results and Discussion

Physico-chemical properties

The pH of the contaminated soils through industrial effluents representing from 13 districts of Odisha, India ranged from 4.23 to 7.85 (Table 1). Relatively higher status of soil pH was observed in the soils of Angul (pH 7.85) followed by iron mining areas of Keonjhar (pH 7.78), while it was strongly acidic (pH 4.23) adjacent to sugar factory of Ganjam district followed by industrial areas of Jagatsinghpur district (pH 4.47). The soils of the study area are non saline (0.078 - 1.869 dS m^{-1}). The soil organic carbon in the polluted soils ranged from 0.15 - 1.88% with a mean value of 0.71%. The mean soil organic carbon content adjacent to industrial areas of Rayagada was found to be deficient (0.43%), however, it was medium in the soils from Mayurbhanj (0.52%), Ganjam (0.53%), Jagatsinghpur (0.54%), Balasore (0.55%), Bhadrak (0.56%) and Cuttack (0.60%). Around 36% soils found deficient (< 0.50%), 29% soils are medium (0.50 - 0.75%) and the rest of soils contain high status of organic carbon (> 0.75%). Highest mean value of organic C (1.04%) was observed in the soils from iron mining areas of Keonjhar district followed by Jajpur (0.91%), Koraput (0.87%), Jharsuguda (0.78%) and Sundargarh (0.77%). Most of the contaminated soils of the study area are barren due to release of effluents and accumulated with organic residues led to build up of organic matter in the soils.

The available N in the soils of the present study area ranged from 101 - 385 kg ha^{-1}.with a mean value of 216 kg ha^{-1}. Around 65% of the polluted soils found deficient in available N (< 250 kg ha^{-1}) and the rest of the soils contain medium status of available N (250 - 500 kg ha^{-1}). The mean available N was found lowest in the soils of Bhadrak (164.9 kg ha^{-1}), Sundargarh (165.2 kg ha^{-1}), Balasore (181.5 kg ha^{-1}), Jagatsinghpur (184.6 kg ha^{-1}), and Mayurbhanj (185.4 kg ha^{-1}), while it was highest in the areas of Ganjam district (329 kg ha^{-1}). The results of the study indicated that the available N status in the degraded soils of Odisha is very low to medium. The available P in the mining and industrial areas ranged from 5.82 - 95.79 kg ha^{-1} with a mean value of 29.33 kg ha^{-1}. The mean available P in the soils of Mayurbhanj district was found to be medium (11.35 kg ha^{-1}) followed by Rayagada (15.50 kg ha^{-1}), Balasore (16.13 kg ha^{-1}), Bhadrak (17.71 kg ha^{-1}), Angul (18.37 kg ha^{-1}), Jharsuguda (21.61 kg ha^{-1}), and Jagatsinghpur (24.10 kg ha^{-1}). Lowest mean available K was noticed in the soils of Ganjam (116.5 kg ha^{-1}), however, it was found medium in the soils of Mayurbhanj (143.6 kg ha^{-1}), Balasore (171.3 kg ha^{-1}), Sundargarh (188.0 kg ha^{-1}), Bhadrak (189.3 kg ha^{-1}), Angul (189.7 kg ha^{-1}), Cuttack (194.3 kg ha^{-1}), Jharsuguda (207.1 kg ha^{-1}), Rayagada (221.6 kg ha^{-1}), Jagatsinghpur (237.7 kg ha^{-1}), and Jajpur (271.2 kg ha^{-1}). Highest mean available K was observed adjacent to bauxite mining areas of Koraput (340.6 kg ha^{-1}) followed by iron mining areas of Keonjhar (320.4 kg ha^{-1}). The degraded soils of the present study were low to moderate in fertility status and mostly unsuitable for cultivation.

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Location and source of pollution	Block	District	pH (1:2.5)	EC (dS m^{-1})	Org. C (%)	Available nutrient (kg ha^{-1})		
						N	P	K
1. Malhar Hatting Tisco Tata (Tata Chromium Factory)	Sukinda	Jajpur	6.51	0.374	1.02	263.4	18.96	286.2
2. Kaliapani (Indian Metals and Ferro Alloys Limited)	Sukinda	--do--	7.24	0.416	0.78	295.8	22.64	246.9
3. Hatibari (Chromium mining areas)	Sukinda	--do--	7.51	0.639	0.94	318.3	36.68	280.4
4. Palaskaa (Iron mines)	Joda	Keonjhar	6.24	0.599	1.02	263.4	32.44	375.7
5. Baneikela (Essel mining and Industries Limited)	Joda	--do--	7.78	0.911	0.79	280.9	26.42	327.3
6. Lohanda (Iron mines)	Joda	--do--	5.96	0.558	0.87	224.6	24.56	240.3
7. Suakati (OMC Fe mines)	Banspal	--do--	6.06	0.572	1.88	265.9	38.64	374.4
8. TolaJagar (Iron mines)	Banspal	--do--	5.89	0.663	0.63	250.9	9.72	284.3
9. Santhapada (Ash pond of NTPC Limited)	Talcher	Angul	5.75	0.172	0.69	238.9	13.68	166.4
10. Kudulau (Ash pond of NALCO Limited)	Talcher	--do--	7.85	0.914	1.12	305.9	32.64	279.2
11. Bhogabereni (NTPC Limited)	Banarpal	--do--	6.91	0.237	0.35	238.3	8.78	123.5
12. BitharBejaput (Bauxite mines)	Damonjodi	Koraput	6.62	0.159	0.52	263.7	16.94	168.7
13. Ambagaon (NALCO Refinery)	Damonjodi	--do--	6.12	0.258	1.22	275.7	28.74	512.5
14. Sukuabada (Utkal Alumina International Ltd.)	Rayagada	Rayagada	6.17	0.143	0.34	265.7	6.27	203.4
15. Karlakona (Dumping yard of JK Paper Mills)	Rayagada	--do--	6.76	0.234	0.51	258.2	22.69	261.2
16. Chanchandli (Dumping yard of JK Paper Mills)	Rayagada	--do--	6.42	0.136	0.45	233.3	17.55	200.3
17. Musadia, Paradeep (IFFCO Plant)	Kujang	Jagatsinghpur	6.36	0.871	0.21	165.6	12.70	109.5
18. Baularia Palanda (Cargill India Pvt. Ltd.)	Kujang	--do--	6.21	0.112	0.69	189.7	21.74	482.7
19. Jhimani, Paradeep (Oil Refinery)	Kujang	--do--	4.47	0.109	0.15	133.4	10.78	85.8
20. PPL Township, Paradeep (Paradeep Phosphate Ltd.)	Kujang	--do--	4.59	0.097	0.47	164.9	18.89	210.9
21. Atharbanki (Gypsum storage site of IFFCO plant)	Kujang	--do--	5.51	0.088	1.08	229.7	60.12	242.8
22. Udayabata (Goa Carbon Limited)	Kujang	--do--	5.37	0.092	0.63	224.3	20.38	294.2
23. Jhartarang (Kalunga Industrial Estate)	Lathikata	Sundargarh	6.74	0.153	0.99	156.5	28.89	315.1
24. Marang Phiring (Sponge Iron Factory)	Lathikata	--do--	6.93	0.709	0.21	139.5	12.54	109.7
25. Goibhanga (SLM Metal Industries)	Lathikata	--do--	5.94	0.574	0.24	182.9	9.18	103.2
26. San Brahmanitarang (Lotus Chemicals Ltd.)	Brahmanitarang	--do--	7.25	0.208	0.39	172.9	9.41	244.5
27. Padmalaya Colony (Ferro Alloys)	Kuarmunda	--do--	6.97	0.837	0.46	145.7	15.85	221.3
28. Deogaon Colony (Rourkela Steel plant)	Panposh	--do--	6.81	0.149	1.59	242.4	82.88	142.8
29. Sitalpada (Dumping yard, Rourkela Steel Plant)	Panposh	--do--	7.25	0.125	0.32	208.7	19.84	114.1
30. Ramabahal (Scan Steels Ltd.)	Rajgangpur	--do--	7.22	0.119	0.24	152.6	18.59	179.1
31. Rajgangpur (OCL India Ltd.)	Rajgangpur	--do--	7.23	0.143	1.77	160.3	12.32	171.5
32. Lamloi (M.R. Ferro Pvt. Ltd.)	Rajgangpur	--do--	6.75	0.291	0.75	159.3	41.44	128.6

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33. Kiripsira (Coal mines)	Hemgiri	--do--	6.79	0.211	1.74	112.6	45.38	232.1
34. Kanika Hemgiri Road (ACB India Ltd.)	Hemgiri	--do--	6.63	0.145	0.58	149.5	8.81	293.7
35. Kurebaga (Ash pond, Vedanta Aluminiun Ltd.)	Jharsuguda	Jharsuguda	6.56	0.121	0.53	126.9	5.82	173.3
36. Kudopali (Samleswari Coal mines)	Jharsuguda	--do--	6.22	0.162	1.05	130.6	23.38	169.6
37. Belpahar (Mahanadi Coal Fields Ltd.)	Lakhanpur	--do--	6.44	0.158	1.38	315.9	44.26	378.1
38. Ubuda (Global Coal and Mining Pvt. Ltd.)	Lakhanpur	--do--	6.66	0.154	0.16	100.9	12.99	107.4
39. Randia (Ferro Alloys Corporation)	Bhadrak	Bhadrak	6.33	0.078	0.43	178.4	13.89	190.9
40. Chengagadia (Chromite plant)	Bhadrak	--do--	6.49	0.134	0.69	151.5	21.52	187.6
41. Khantapara (Biotechayur Pvt. Ltd.)	Bahanaga	Balasore	6.77	0.122	0.45	170.6	13.44	127.2
42. Banparia (KarniThermoplast Pvt. Ltd)	Remuna	--do--	6.39	0.151	0.44	146.3	22.40	196.9
43. Khannagar (HariPlast)	Balasore Sadar	--do--	6.51	0.096	0.63	174.2	14.34	125.7
44. Bampada (Birla Tyres)	Remuna	--do--	7.05	0.897	0.69	232.3	22.62	300.2
45. Balagopalpur (Balasore Alloys Ltd)	Remuna	--do--	6.43	0.205	0.35	185.4	8.96	92.5
46. Rathalpur (Emami Paper Mills Ltd)	Remuna	--do--	7.03	0.342	0.76	180.4	15.01	185.2
47. Hemachandrapur (Sri Mayur Biscuit Co Pvt. Ltd)	Sarasakana	Mayurbhanj	6.53	0.155	0.41	154.2	11.04	136.3
48. Pandarsil (Shiva Shakti Sponge Iron Ltd)	Sukruli	--do--	6.51	0.189	0.62	216.5	11.65	150.8
49. Jagaatpur (Cosboard Factory)	Jagatpur	Cuttack	4.73	0.672	0.74	264.2	65.12	128.2
50. Jagatpur (Pragati Milk Products Ltd.)	Jagatpur	--do--	5.03	1.067	0.20	193.3	89.53	132.5
51. Choudwar (Indian Metals and Ferro Alloys Ltd.)	Jagatpur	--do--	5.41	1.268	0.85	372.0	90.46	289.2
52. Bainchua (Maa Durga Thermal Power Company Ltd.)	Tangi	--do--	5.26	1.869	0.57	265.4	92.67	268.8
53. Bhayatangi (RSB Castings Ltd.)	Tangi	--do--	5.67	0.725	0.65	305.2	74.89	152.7
54. Nuagam (Aska Cooperative Sugars Ltd.)	Aska	Ganjam	4.23	0.358	0.59	384.6	95.79	87.6
55. Jayshree (Grasim Chemicals Ltd.)	Ganjam	--do--	7.04	0.763	0.46	272.8	56.52	145.3
Range			4.23-7.85	0.078-1.869	0.15-1.88	100.9-384.6	5.82-95.79	85.8-512.5
Mean			6.37	0.39	0.70	215.5	29.33	213.4

Table 1: Physico-chemical properties in soils from mines and industrial areas.

Micronutrient contents in the soils from mines and industrial areas

The available Fe in the mines and adjacent to industrial areas ranged from 5.8 - 240.8 mg kg^{-1} with a mean value of 95.1 mg kg^{-1} (Table 2). Highest mean available Fe (208 mg kg^{-1}) was recorded in the soils of Ganjam district (208 mg kg^{-1}) followed by Jharsuguda (154.3 mg kg^{-1}) and Jagatsinghpur (132.6mg kg^{-1}), however, the available Fe content in all the soils of the study area was found more than the critical limit of 4.0 mg kg^{-1} and around 67% soils contain > 50 mg kg^{-1} and 42% soils contain > 100 mg kg^{-1}. The available Mn in the soils ranged from 4.2 - 146.0 mg kg^{-1}) with a mean value of 59.3 mg kg^{-1}. Highest mean available Mn was observed in the soils of Ganjam (109.4 mg kg^{-1}) followed by Jharsuguda (91.3 mg kg^{-1}), Keonjhar (87.9 mg kg^{-1}) and Jajpur (85.1 mg kg^{-1}). It was noticed that more than 50% soils contain > 50 mg kg^{-1}and 18% soils contain > 100 mg kg^{-1} of available Mn, All the soil samples contain available Mn beyond the critical limit of 2.0 mg kg^{-1}. The available Fe is one of the most abundant elements in the composition of the earth material. It is mainly associated with atmospheric coarse particles, where it is normally accumulated in the neighborhood of emission sources [14].

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Location and source of pollution	Block	District	Fe	Cu	Mn	Zn	Cr	Ni	Pb
1. Malhar Hatting Tisco Tata (Tata Chromium Factory)	Sukinda	Jajpur	145.9	0.24	129.2	1.16	178.37	3.08	11.25
2. Kaliapani (Indian Metals and Ferro Alloys Limited)	Sukinda	--do--	117.2	0.32	82.6	1.57	135.24	12.84	9.38
3. Hatibari (Chromium mining areas)	Sukinda	--do--	60.1	0.21	43.5	2.34	137.81	1.75	4.63
4. Palaskaa (Iron mines)	Joda	Keonjhar	160.2	0.25	132.5	1.48	79.53	0.78	9.54
5. Baneikela (Essel mining and Industries Limited)	Joda	--do--	115.2	0.54	95.7	1.21	40.27	0.71	7.07
6. Lohanda (Iron mines)	Joda	--do--	91.1	0.57	79.6	2.58	45.42	1.35	7.17
7. Suakati (OMC Fe mines)	Banspal	--do--	33.8	0.62	47.5	1.31	62.36	0.24	4.92
8. TolaJagar (Iron mines)	Banspal	--do--	103.3	1.33	84.4	0.91	24.93	1.42	5.31
9. Santhapada (Ash pond of NTPC Limited)	Talcher	Angul	114.9	0.39	84.7	1.48	15.35	1.33	9.67
10. Kudulau (Ash pond of NALCO Limited)	Talcher	--do--	49.6	0.22	27.1	0.96	10.41	2.92	10.90
11. Bhogabereni (NTPC Limited)	Banarpal	--do--	65.9	0.34	42.6	0.87	13.22	0.66	9.54
12. BitharBejaput (Bauxite mines)	Damonjodi	Koraput	105.2	2.23	25.7	0.72	8.94	0.26	18.92
13. Ambagaon (NALCO Refinery)	Damonjodi	--do--	40.6	2.48	101.4	2.65	12.35	2.08	11.75
14. Sukuabada (Utkal Alumina International Ltd.)	Rayagada	Rayagada	48.4	1.34	40.2	0.72	7.56	1.52	5.04
15. Karlakona (Dumping yard of JK Paper Mills)	Rayagada	--do--	5.8	0.63	31. 6	0.51	5.44	0.12	10.72
16. Chanchandli (Dumping yard of JK Paper Mills)	Rayagada	--do--	56.6	3.40	69.4	1.61	15.27	0.95	8.97
17. Musadia, Paradeep (IFFCO Plant)	Kujang	Jagatsinghpur	17.4	1.21	18.8	0.95	6.85	0.48	4.84
18. Baularia Palanda (Cargill India Pvt. Ltd.)	Kujang	--do--	84.5	3.22	54.8	2.13	32.18	1.48	12.26
19. Jhimani, Paradeep (Oil Refinery)	Kujang	--do--	235.8	0.49	131.4	0.58	18.57	0.68	8.45
20. PPL Township, Paradeep (Paradeep Phosphate Ltd.)	Kujang	--do--	197.4	5.46	11.6	1.45	21.69	1.65	9.16
21. Atharbanki (Gypsum storage site of IFFCO plant)	Kujang	--do--	105.2	8.68	117.4	2.01	13.42	3.04	8.27
22. Udayabata (Goa Carbon Limited)	Kujang	--do--	155.4	6.14	123.9	1.84	16.29	2.12	9.09
23. Jhartarang (Kalunga Industrial Estate)	Lathikata	Sundargarh	38.6	2.56	13.3	2.24	14.29	4.27	6.17
24. Marang Phiring (Sponge Iron Factory)	Lathikata	--do--	52.2	7.14	69.2	4.08	7.59	1.65	4.79
25. Goibhanga (SLM Metal Industries)	Lathikata	--do--	216.4	2.83	143.7	2.17	20.37	6.44	11.84
26. San Brahmanitarang (Lotus Chemicals Ltd.)	Brahmanitarang	--do--	36.8	2.56	19.4	3.48	6.85	0.89	4.25
27. Padmalaya Colony (Ferro Alloys)	Kuarmunda	--do--	20.3	3.92	21.5	4.16	4.79	0.49	3.19
28. Deogaon Colony (Rourkela Steel plant)	Panposh	--do--	177.9	9.02	47.2	4.28	23.48	5.64	9.75
29. Sitalpada (Dumping yard, Rourkela Steel Plant)	Panposh	--do--	42.6	2.41	6.9	6.36	6.09	1.08	5.12
30. Ramabahal (Scan Steels Ltd.)	Rajgangpur	--do--	91.4	0.69	36.5	1.21	7.39	1.37	6.37
31. Rajgangpur (OCL India Ltd.)	Rajgangpur	--do--	11.5	2.43	4.2	1.21	4.28	0.32	3.18
32. Lamloi (M.R. Ferro Pvt. Ltd.)	Rajgangpur	--do--	42.4	3.69	32.6	2.09	5.37	0.45	4.69
33. Kiripsira (Coal mines)	Hemgiri	--do--	31.3	7.78	89.6	6.12	4.85	0.29	3.56
34. Kanika Hemgiri Road (ACB India Ltd.)	Hemgiri	--do--	50.9	2.92	100.8	2.44	5.16	0.62	4.22
35. Kurebaga (Ash pond, Vedanta Aluminiun Ltd.)	Jharsuguda	Jharsuguda	33.6	1.31	60.8	1.72	3.89	0.19	3.67

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No. Name	Block	District							
36. Kudopali (Samleswari Coal mines)	Jharsuguda	--do--	228.0	5.51	146.0	3.64	27.64	4.19	8.64
37. Belpahar (Mahanadi Coal Fields Ltd.)	Lakhanpur	--do--	199.2	2.36	82.6	4.78	19.74	2.47	9.15
38. Ubuda (Global Coal and Mining Pvt. Ltd.)	Lakhanpur	--do--	156.3	2.30	75.6	3.92	13.29	1.59	7.29
39. Randia (Ferro Alloys Corporation)	Bhadrak	Bhadrak	78.2	3.29	41.2	1.35	13.84	1.86	5.82
40. Chengagadia (Chromite plant)	Bhadrak	--do--	151.6	3.43	12.7	1.28	11.76	2.05	5.16
41. Khantapara (Biotechayur Pvt. Ltd.)	Bahanaga	Balasore	45.6	2.17	17.4	0.52	2.98	2.54	11.71
42. Banparia (Karni Thermoplast Pvt. Ltd)	Remuna	--do--	114.8	2.34	20.8	2.04	8.85	2.37	12.49
43. Khannagar (HariPlast)	Balasore Sadar	--do--	103.8	2.06	61.5	5.42	29.48	1.21	11.54
44. Bampada (Birla Tyres)	Remuna	--do--	73.6	5.40	16.1	1.27	3.99	0.79	12.68
45. Balagopalpur (Balasore Alloys Ltd)	Remuna	--do--	93.2	2.27	37.2	5.44	6.75	0.98	12.68
46. Rathalpur (Emami Paper Mills Ltd)	Remuna	--do--	46.5	3.83	31.5	2.12	3.99	0.88	6.08
47. Hemachandrapur (Sri Mayur Biscuit Co Pvt. Ltd)	Sarasakana	Mayurbhanj	70.3	1.86	32.8	2.28	2.52	0.32	9.68
48. Pandarsil (Shiva Shakti Sponge Iron Ltd)	Sukruli	--do--	110.9	4.42	57.8	1.69	7.93	0.91	11.73
49. Jagaatpur (Cosboard Factory)	Jagatpur	Cuttack	122.8	6.64	61.5	1.85	3.65	0.35	5.21
50. Jagatpur (Pragati Milk Products Ltd.)	Jagatpur	--do--	76.8	2.76	7.2	1.08	4.08	0.51	10.29
51. Choudwar (Indian Metals and Ferro Alloys Ltd.)	Jagatpur	--do--	46.7	7.83	20.8	2.46	9.92	1.21	12.48
52. Bainchua (Maa Durga Thermal Power Company Ltd.)	Tangi	--do--	85.5	4.51	50.3	1.28	6.36	1.95	9.58
53. Bhayatangi (RSB Castings Ltd.)	Tangi	--do--	52.0	3.76	23.2	0.61	4.76	0.95	6.34
54. Nuagam (Aska Cooperative Sugars Ltd.)	Aska	Ganjam	240.8	5.22	126.8	1.47	7.29	1.20	4.21
55. Jayshree (Grasim Chemicals Ltd.)	Ganjam	--do--	176.1	5.34	91.9	1.35	15.36	5.68	18.42
Range			5.8-240.8	0.21-9.02	4.2-146.0	0.51-6.36	2.52-178.37	0.12-12.84	3.18-18.92

Table 2: Heavy metal contents (mg kg^{-1}) in the soils from mines and industrial areas of Odisha.

All the soils from these polluted areas have recorded higher than the critical limits of 0.60 and 0.20 mg kg^{-1} of available Zn and Cu, respectively. The available Zn in the soils of the present study ranged from 0.51 - 6.36 mg kg^{-1} with a mean value of 2.15 mg kg^{-1}. Highest mean available Zn was found in the soils of Jharsuguda (3.52 mg kg^{-1}) followed by Sundargarh (3.32 mg kg^{-1}) and Balasore (2.80 mg kg^{-1}). The available Cu in the soils varied from 0.21 - 9.02 mg kg^{-1} with a mean value of 3.03 mg kg^{-1}. Highest mean available Cu was observed in these polluted soils of Ganjam (5.28 mg kg^{-1}) followed by Cuttack (5.10 mg kg^{-1}), Jagatsinghpur (4.20 mg kg^{-1}), Sundargarh (3.99 mg kg^{-1}) and Jharsuguda (2.87 mg kg^{-1}).

The DTPA extractable Cr in the polluted soils ranged from 2.52 - 178.37 mg kg^{-1}. Highest Cr values (Figure 1) were observed in the mining areas of Jajpur district (ranged from 135.2 - 178.4 mg kg^{-1}, with a mean of 150.5 mg kg^{-1}) followed by Keonjhar (ranged from 24.9 - 79.5 mg kg^{-1}, with a mean of 50.5 mg kg^{-1}). The soils also contain 3.18 - 18.92 of Pb (mean 8.34 mg kg^{-1}) (Figure 2) and 0.12 - 12.84 mg kg^{-1} of Ni (mean 1.80 mg kg^{-1}) (Figure 3). Thus, it was observed that Sukinda block of Jajpur district contain very high levels of Cr, Ni, and Fe, bauxite mining areas of Koraput and industrial areas of Ganjam contain high levels of Pb, industrial areas of Sundargarh contain high levels of Zn, iron mining areas of Keonjhar contain toxic levels of Mn and Fe and these heavy metals through soil - plant - animal ecosystem causing numerous hazards to crops, livestock and human beings.
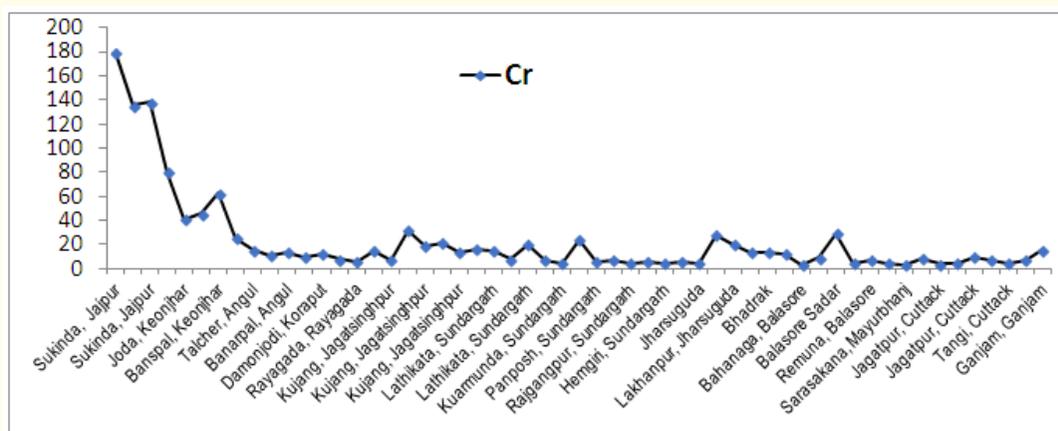
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Figure 1: Accumulation of chromium in the soils adjacent to mining and industrial areas of Odisha.
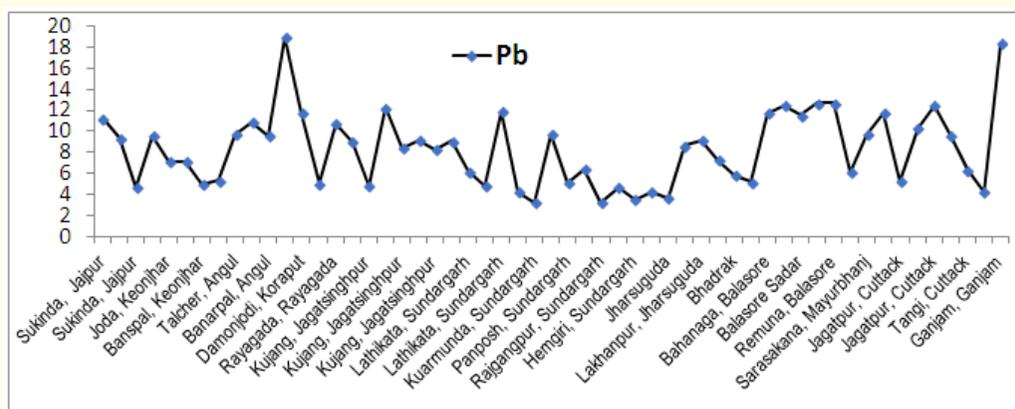

Figure 2: Accumulation of lead in the soils adjacent to mining and industrial areas of Odisha.
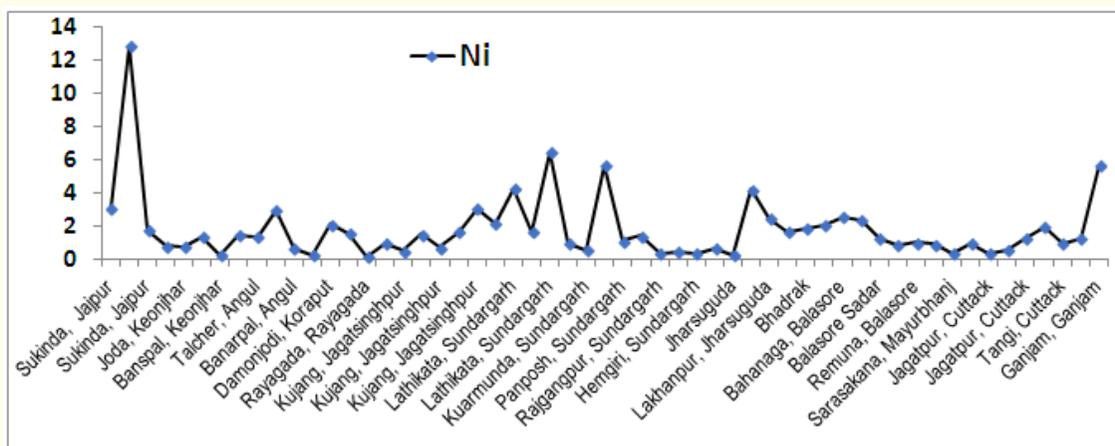

Figure 3: Accumulation of nickel in the soils adjacent to mining and industrial areas of Odisha.

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Microbial diversity and biological activities in the soils from mining and industrial areas

Highest microbial counts (Table 3) were recorded in the soils of bauxite mining areas of Koraput district followed by Keonjhar, Jajpur and Rayagada. Highest fungal counts (47 x 10^4 cfu g^{-1}) were observed in the iron mining areas of Keonjhar, whereas highest bacterial counts (54 x 10^5 cfu g^{-1}) and actinomycetes (54 x 10^4 cfu g^{-1}) were noticed in the soils adjacent to paper mill of Rayagada and coal mining areas of Sundargarh districts, respectively. Lowest microbial counts were observed in the soils adjacent to industrial areas of Cuttack and Ganjam districts.

Location and source of pollution	Total microbial counts			Soil enzyme activities			
	Fungi (1x10^4 cfu. g^{-1})	Bacteria (1x10^5 cfu g^{-1})	Actinomy-cetes (1x10^4 cfu.g^{-1})	DHA (μg TPF hr^{-1} g^{-1})	FDA (μg g^{-1} hr^{-1})	Acid Phos-phatase (μg PNP g^{-1} hr^{-1})	Alkaline Phospha-tase (μg PNP g^{-1} hr^{-1})
1. Malhar Hatting Tisco Tata (Chromium mines)	39	30	32	2.183	2.475	69.96	31.83
2. Kaliapani (Indian Metals and Ferro Alloys Limited)	32	37	25	2.457	2.511	65.91	29.88
3. Hatibari (Chromium mining areas)	38	34	27	2.356	2.522	70.14	33.1
4. Palaskaa (Iron mines)	43	45	39	2.502	2.656	60.17	27.08
5. Baneikela (Essel mining and Indus-tries Limited)	30	36	32	2.265	2.458	75.38	36.1
6. Lohanda (Iron mines)	35	48	23	1.591	1.601	31.08	23.21
7. Suakati (OMC Fe mines)	47	35	46	2.506	2.707	22.95	18.87
8. TolaJagar (Iron mines)	27	45	22	0.741	0.884	22.71	15.04
9. Santhapada (Ash pond of NTPC Limited)	26	31	24	0.686	0.882	46.79	28.35
10. Kudulau (Ash pond of NALCO Lim-ited)	36	36	31	2.046	1.456	53.63	37.34
11. Bhogabereni (NTPC Limited)	29	34	18	0.733	1.338	56.78	26.21
12. BitharBejaput (Bauxite mines)	36	52	29	0.918	0.622	24.56	26.04
13. Ambagaon (NALCO Refinery)	45	47	51	2.031	1.639	64.03	49.87
14. Sukuabada (Utkal Alumina Interna-tional Ltd.)	36	31	24	0.728	0.523	6.12	11.17
15. Karlakona (Dumping yard of JK Paper Mills)	46	54	32	1.629	1.726	11.55	16.08
16. Chanchandli (Dumping yard of JK Paper Mills)	24	25	28	0.483	0.244	13.9	19.07
17. Musadia, Paradeep (IFFCO Plant)	21	23	22	0.186	0.152	13.48	15.83
18. Baularia Palanda (Cargill India Pvt. Ltd.)	24	27	31	0.311	0.302	22.08	23.44
19. Jhimani, Paradeep (Oil Refinery)	19	20	14	0.291	0.226	16.07	9.68
20. PPL Township, Paradeep (Paradeep Phosphate Ltd.)	28	33	27	0.596	0.221	21.24	22.27
21. Atharbanki (Gypsum storage site of IFFCO plant)	39	35	42	0.728	0.523	19.12	17.17
22. Udayabata (Goa Carbon Limited)	27	41	29	0.629	0.726	11.55	16.08
23. Jhartarang (Kalunga Industrial Estate)	24	22	33	1.256	0.665	38.54	40.72
24. Marang Phiring (Sponge Iron Factory)	21	26	22	1.059	0.517	16.14	14.76
25. Goibhanga (SLM Metal Industries)	24	29	27	1.224	0.523	22.25	25.66

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26. San Brahmanitarang (Lotus Chemicals Ltd.)	27	27	29	1.504	1.024	16.29	24.35
27. Padmalaya Colony (Ferro Alloys)	29	19	23	1.124	0.646	46.38	30.56
28. Deogaon Colony (Rourkela Steel plant)	44	36	46	1.866	1.631	49.72	35.49
29. Sitalpada (Dumping yard, Rourkela Steel Plant)	23	30	35	1.085	0.297	27.83	25.62
30. Ramabahal (Scan Steels Ltd.)	21	23	29	1.189	0.652	28.45	29.17
31. Rajgangpur (OCL India Ltd.)	46	34	35	2.671	1.256	18.15	17.08
32. Lamloi (M.R. Ferro Pvt. Ltd.)	31	26	29	1.672	1.552	39.69	32.56
33. Kiripsira (Coal mines)	38	46	54	1.081	0.638	24.78	25.19
34. KanikaHemgiri Road (ACB India Ltd.)	25	29	32	1.214	0.224	13.36	17.97
35. Kurebaga (Ash pond, Vedanta Aluminiun Ltd.)	24	23	26	1.288	1.319	12.39	14.59
36. Kudopali (Samleswari Coal mines)	28	18	21	1.788	1.019	12.66	19.86
37. Belpahar (Mahanadi Coal Fields Ltd.)	37	45	42	1.849	1.862	57.84	43.12
38. Ubuda (Global Coal and Mining Pvt. Ltd.)	19	17	17	1.281	1.049	16.94	15.62
39. Randia (Ferro Alloys Corporation)	22	45	35	1.017	0.525	28.19	21.64
40. Chengagadia (Chromite plant)	31	28	34	1.669	1.283	16.34	20.81
41. Khantapara (Biotechayur Pvt. Ltd.)	19	22	28	1.392	1.054	12.17	19.12
42. Banparia (KarniThermoplast Pvt. Ltd)	21	33	26	1.429	1.296	26.62	22.54
43. Khannagar (HariPlast)	33	28	29	1.479	1.365	12.26	18.75
44. Bampada (Birla Tyres)	35	47	35	1.605	0.888	36.48	31.79
45. Balagopalpur (Balasore Alloys Ltd)	22	21	36	1.364	1.424	12.38	20.95
46. Rathalpur (Emami Paper Mills Ltd)	38	33	45	1.712	1.165	21.38	21.78
47. Hemachandrapur (Sri Mayur Biscuit Co Pvt. Ltd)	21	22	23	1.393	1.543	11.88	18.38
48. Pandarsil (Shiva Shakti Sponge Iron Ltd)	26	32	29	1.595	2.058	12.77	18.94
49. Jagaatpur (Cosboard Factory)	19	23	17	0.436	0.703	16.26	12.59
50. Jagatpur (Pragati Milk Products Ltd.)	22	31	25	0.485	0.596	18.59	16.35
51. Choudwar (Indian Metals and Ferro Alloys Ltd.)	15	27	23	0.716	1.048	15.84	17.85
52. Bainchua (Maa Durga Thermal Power Company Ltd.)	17	24	25	0.695	0.569	21.30	17.47
53. Bhayatangi (RSB Castings Ltd.)	20	26	27	0.357	0.548	18.87	20.31
54. Nuagam (Aska Cooperative Sugars Ltd.)	18	27	16	0.758	1.124	21.25	16.52
55. Jayshree (Grasim Chemicals Ltd.)	14	19	18	0.638	0.836	15.34	17.95
Range	14-47	17-54	14-54	0.186-2.671	0.152-2.707	6.12-75.38	9.68-49.87
Mean	28.7	31.6	29.4	1.282	1.114	28.34	23.27

Table 3: Microbial counts and enzyme activities in soils from mines and industrial areas.

Citation: K Laxminarayana., *et al.* "Assessment of Soil Microbes and Enzyme Activities in the Degraded Soils Adjacent to Industries and Mines and its Relation with Heavy Metal Contaminants". *Acta Scientific Agriculture* 4.8 (2020): 77-90.

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Dehydrogenase activity is a measure of microbial metabolism and thus of the oxidative microbial activity of soils and dehydrogenases are involved in the oxidation and energy transfer of microbial cells. Highest dehydrogenase activity (Table 3) was noticed in the soils of Jajpur district (ranged from 2.183 - 2.457 µg TPF hr^{-1}g^{-1}, mean 2.332 µg TPF hr^{-1}g^{-1}) followed by Keonjhar (mean 1.921 µg TPF hr^{-1}g^{-1}). Fluorescein Diacetate Hydrolysis Assay is often used as an indicator of microbial activity and is correlated with microbial respiration [15]. As such it is a simple, non-specific, but sensitive technique that can be used to estimate relative levels of microbial activity in soils, and has been recommended as a useful parameter to assess soil quality [16]. In line with the dehydrogenase activity, highest Fluorescein Diacetate Activity (ranged from 2.475- 2.522 µg g^{-1} hr^{-1}, mean 2.508 µg g^{-1}hr^{-1}) was observed in the Cr mining areas of Jajpur district followed by iron mining areas of Keonjhar district (mean 2.062 µg g^{-1} hr^{-1}). Lowest biological activities in terms of DHA and FDA were observed in the soils contaminated with industries of Cuttack, Ganjam, Jagatsinghpur and Jharsuguda districts of Odisha. Higher activities of dehydrogenase and fluorescein diacetate in these polluted soils, which may be ascribed to greater availability of substrates that support such activities as well as the cofactors of several enzymes, were highly influenced by supplementing of micronutrients [17].

An increasing trend of acid phosphatase was observed in all the soil samples collected from polluted areas of Odisha over that of alkaline phosphatase. Highest acid phosphatase activities (Table 3) were observed in the soils contaminated with Cr mining activities at Sukinda block of Jajpur district (mean of 68.67 µg PNP g^{-1} hr^{-1}) followed by bauxite mining areas of Koraput (44.30 µg PNP g^{-1} hr^{-1}), while the lowest acid phosphatase activities were noticed in the soils. Highest mean alkaline phosphatase activities were recorded in the soils of Koraput district (37.96 µg PNP g^{-1}hr^{-1}) followed by Sundargarh (26.59 µg PNP g^{-1} hr^{-1}). Both acid and alkaline phosphatase activities were found lowest in the polluted soils of Cuttack, Ganjam and Rayagada districts. The activities of both alkaline and acid phosphatases were closely related to soil pH, parent material and other soil forming factors [18].

Relationship between soil microbes and enzyme activities

Perusal of the data in table 4 revealed that the fungi had significantly higher relationship with dehydrogenase activity (r = 0.599**) and FDA (r = 0.529**). It was noticed that among the soil microflora only fungi had significant relationship with acid phosphatase (r = 382*) and alkaline phosphatase (r = 0.332*), whereas actinomycetes had significant relationship with alkaline phosphatase (r = 0.429*). The results indicated that fungi and actinomycetes significantly influenced the soil enzymes, which in turn involved in biochemical transformation of nutrients in the soil.

Soil microbes	DHA	FDA	Acid Phosphatase	Alkaline Phosphatase
Fungi	0.667**	0.534**	0.427*	0.412*
Bacteria	0.307*	0.300	0.341*	0.318*
Actinomycetes	0.467**	0.269	0.262	0.487**

Table 4: Relationship (r) between soil microbes and enzymes activities.

*and** Significant at 5.0 and 1.0 per cent level, respectively.

Relationship between soil properties and microbial variables

The soil pH had significant relationship with dehydrogenase activity (r = 0.510**), FDA (r = 0.331), acid phosphatase (r = 0.349*) and alkaline phosphatase (r = 0.380*) (Table 5). Variations in soil reaction had no effect on multiplication of soil microbes, but it had positive effect on enzyme activities in the soil. The changes in microbial biomass and microbial activity were related to the variations in pH, which induce the development of bacteria to the detriment of fungi, and to the nutrient levels after addition of various organic amendments [19].

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Soil properties	Fungi	Bacteria	Actinomycetes	DHA	FDA	Acid phosphatase	Alkaline phosphatase
pH	0.310*	0.097	0.291	0.568**	0.340*	0.363*	0.445**
EC	-0.195	-0.050	-0.207	-0.075	0.043	0.151	-0.010
Org. C	0.696**	0.387*	0.666**	0.574**	0.474**	0.364*	0.406*
Available N	0.170	0.348*	0.005	0.096	0.375*	0.395*	0.231
Available P	-0.113	-0.025	0.037	-0.171	0.014	0.054	0.018
Available K	0.459**	0.469**	0.494**	0.334*	0.322*	0.444**	0.499**

Table 5: Relationship (r) between soil chemical properties and microbial variables.

*and** Significant at 5.0 and 1.0 per cent level, respectively.

The organic carbon showed highly significant relationship with soil fungi (r = 0.763**) followed by actinomycetes (r = 0.701**) and fungi (r = 0.389*). It was also noticed that dehydrogenase activity, fluorescein diacetate assay, acid phosphatase and alkaline phosphatase had significant relationship with soil organic C and the 'r' values were found to be 0.593**, 0.466*, 0.359* and 0.402*, respectively). Organic matter is the store house of various groups of microbes and hence improvement in organic matter had significant role in accumulation of micro-flora and various groups of enzymes involved in different bio-chemical processes in the soil. Soil phosphatase activity was closely related to soil organic matter content, supporting previous reports that elevated organic matter levels promote soil phosphatase activity [20].

The salt content of the soil had non-significant relationship with microbes and biological activities. Significant relationship was observed between soil fungi and available N, P and K (r = 0.567**, 0.549**and 0.474**, respectively), however, available P showed highly significant relationship with actinomycetes (r = 0.601**) and available K had significant relationship with bacteria (r = 0.474**), indicated that soil bacteria were mostly involved in the transformation of N, P and K in comparison to other microbes in the heavy metal contaminated soils of Odisha. Dehydrogenase Activity had significant relationship with available N and P (r = 0.367* and 0.313*, respectively), whereas FDA showed significant relationship with available N and K (r = 0.539** and 0.314*, respectively). Both dehydrogenase and FDA had significant relationship with available N, P and K, indicated that these two enzymes are involved in the transformations of N, P and K. Alkaline phosphatase had highly significant relationship with available P (r = 0.470**) rather than acid phosphatase (r = 0.399*), indicated that alkaline phosphatase had greater contribution in the buildup of available P status of the soil in comparison to acid phosphatase activity. Organic amendments and associated plant residues may supply additional sources of la-bile C and P to the oil, which can stimulate microbial growth and biochemical activity (Carpenter-Boggs., *et al*. 2000).

Relationship between soil microbial variables and heavy metals

The data in table 6 revealed that the soil micro-flora had negative and/or non-significant relationship with all the heavy metals, except Cu and Cr which had significant relationship with actinomycetes and bacteria (r = 0.356* and 0.312*, respectively), indicated that the accumulation of heavy metals in these polluted soils as influenced by effluents released from the industries as well as mining activities had detrimental effect on soil microbes. Microorganisms are the first biota that undergoes direct and indirect impacts of heavy metals. Some metals (e.g. Fe, Zn, Cu, Ni, Co) are of vital importance for many microbial activities when occur at low concentrations. These metals are often involved in the metabolism and redox processes. Metals facilitate secondary metabolism in bacteria, actinomycetes and fungi [22,23]. Chromium is known to have stimulatory effect on both actinorhodin production and growth yield of the model actinomycetes. However, high concentrations of heavy metals may have inhibitory or even toxic effects on living organisms [24]. Adverse effects of metals on soil microbes result in decreased decomposition of organic matter, reduced soil respiration, decreased diversity and declined activity of several soil enzymes [25]. The toxic concentration of heavy metals may cause enzyme damage and consequently their inactivation, as the enzymes-associated metals can be displaced by toxic metals with similar structure [24]. Similarly, the soil enzyme activities also greatly influenced by the accumulation of heavy metals as indicated by negative and/or non significant relationship was observed between enzyme activities and heavy metals, except Cr, which showed positive and significant relationship with microbial variables. The results indicated that increased levels of heavy metals in the soils of the present study caused deleterious effects on microbial activities that led to degradation of the soil quality.

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Microbial variable	Fe	Cu	Mn	Zn	Cr	Ni	Pb
Fungi	-0.172	-0.152	0.082	0.037	0.343[*]	-0.001	-0.067
Bacteria	-0.092	-0.092	0.095	-0.099	0.150	-0.040	0.159
Actinomycetes	-0.253	0.155	-0.043	0.314[*]	0.051	-0.022	-0.042
DHA	-0.072	-0.318[*]	0.054	0.120	0.494[**]	0.226	-0.069
FDA	0.042	-0.379[*]	0.161	-0.027	0.628[**]	0.180	0.073
Acid Phosphatase	0.062	-0.330[*]	0.155	0.001	0.603[**]	0.291	0.041
Alkaline Phosphatase	-0.039	-0.165	-0.033	0.196	0.273	0.266	0.137

Table 6: Relationship (r) between soil microbial variables and heavy metals.

[*]and[**] Significant at 5.0 and 1.0 per cent level, respectively.

Conclusion

Heavy metals pose a significant threat towards the soil environment and the rapid industrialization will result in increasing problems of environmental pollution. Therefore, it is necessary to carry out the continuous monitoring of both industrial areas and their vicinities for possible transgressions of the limits given by the authorities. When necessary, the remedial measures should be applied as soon as possible by all available means. The soils adjacent to mining and industrial areas in some parts of Odisha contain toxic levels of Fe, Mn, Cr, Pb, and Ni limiting the productivity of various crops and these heavy metals suppress the soil enzyme activities. Accumulation of heavy metals due to mining activities and release of effluents from industrial areas and consequently their entry in to the soil-plant system is very much harmful and there is an urgent need to advocate proper remedial measures so as to minimize the levels of these toxic elements in the soil-plant-animal-human chain. On the other hand, research should be promoted to understand the mechanisms of microbial response to heavy metal pollution and to enable screening for possible resistant microorganisms that could be used for both remediation and restoration of soil environment fertility.

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