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Soil Quality and Heavy Metal Contamination of Soils in Mindi Industrial Area, Visakhapatnam, Andhra Pradesh, India

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Abstract: Agricultural land near to industries, often un-noticed, accumulates lot of harmful chemicals and heavy metals. A study was done to assess the soil quality (chemical and biological) near Hindustan Zinc Limited (HZL) in Mindi area, for paddy fields (major crop) and corresponding adjacent fallow area with and without exposure to effluents. Soil samples were collected from paddy growing site exposed to effluents (PGSEE), paddy growing site without exposure to effluents (PGSWE), fallow land without exposure to effluents (FWE) and fallow land exposed to effluents (FEE). Fallow fields with effluents release (FEE) were high in Cu (7.8 mg kg^{-1}), Zn (15.5 mg kg^{-1}), Pb (87.8 mg kg^{-1}) and Cd (1.8 mg kg^{-1}) in comparison to paddy cultivated fields. The chemical and biological soil quality index and relative soil quality index shows that PGSWE is having better chemical soil quality index (CSQI): 14.29, biological soil quality index (BSQI): 2.00 soil health condition than PGSEE (CSQI: 10.20 and BSQI: 0.69).

Keywords: Heavy metal, Soil Quality, Soil health, Industrial effluent

Soil is an important system of terrestrial ecosystem. There is a direct impact of pollutants on minerals, organic matter and microbial community of soil (Nagaraju *et al.,* 2007). The discharge of industrial effluents especially without treatment may have profound influence on physico-chemical and biological properties of soil related to soil fertility. Rapid industrialization and ever increasing population, there has been a substantial increase in the generation of industrial wastes leading contamination of water, air and land resources. Increased inputs of metals and synthetic chemicals in the terrestrial environment due to rapid industrialization coupled with inadequate environmental management in the developing country like India, has led to large-scale pollution of the environment (Adriano,1995; Hooda *et al*., 2004). Many metals such as Zn, Cu, and Se are essential elements for normal growth of plants and living organisms, however, high concentrations of these metals become toxic, other metals, which are not included in the group of essential elements, such as Pb or Cr, may be tolerated by the ecosystem in low concentration, but become harmful in higher concentrations. The availability of metal compounds in soil is influenced by the pH, temperature, redox potential, cation exchange capacity of the solid phase, competition with other metal ions, ligation by anions and composition and quality of the soil solution (Mapanda *et al.,* 2005; Skordas *et al*., 2005)

The contamination of soils by heavy metals is a significant problem as it negatively influences soil characteristics that potentially influence productivity and food quality, and environmental quality. The fate of heavy metals in soil is controlled by the effects of various chemical, physical and biological processes and their interactions on the soil. With accumulation of heavy metals in soil beyond its holding capacity makes them available to plants growing on them, leading to contamination of food, which potentially could be a health hazard (Muchuweti *et al*., 2006). Many field studies of metal contaminated soils have demonstrated that the elevated metal loadings can result in decreased microbial community size and decrease in activities such as organic matter mineralization and leaf litter decomposition. Industries are the major sources of soil pollution with the heavy metals Zinc (Zn) and Cadmium (Cd). Elevated levels have toxic effects on micro- organisms, which play an important role in soils.

Visakhapatnam attracted for establishment of major industries like M/s. Hindustan Petroleum Corporation Ltd., (Formerly M/s. CALTEX – Refinery), M/s. Hindustan Zinc Ltd., (Zinc & Lead Smelter), M/s. Coromandel Fertilisers Ltd., (Complex Fertiliser Plant) etc., due to close proximity to a natural harbor and sea port. Mindi area has been identified as one of the most polluted industrial area of Vishakhapatnam; AP (A.P. Pollution Control Board, 2010). The present work was undertaken at Mindi industrial area with an objective to study the impact of industrial pollution on soil quality and heavy metal contamination to cropped field near to the industry.

MATERIAL AND METHODS

Mindi, Vishkhapatnam lies between 17^0 40' 30" and 17^0 40' 45" North latitude and 83^0 16' 15" and 83^0 21' 30" East longitude is identified as critically polluted area in Vishakhapatnam. The industries dispose wastes into soil or water which changes the chemical and biological parameters of the soils. In order to analyse soil quality (chemical and biological), thirty two soil samples were collected from three different locations (paddy growing site exposed to effluent (PGSEE) and not exposure to effluent (PGSWE), fallow lands exposed to effluents (FEE) in Mindi area of Visakhapatnam. The composite samples were air dried, crushed lightly, and then passed through a 2-mm sieve. All subsequent analyses were performed on the <2-mm fraction using standard methods. The soil pH and electrical conductivity was measured in a 1:2.5 soil water suspension using a glass electrode and conductivity meter (Elico, India), respectively. Organic carbon was determined by wet digestion method (Walkley and Black, 1934) and cation exchange capacity by ammonium acetate method (Jackson, 1973). Available heavy metals in the soil were determined by extracting the soil with 0.01 M DTPA as described by Lindsay and Norvell (1978). Soil samples were digested in HNO3–HClO4 acid mixture (6:3) as described by Jackson (1973) and analysed for Cd, Cr, Ni and Pb contents with an atomic absorption spectrophotometer. Particle size distribution determined by the hydrometer method (Bouyoucos, 1962), Available nitrogen, potassium and phosphorus were estimated by Kjeldalhl method, flame photometer method and Olsen method, respectively. Micronutrients like Na, Ca, Mg, Fe, Cu, Zn and Mn estimated by DTPA method. Calculation of soil microbial biomass carbon was done by Fumigation extraction method.

Soil quality: The chemical soil quality index (CSQI), biological soil quality index (BSQI) and overall soil quality index (SQI) were estimated by using linear scoring technique following 'more is better' and 'less is better' approach depending upon the importance and nature of the parameters. To assign the scores, these parameters were arranged in order depending on whether a higher value was considered "good" or "bad" in terms of soil quality and function. In case of 'more is better' indicators (pH, EC, OC, N, P, K, Ca, Mg, Carbon fractions, CEC, DHA, MBC and Mn), each observation was divided by the highest observed value such that the highest observed value received a score of 1. For 'less is better' indicators (Na, Pb, Cr, Cd, Ni, Fe, Zn, Cu), the lowest observed value (in the numerator) was divided by each observation (in the denominator) such that the lowest observed value received a score of 1. After performing these steps, to obtain soil quality index (SQI), the soil quality indicator scores for each observation were summed up using the following relation:

$$SOI = \sum_{i=1}^{n} (Si)$$

Where Si is the score for the subscripted variable based on the assumption is that higher index scores meant better soil quality or greater performance of soil function. The SQI values for chemical and biological indicators were computed separately. Finally the overall SQI were computed to understand the performance of the soil quality indicators by pooling CSQI and BSQI. For better understanding and relative comparison of the performance of treatment type/situations, the SQI values were reduced to a scale of 0-1 by dividing all the SQI values with the highest SQI value. The numerical values so obtained clearly reflect the relative performance of the management treatments, hence were termed as the relative soil quality indices (RSQI).

RESULTS AND DISCUSSION

Physico-chemical properties: The bulk density of soils varied between 1.1 to 1.09 Mg m^{-3} and was slightly higher in the cultivated land than in fallow may be because lands are under continuous paddy cultivation. Soil texture for PGSEE is mainly sandy loam while texture of PGSWE varied from sandy clay loam to clay loam while fallow lands had clay loam texture. The percentage of clay is relatively higher in PGSWE than PGSEE thus better soil health. The pH of the test soil ranged from 6.37 to 7.45. In PGSEE, the soil is slightly acidic (6.37) while in PGSWE soil is mildly alkaline (7.45). Fallow lands without exposure to effluents (FWE) and fallow lands exposed to effluents (FEE) were near to neutral. The salt content of soils, measured in terms of EC, ranged from 0.217-1.08 dS m^{-1} (Table 1). The EC value was slightly more in cultivated area than fallow plots. Soil organic carbon was remarkably high in this area, even in fallow lands there was good amount of organic carbon build-up. The organic carbon ranged in between 0.18 to 0.46 g kg^{-1}. The area affected by industries effluent had more organic carbon because of some organic material present in the effluent. Available nitrogen was significantly low in all the sites in comparison with PGSWE. The CEC ranged from 21.38 to 31.08 cmol (p^+) kg^{-1}. In PGSEE and FEE soils, its concentration was 22.88 and 21.38 cmol (p^+) kg^{-1}, respectively while in soils of PGSWE and

FEW; the value was 31.08 and 29.60 cmol (p^+) kg^{-1} respectively, indicating better nutrient storage capacity of these soils. The calcium ranged in the soil between 3.66 to 9.21 cmol kg^{-1}. The soils of paddy growing site exposed to effluent (PGSEE) and FWE, recorded was 3.66 and 4.99 cmol kg^{-1}, whereas, in soils of PGSWE and FEE was 9.09 and 9.21 cmol kg^{-1}, respectively. The Magnesium ranged between 1.53 to 2.69 cmol kg^{-1}, PGSEE and FWE were 1.76 and 1.53 cmol kg^{-1}. In soils of PGSWE and FEE values were 2.69 and 2.16 cmol kg^{-1} respectively. In soils of PGSEE, the Sodium concentration was 1.71 cmol kg^{-1}, while PGSWE having high level of sodium concentrations (2.31 cmol kg^{-1}). In soils of FEW and FEE, concentration was 0.72 and 0.54 cmol kg^{-1}, respectively indicating very low levels of sodium in soil.

Biological properties: The Dehydrogenase activity is very high in soils of PGSWE followed by PGSEE showing 2.31 mg and 1.71 mg, while for fallow land, values were very low showing 0.72 mg in FWE and 0.54mg in FEE. The SMBC values were in the range of 145.26 to 194.51 µg g^{-1} being very high in soils of PGSWE. The SMBC value was 145.26 indicating low in soils of FEW followed by 139.46 in soils of PGSEE. This shows that effluent from industries affect the microbial population especially in agricultural fields. The lowest SMBC in the PGSEE proves how badly the effluent from industries reduces the microbial population in cultivated area nearby to industry.

Heavy metal concentration: The concentration of heavy metals (Cd, Ni, Cu, Zn, Cr, Pb and Mn) in soils varied from 1.0 to 967 mg kg-^{1} and, the values for most of the metals were within the critical limits for Indian soils. The concentration of Cr was low compared to other heavy metals and ranged from 0.03 to 0.04 mg kg^{-1}. The Fe and Cu concentration was more in PGSWE than PGSWE soils. The zinc concentration was higher (11.70 mg kg^{-1}) in PGSEE than PGSWE (11.16 mg kg^{-1}), this may be because of the effluents of zinc metal industry added to soil. Pb concentration was between 3.80 to 87.77 mg kg^{-1}. The heavy metals from the industries effluent is not showing huge accumulation in the cultivated area may be because of constant uptake by the crop. Thus, it is severely affecting the quality of crops grown in this area.

Soil quality: The chemical and biological soil quality index

Table 1. Primary properties of soils of Mindi area

Location	pH	EC	OC	CEC	Very labile	Labile	Less labile	Available N	Available P	Available K
					OC (%)			Kg ha^{-1}		
PGSEE	6.37	0.46	0.40	22.88	0.18	0.11	0.13	108.71	16.70	184.46
PGSWE	7.45	1.08	0.46	31.08	0.22	0.28	0.11	154.71	24.10	251.63
FWE	7.41	0.21	0.18	29.60	0.10	0.12	0.05	39.38	12.48	179.42
FEE	7.32	0.33	0.27	21.38	0.10	0.09	0.18	105.92	18.85	196.94
CD (p=0.05)	0.34	0.15	0.66	4.32	0.07	0.07	NS	35.51	3.03	55.09

Paddy growing site exposed to effluents (PGSEE), Paddy growing site without exposure to effluents (PGSWE)
Fallow land without exposure to effluents (FWE) and Fallow land exposed to effluents (FEE)

Table 2. Secondary micronutrient and heavy metal concentration in study area

Location	Na	Ca	Mg	Fe	Cu	Zn	Mn	Pb	Cr	Cd	Ni
	cmol kg^{-1}			mg kg^{-1}							
PGSEE	1.71	3.66	1.76	82.79	3.73	11.70	4.61	30.17	0.04	0.37	0.63
PGSWE	2.31	9.09	2.69	88.30	4.90	11.16	11.04	46.04	0.04	0.29	0.86
FWE	0.72	4.99	1.53	6.26	0.89	2.49	6.57	3.80	0.04	0.03	0.20
FEE	0.54	9.21	2.16	7.94	7.85	15.51	7.09	87.77	0.03	1.81	0.03
CD (p=0.05)	1.13	1.18	0.34	32.04	1.61	3.54	3.85	4.52	NS	0.05	0.23
Mean	1.32	6.74	2.04	46.32	4.34	10.22	7.33	41.95	0.04	0.63	0.43

Table 4. Chemical and biological soil quality index and relative soil quality index

Location	*CSQI*	RSQI (Chemical)	BiSQI	RSQI (Biological)	Overall SQI	Overall SQI
PGSEE	10.20	0.71	1.16	0.69	11.36	0.70
PGSWE	14.29	1.00	2.00	1.20	16.29	1.00
FWE	13.89	0.97	0.84	0.50	14.73	0.90
FEE	13.32	0.93	0.86	0.52	14.18	0.87

and relative soil quality index shows that PGSWE is better (CSQI: 14.29 and BSQI: 2.00) soil health than PGSEE (CSQI: 10.20 and BSQI: 0.69), (Table 4). This indicate that effluents from the industry are affecting the agricultural field.

Table 3. Dehydrogenase activity and microbial biomass carbon status

Location	Soil enzymes-dehydrogenase (DHA) mg TPF 24/h/g	Soil microbial biomass carbon (SMBC) µg/g
Effluent effected area	1.71	139.46
Non-effected area	2.31	194.51
Fallow land-far industry	0.72	145.26
Fallow land-near industry	0.54	160.25
CD (p=0.05)	0.99	17.22

CONCLUSION

Soil environments of the study that effluent coming out of HZL affecting indicate better nutrient storage capacity of these soils may have become polluted by a large variety of toxic compounds. Many of these compounds at high concentrations or following prolonged exposure have the potential to produce adverse effects in human and other organisms. These include the danger of acute toxicity, mutagenesis (genetic changes), carcinogenesis, and teratogenesis (birth defects) for humans and other organisms. Some of these man-made toxic compounds are also resistant to physical, chemical, or biological degradation and thus represent an environmental burden of considerable magnitude. The study area *i.e.* Mindi in Visakhapatnam is also worst affected by the industrial growth. Our investigation shows that the soil quality of both fallow and agriculture land near Hindustan Zinc limited are severely affected by the effluent coming out of the industry and require immediate attention from the people and farmers living in this area. It was concluded from the study that effluent coming out of HZL affect nutrient storage capacity of these soils. The paddy growing site having exposure to effluent from the industry shows drastic reduction in soil quality as compared to fallow land nearby.

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