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Micronutrient Status in Soil of Central India

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Abstract

Two major issues, *i.e.* large crop productions and huge anthropogenic activities (e.g. fuel burning and mineral roasting) disturb the micronutrient balance in the soil of India. In this work, the available and total status of eight micronutrients *i.e.* Fe, Mn, Cu, Zn, Co, Ni, Mo, and S of the soils in the most urbanized area: Raipur area, Chhattisgarh, India (extending over ≈ 2 × 10^4 km^2) is described. The available status of micronutrients *i.e.* Fe, Mn, Cu, Zn, Co, Ni, Mo and SO_4^{2-} in the soils (n = 100) was ranged from 30 - 8253, 205 - 2800, 2.0 - 8.1, 0.7 - 5.0, 2.2 - 31.2, 0.1 - 13.4, 0.1 - 8.9 and 41 - 747 mg/kg with mean value of (at 95% probability) 642 ± 186, 1178 ± 119, 4.3 ± 0.3, 2.3 ± 0.2, 12.8 ± 1.3, 3.9 ± 0.6, 1.5 ± 0.3 and 281 ± 25 mg/kg, respectively. The concentration variations, deficiencies and toxicities of the micronutrients in the soil are discussed.

Keywords

Soil, Micronutrient, Available, Total Content

1. Introduction

The micronutrients *i.e.* Fe, Cu, Zn, Mn, Co, Ni, Mo, and S in soil play a very important role in plant growth, productivity, soil fertility and animal nutrition [1]. The main functions of the micronutrients in living organism are structural components of cell constituents and its metabolically active compounds, in the maintenance of cellular organization, in energy transformation, in enzyme action, etc. [2]. The increment in nutrient supply beyond a certain limit resulting in the decreased yield of plants is often be associated with the production of specific toxic effects [3]. The incidence of micronutrient deficiencies in soil and plants is increasing due to high and multiple plant yields. The quantification of both total and available (active form) of nutrients in soil is important [4]. The main sources of micronutrients in soils are rock weathering and atmospheric deposition in form of dust, precipitates, volatile compounds, etc. The micronutrients in soil occur in different chemical forms *i.e.* water so-

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luble, exchangeable, specifically adsorbed, chelated or complexed, secondary clay minerals or oxide, primary minerals, etc. [5].

Their available contents were leached out from soil with various extractants *i.e.* diethylenetriaminepenta acetic acid (DTPA), ammonium bicarbonate-DTPA (AB-DTPA), triethanolamine-DTPA (TEA-DTPA), Mehlich-1 (0.05 N HCl + 0.025 N H_2SO_4), Mehlich-3 (0.2 N CH_3COOH + 0.25 N NH_4NO_3 + O.O15 N NH_4F + 0.013 N HNO_3 + 0.001 M EDTA), acid ammonium acetate-EDTA (AAA-EDTA), $MgCl_2$, HCl (0.05 N), HNO_3 (0.31 N), ammonium acetate, water, etc. [6]. However, most of these extractants were suffered from some shortcoming *i.e.* unable to extract several trace elements present in soil, not always efficient for all nutrients, etc. Thus now a days, multi-nutrient extractants *i.e.* Mehlich-3, AB-DTPA, TEA-DTPA, acid ammonium acetate-EDTA etc. were widely used for the extraction of micronutrients and trace elements from the soils [6]. Among them, AB-DTPA and TEA-DTPA were claimed better extractant than Melich-3 for Zn and Cu, but they extracted only Zn, Cu, Mn, and Fe. However, the AAA-EDTA leached out several nutrients *i.e.* Mn, Fe, Co, Ni, Cu, Zn, Al, Cd, Mo, Cr, Pb, Sr, P, etc. Ammonium oxalate, ammonium acetate, hot water, etc. were reported for the leaching of the available Mo from the soil. Of these oxalate is widely used for the extraction of available Mo from soil but it required prolonged extraction period (≈ 24 hr). The hot water extraction was recommended for leaching of the available Mo from the soil. Calcium chloride, Bray-1 (0.03N NH_4F + 0.025 N HCl), Morgan's reagent (sodium acetate-acetic acid, pH 4.8), deionized water, etc. were reported for the extraction of S from soil. The total content of micronutrients in soil was leached out with acids *i.e.* aqua-regia, $HClO_4$, HF, $HClO_4$ + HNO_3, H_2SO_4 + HCl + HNO_3, etc. [6].

The micronutrient status in surface soils of some parts of India was reported [7]-[23]. However, the information on the levels of micronutrient *i.e.* Co, Ni and Mo in the soil is lacking. In this work, the status of eight micronutrients *i.e.* Fe, Cu, Zn, Mn, Co, Ni, Mo, and S in surface soils of 100 villages of Raipur district is described. The concentration variations, deficiencies and toxicities of the micronutrients in the soil are discussed.

2. Materials and Methods

2.1. Study Area

The most of urbanization and industrialization in central India has been marked nearby capital city, Raipur, Chhattisgarh state, India. Raipur area includes Raipur district (22˚33'N - 21˚14'N and 82˚6' - 81˚38'E) and surrounding districts *i.e.* Balodabazar and Gariabandh. They are situated in the fertile plains of Chhattisgarh region of the country. Hundred city, town and villages of Raipur area ($\approx 2.0 \times 10^4$ km^2) were selected for determining the micronutrient status of the soil.

2.2. Sample Collection

Generally, three different types of soil *i.e.* red laterite, gray, yellow soils occurred in this region. Three different types of soil from 100 villages of Raipur block were collected, **Figure 1**. Soils were taken from horizon of 0 - 15 cm depth. A total 300 soil samples were collected in February 2013 as described in the literature [24].

2.3. Analysis of pH and Extraction

The soils were dried, ground and sieved through a 2-mm sieve. All samples were stored in a 500-mL wide mouth polythene bottles for the analysis. A 10.0 g weighed amount of soil was taken in a 100-mL polythene conical flask by mixing with 20 mL deionized water. The mixture was shaken for 6 hrs, and their pH and electrical conductivity (EC) values were measured with the Hanna sensor-HI 991300N.

A mixed solution of reagents (E. Merck) *i.e.* AAAA-EDTA for the extraction of nutrient *i.e.* Mn, Fe, Co, Ni, Cu, Zn and $PO_4^{3-}$was used by dissolving 38.5 g ammonium acetate, 9.5 g Na_2EDTA and 29 mL acetic acid (17 M) into 1 L deionized water [25]. A 10 g dried and ground soil sample was taken into a 250-mL polyethylene flask with subsequent addition of 100 mL AAAA-EDTA solution. The mixture was equilibrated for 1 hr with a shaker, and solution was filtered through a 0.45 µm glass fiber filter in a 100-mLpolyethylene volumetric flask.

For Mo, a 10 g soil sample was taken into 250-mL conical polyethylene flask by mixing with 100 mL deionized water [26]. It was heated at boiling temperature for 10 min by subsequent filtering the cold solution as above. The activated charcoal and hot water were employed for the extraction of the available content of sulfate. A 10 g soil sample was mixed with 1 g activated charcoal and 100 mL deionized water into a 250-mL conical

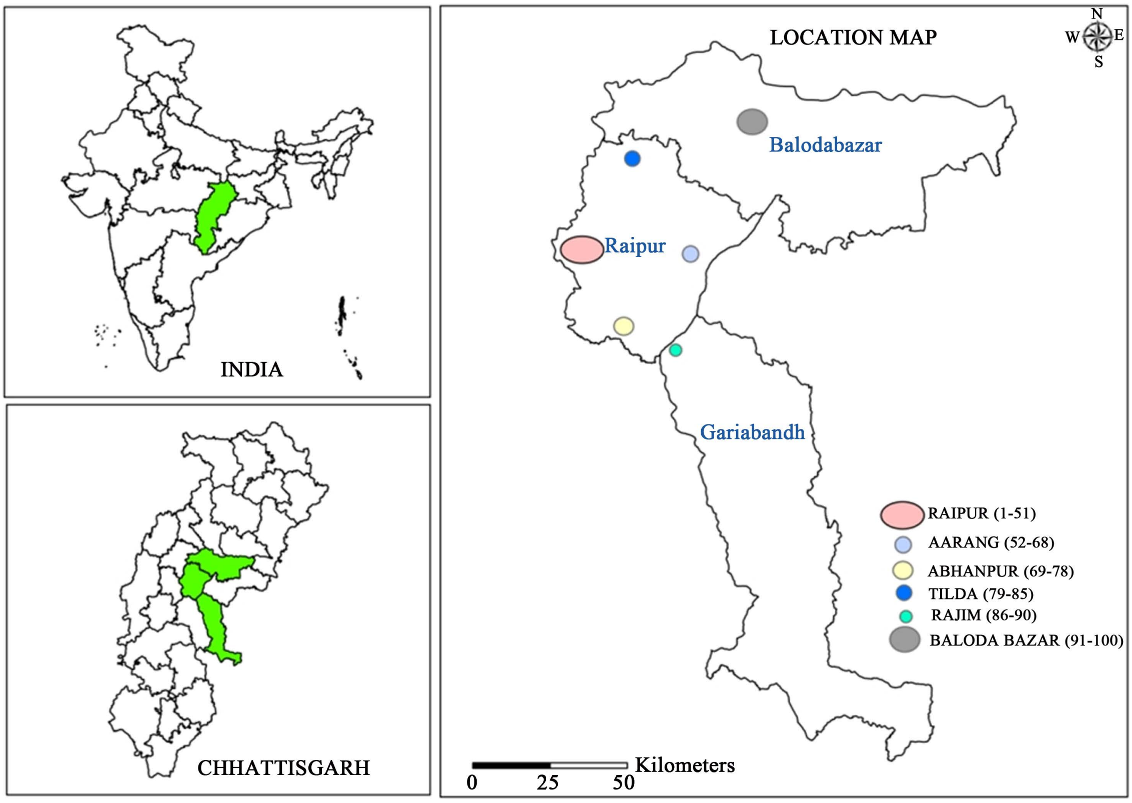


Figure 1. Representation of sampling locations in Chhattisgarh state of the country.

polyethylene flask. The mixture was shaken for a duration of 1 hr by a shaker and solution was filtered through a 0.45 µm glass fiber as above.

The mixed acid (H_2SO_4 + HCl + HNO_3) was used for extraction of the total content of micronutrients *i.e.* Mn, Fe, Co, Ni, Cu and Zn. A 1.0 g dried and powdered soil sample was taken in a 100-mL Teflon beaker. Into it, 30.0 ml of mixed acid solution (H_2SO_4 + HCl + HNO_3) was added. The mixture was heated until white fumes were no longer emitted. The residue was washed with hot dilute hydrochloric acid (0.01 N) and the hot water (50˚C). The mixture was filtered through a 0.45 µm glass fiber as above.

For leaching of total content of sulfate, a 1 g soil sample was mixed with 50 mL solution of acids: (HNO_3 + $HClO_4$) into a 100-mL Teflon beaker by keeping overnight (12 hr). The solution was concentrated to 20 mL by gentle heating, and the cold solution was filtered through a glass fiber as above. The filtrate was evaporated to the dryness by subsequent dissolving with deionized water in a 50-mL polyethylene flask.

2.4. Analysis of Micronutrients

The Flame GBC 932AAwas used for analysis of metals *i.e.* Mn, Fe, Co, Ni, Cu, Zn and Mo in the soil. The Dionex ion chromatography-1100—was employed for analysis of SO_4^{2-} and PO_4^{3-}.

3. Results and Discussion

3.1. Soil Characteristics

The agricultural land includes ≈ 50% area of the total land of the studied area. Three types of soils *i.e.* gray, yellow and red are available in the studied area. The red and yellow soil was originated by weathering of various rocks *i.e.* quartz, feldspars, mica and iron coated quartz formed over different geological periods. The yellow color was ascribed to the higher degree of hydration of the ferric oxide in these soils. The color shaded was also varied from reddish yellow to yellowish brown with often fine textured. The pH and EC of soil was ranged from 4.7 -7.7 and 100 - 900 µS/cm.

3.2. Iron

The levels of available micronutrients in the soils of Raipur area is presented in **Table 1**. Iron comprises about 5% of the earth's crust and is the fourth most abundant element in the lithosphere [27]. The most of the soil iron was found in primary mineral, clays, oxides and hydroxides. The available and total content of Fe in soils of the studied area were varied widely and ranged from 30 - 8253 and 11676 - 40,928 mg/kg with mean value of 642 ± 186 and 19930 ± 5979 mg/kg, respectively. Considering 6 mg/kg as the critical value of Fe, the soils of studied area was found to be contaminated with a very high level of Fe.

3.3. Copper

The concentration of Cu in the earth's crust is averaged 28 mg/kg [27]. The available and total status of Cu in soils of the studied area was ranged from 2.0 - 8.0 and 45 - 69 mg/kg with mean value of 4.3 ± 0.3 and 53 ± 16 mg/kg, respectively. A 0.2 and 50 mg/kg Cu were reported as critical and threshold value for Cu-deficiency and Cu-toxicity to plant growth. Almost all soil of this region was found to be contaminated with sufficient amount of Cu for the healthy growth of plants.

3.4. Zinc

The Zinc content of the lithosphere is 67 mg/kg [27]. Zinc has a strong tendency to combine with sulfide ores, and it occurs most frequently in the lithosphere as sphalerite. The available and total status of Zn in soils of this region was ranged from 0.7 - 5.0 and 27 - 56 mg/kg with mean value of 2.3 ± 0.2 and 38 ± 14 mg/kg, respectively. Critical limit for Zn-deficiency in different type of soils for different crops were ranged from 0.4 to 0.8 mg/kg. A few soils of studied area was found to be deficient in available Zn for the plant growth if the value 0.80 mg/kg was considered as a critical limit. A value of 50 mg/kg Zn was reported as threshold value for the plant toxicity. None of soil of the studied is contaminated Zn at the toxic level.

3.5. Manganese

Manganese concentration in the earth's crust is 1000 mg/kg [27]. The available and total level of Mn in soils of this region lie in the range of 205 - 2800 and 2737 -10,122 mg/kg with mean value 1178 ± 119 and 6889 ± 2274 mg/kg, respectively. A 5.7 and 55 mg/kg were reported as the critical limit for Mn-deficiency and threshold value of Mn-toxicity for plant growth, respectively.

3.6. Cobalt

The average total cobalt concentration in the earth's crust is 40 mg/kg [27]. The available and total concentration of cobalt in soils of this region were varied from 2.2 - 31.2 and 64 - 139 mg/kg with mean value 12.8 ± 1.3 and 119 ± 30 mg/kg, respectively. Considering the 2.5 mg/kg as the critical limit for Co deficiency in soil, almost all soils of this region may be rated as contaminated with sufficient level of Co for plant growth.

3.7. Nickel

The natural abundance of nickel in the earth' crust is 47 mg/kg [27]. The available and total level of Ni in soils of this region were varied from 0.1 - 13.4 and 15 - 70 mg/kg with mean value of 3.9 ± 0.6 and 35 ± 11 mg/kg, respectively. A 0.1 and 50 mg/kg Ni in soil were considered as the critical limit, and threshold value of toxicity for plant growth, respectively. All type of soils were found to be contaminated with a sufficient level of Ni for plant growth.

3.8. Molybdenum

Molybdenum occurs in the soils in extremely small quantities, is usually found in concentrations of less than 1 mg/kg [27]. The available, and total Mo content in soils of the studied area varied from 0.1 - 8.9 and 3.4 - 9.2 mg/kg with mean 1.5 ± 0.3 and 4.6 ± 2.6 mg/kg, respectively. A 0.1 mg/kg was considered as the critical limit for Mo deficiency in soil. A 20.0 mg/kg Mo in soil was considered as threshold value for toxicity. None of the soil in this region was found to contain Mo at the toxic level.

Table 1. Mean (n = 3) micronutrient status of soil, mg/kg.

S. No.	Area	Location	Fe	Cu	Zn	Mn	Co	Ni	Mo	SO_4^{2-}
1	Raipur	Dagniya	333	3.2	0.8	1736	19.7	0.1	1.4	269
2		Jaunda	450	3.4	1.4	1709	6.9	0.1	1.9	410
3		Raipura	151	3.4	2.1	504	4.6	6.0	1.1	210
4		Sarona	157	3.2	1.4	1064	9.9	6.3	1.4	167
5		Atari	326	4.5	1.8	1316	11.9	7.6	0.1	165
6		Ravabhata	323	6.0	4.1	672	12.6	4.1	0.1	199
7		Dhaneli	386	6.3	2.7	840	9.5	4.9	1.9	185
8		Sankara	157	3.4	1.5	924	16.0	3.2	2.9	110
9		Dharsiva	257	4.8	1.4	869	8.1	3.1	8.9	229
10		Deori	280	4.5	2.0	1036	12.3	7.3	7.1	222
11		Sardoo	238	4.3	1.7	2296	21.6	12.3	1.4	249
12		Sarora	208	4.8	1.4	448	18.5	5.2	0.1	324
13		Deopuri	139	3.9	4.5	1764	17.5	2.0	2.5	199
14		Mana	165	4.8	5.0	1400	16.9	11.1	1.5	285
15		Parsatti	321	4.3	2.9	1485	18.3	2.7	1.6	207
16		Labhandi	74	3.9	2.1	1260	18.9	8.0	0.1	585
17		Jora	74	3.6	1.8	504	8.0	0.6	3.2	176
18		Piroda	146	4.1	0.7	1316	12.5	4.3	2.3	276
19		Chherkhedi	55	3.5	2.2	1120	7.7	0.8	2.5	384
20		MandirHasaud	233	4.9	2.1	2800	11.8	1.5	2.0	310
21		Kurud	134	4.1	1.1	350	17.2	0.4	1.2	170
22		Baradera	177	3.5	1.0	476	17.2	0.3	1.5	188
23		Bhanakhedi	263	4.3	2.2	1092	27.0	3.1	1.4	677
24		Chandkhurai	839	4.5	0.7	742	15.3	2.0	0.1	392
25		Badgaon	800	3.4	4.8	420	13.7	7.3	0.1	299
26		Khamtarai	8253	6.0	4.9	1680	13.2	1.7	0.7	747
27		Bothali	935	4.2	1.5	913	14.6	5.3	1.0	436
28		Gullu	427	7.3	3.6	1147	12.3	0.4	0.9	332
29		Bhandarpuri	1004	2.9	1.8	2062	15.0	5.3	0.1	282
30		Boriyakhurd	1832	7.0	3.8	2478	14.1	1.7	1.4	269
31		Dunda	2124	7.0	2.5	2103	15.0	1.3	0.1	254
32		Sejbahar	1428	5.0	2.2	1467	19.2	5.5	0.1	155

Continued

33		Datrenga	1786	4.8	2.0	1006	20.6	4.2	0.1	174
34		Mujgahan	2668	5.7	2.1	888	12.7	3.6	0.1	179
35		Mova	258	3.9	0.7	205	4.3	3.1	2.8	268
36		Daldalseoni	377	5.6	1.7	371	3.2	3.9	2.3	330
37		Saddu	447	7.4	1.0	819	11.8	7.1	2.0	367
38		Sankari	306	3.6	1.5	676	10.1	3.2	2.2	243
39		Dhansuli	235	4.5	1.1	1491	3.2	1.7	1.2	189
40		Lohara	237	4.5	1.4	2746	2.9	0.8	1.7	140
41		Dondekhurd	175	4.5	1.3	680	2.2	1.1	1.3	191
42		Dondekala	251	4.9	1.7	470	5.6	1.5	2.0	358
43		Chataud	258	4.5	1.7	320	3.8	3.1	2.6	343
44		Semaria	132	2.2	2.0	818	4.1	1.3	0.3	163
45		Bhurkoni	44	3.4	1.8	438	2.9	4.9	3.6	162
46		Lalpur	194	4.2	2.4	1217	4.1	0.7	1.6	285
47		Chhapora	122	3.2	2.4	1433	9.5	1.7	1.3	166
48		Donde	226	3.5	1.7	1211	3.4	3.2	1.3	71
49		Saragaon	412	5.6	2.9	321	6.2	3.8	2.2	66
50		Narhada	155	3.4	1.4	1219	7.0	2.5	1.5	41
51		Baronda	429	3.8	1.8	219	13.2	1.1	1.1	101
52	Arang	Godhi	817	4.8	2.5	476	27.9	8.5	0.1	303
53		Paragaon (Arang)	528	3.6	2.2	1792	4.5	1.3	0.6	232
54		Amethi	345	5.6	1.8	717	17.2	9.8	2.0	321
55		Ranisagar	269	4.2	1.1	1408	12.0	1.7	0.4	353
56		Banarasi	482	5.3	2.1	1488	14.8	6.6	0.4	418
57		Bana	1033	4.2	1.7	1379	28.3	3.8	1.9	358
58		Kosrangi	1135	5.5	3.2	984	9.5	3.9	1.2	329
59		Arang	1734	8.1	1.1	907	21.3	4.5	0.7	270
60		Rasani	914	2.0	1.5	644	5.9	1.0	1.5	254
61		Lakholi	1249	2.1	1.5	1515	21.0	1.3	0.7	357
62		Amsena	2240	5.6	2.2	1671	13.9	5.2	0.1	233
63		Chikhali	1189	2.1	2.0	1185	20.9	2.2	0.1	325
64		Kutela	966	2.5	3.2	583	9.0	3.1	0.3	249
65		Kurud	1245	3.1	1.7	290	7.4	1.0	0.9	259
66		Kagdehi	770	2.2	3.1	387	4.5	2.1	1.5	290

Continued

67		Samoda	1685	2.8	2.7	693	6.4	3.4	0.1	118
68		Chaprid	868	2.4	2.8	1909	15.3	3.2	1.2	162
69	Abhanpur	Abhanpur	288	3.2	1.7	2100	13.6	13.4	0.1	426
70		Kendri	218	3.6	2.9	1092	5.5	9.9	0.8	160
71		Manikchauri	130	5.2	1.4	616	18.1	7.8	2.7	325
72		Chhachanpairi	427	3.9	3.5	888	10.9	6.7	1.7	124
73		Kolar	1810	6.4	4.6	1108	26.5	2.0	0.1	343
74		Khopra	367	4.2	1.7	815	9.1	4.5	1.3	275
75		Sakari	609	3.2	0.8	933	3.2	11.2	1.6	252
76		Chandi	378	4.6	0.8	387	8.1	1.3	1.7	262
77		Kachna	250	6.0	2.8	320	4.5	0.7	3.2	385
78		Amasibani	169	6.0	2.0	2301	10.2	1.3	2.3	190
79	Tilda	Tilda	112	6.2	1.8	1652	31.2	7.3	3.4	286
80		Biladi	132	3.4	4.5	2548	6.6	2.8	3.4	395
81		Kota	272	5.5	5.0	1961	11.1	5.5	1.8	332
82		Bahesar	84	4.5	4.6	1485	19.2	6.6	3.1	414
83		Tarashiv	118	4.6	4.6	1540	17.8	5.9	2.9	515
84		Murabangoli	30	5.6	4.9	1988	13.2	2.8	3.9	284
85		Kharora	487	5.7	3.2	1379	15.7	1.1	1.6	253
86	Rajim	Bhelvadih	193	3.6	3.4	1541	13.7	3.2	0.1	285
87		Navapara	169	4.6	1.0	1652	20.2	4.6	0.1	325
88		Kurra	95	4.3	1.3	2045	9.7	2.4	1.6	207
89		Pipraud	125	5.0	3.9	1736	17.4	9.1	2.3	285
90		Rajim	244	2.7	0.8	896	5.3	1.7	1.6	258
91	Balodabazar	Koliyari	500	2.7	0.8	784	13.9	5.2	0.8	213
92		Navagaon	484	4.6	1.0	1933	10.5	6.2	3.3	732
93		Charoda	347	4.6	2.2	934	16.4	7.6	1.8	226
94		Sirri	1089	4.3	2.4	1050	22.3	1.0	2.2	369
95		Kanki	1169	2.1	2.8	539	18.9	1.8	0.5	232
96		Bhaisa	1135	2.0	4.3	1312	4.6	5.9	1.9	274
97		Bhaismudi	1306	2.8	4.3	1302	12.6	4.2	1.3	266
98		Champa Jhar	1513	6.0	1.3	1624	21.8	3.6	0.1	272
99		Torla	367	3.4	2.4	1650	19.6	0.6	1.4	324
100		Tama Seoni	694	3.9	2.0	1092	18.5	4.5	0.8	551

3.9. Sulphur

The earth's crust contain about 0.06% Sulphur [27]. It is mostly present as sulfides, sulfates and organic combinations with C and N. The available and total SO_4^{2-} in this region was lie in the range of 41 - 747 and 294 - 1782 mg/kg with mean value of 281 ± 25 and 631 ± 180 mg/kg, respectively. The critical limit of SO_4^{2-} in the soil was reported to be 10 mg/kg. No soils of the studied area were found to be deficient in sulfur level.

3.10. Concentration Variations and Statistics

The range, mean, median, kurtosis and skewness values of micronutrient concentration in soils of 100 villages of the studied area are presented in **Table 2**. The highest value of Fe or SO_4^{2-}, Cu, Zn, Mn, Co, Ni and Mo was observed in site *i.e.* Khamtarai, Arang, Murabangoli, Mandir Hasaud, Tilda, Abanpur and Dharsiva, respectively, **Figure 2**. The content of six micronutrients *i.e.* SO_4^{2-}, Cu, Zn, Co, Ni and Mo are symmetrically distributed in all locations, **Figure 3**. However, large variations in the content of two micronutrients *i.e.* Fe and Mn was seen, may be due to input by the industrial effluents, **Figure 3**. The data for seven micronutrients *i.e.* Cu, Zn, Mn, Co, Ni, Mo and SO_4^{2-} were found to be distributed normally and symmetrically with comparable median and mean values. A large variation in the case of Fe was noticed, may be due to asymmetric distribution of iron minerals in the soil. The available content of the micronutrients in soils of the studied area was found in the following decreasing order: Mn > Fe > SO_4^{2-}> Co > Cu > Ni > Zn > Mo, **Figure 4**. Among them, manganese was found to be at the highest level followed by Fe. However in the case of total levels, a different trend (Fe > Mn > SO_4^{2-}> Co > Cu > Zn > Ni > Mo) was observed, **Figure 4**. A large fraction of S was found to be available for the plant growth, **Figure 5**. However, low to moderate fractions of other micronutrients were available, **Figure 5**. All of them showed a positive correlation between the available and total metal content with the highest and lowest values for Ni and Cu, respectively, **Figure 6**.

The available content of all micronutrients except Zn and SO_4^{2-} was found to decrease as the soil profile was increased from 0 to 120 cm, may be due to strong adsorption of the cations by the geomedia, **Figure 7**. The total content of all micronutrients except SO_4^{2-} was found to increase as the soil depth profile was increased from 0 to 120 cm due to their poor adsorption by the geo-media, **Figure 8**.

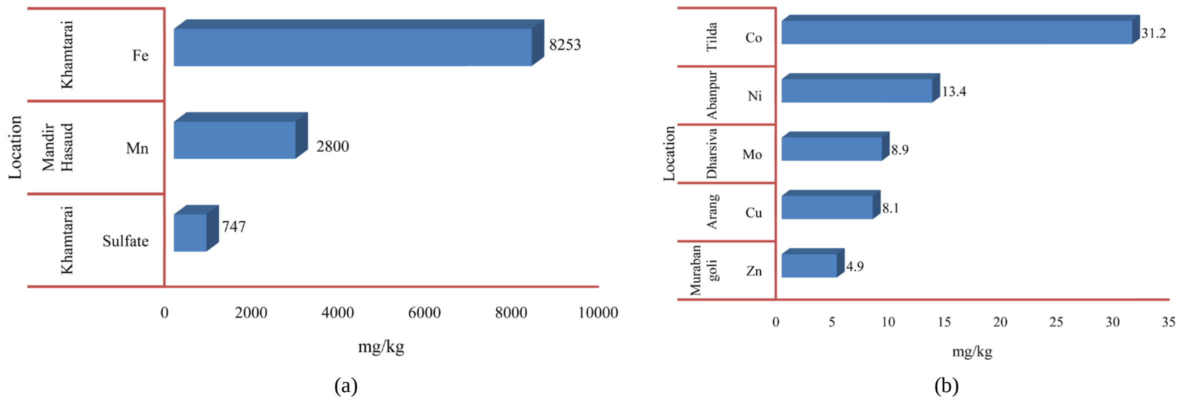


Figure 2. Representation of locations showing maximum micronutrient concentration in studied area.

Table 2. Statistics for distribution of available micronutrients in the soil, (n = 100).

Parameter	Fe	Cu	Zn	Mn	Co	Ni	Mo	SO_4^{2-}
Minimum, mg/kg	30	2.0	0.7	205	2.2	0.1	0.1	41
Maximum, mg/kg	8253	8.1	5	2800	31.2	13.4	8.9	747
Mean, mg/kg	642	4.3	2.3	1178	12.8	3.9	1.5	281
Median, mg/kg	330	4.3	2.0	1100	12.6	3.2	1.4	269
Kurt	41.7	0.1	−0.1	−0.3	−0.3	0.8	9.9	3.3
Skew	5.5	0.4	0.9	0.5	0.4	1.0	2.3	1.4

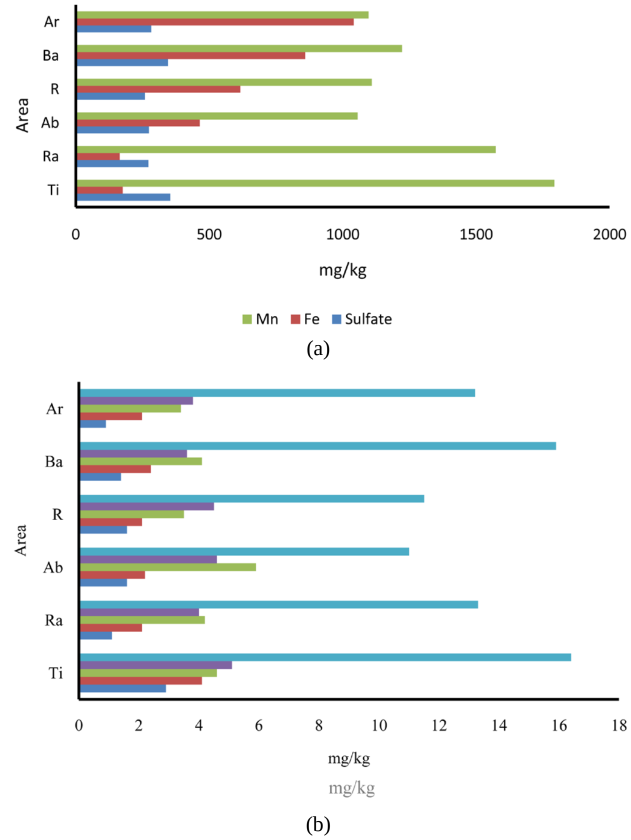


Figure 3. Representation of distribution pattern of micronutrients in surface soil of Raipur area.

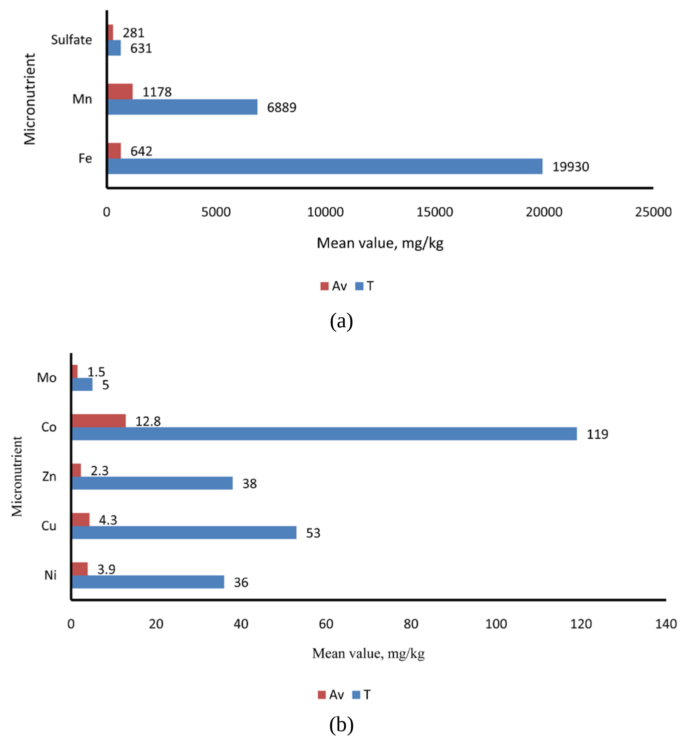


Figure 4. Mean value of total (T) and available (Av) content of micronutrient in the surface soil of Raipur area.

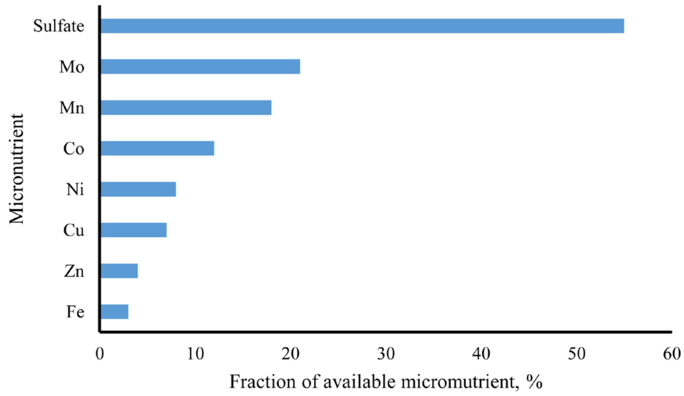


Figure 5. Fraction of available content of micronutrient in surface soil of Raipur area.

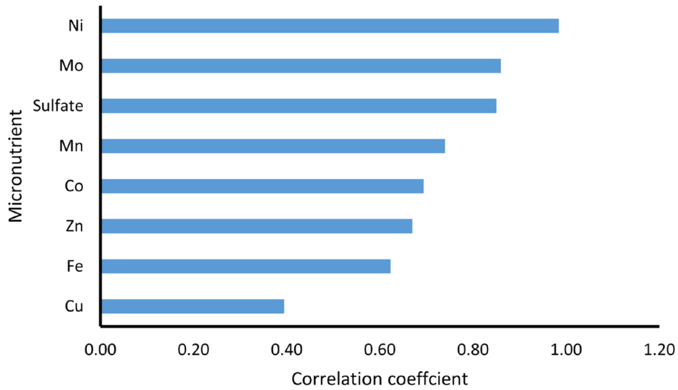
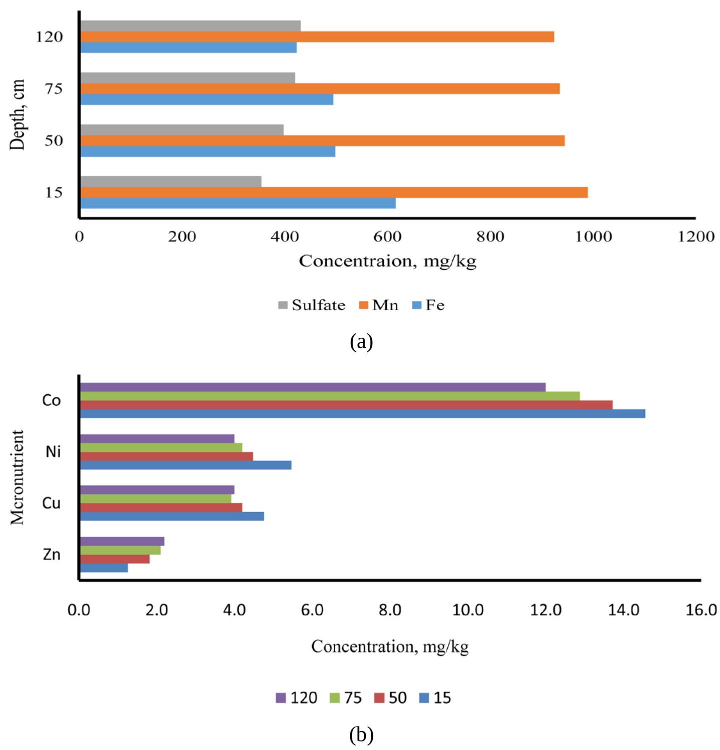
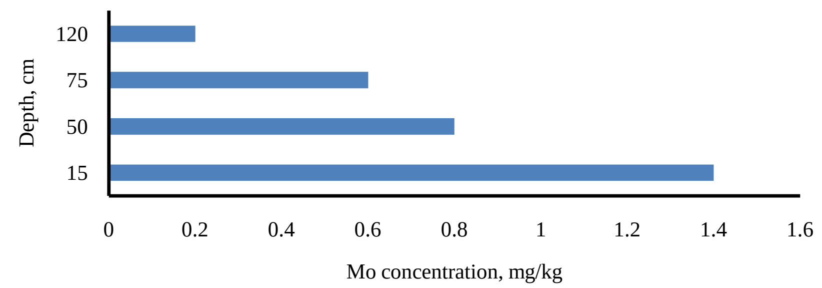


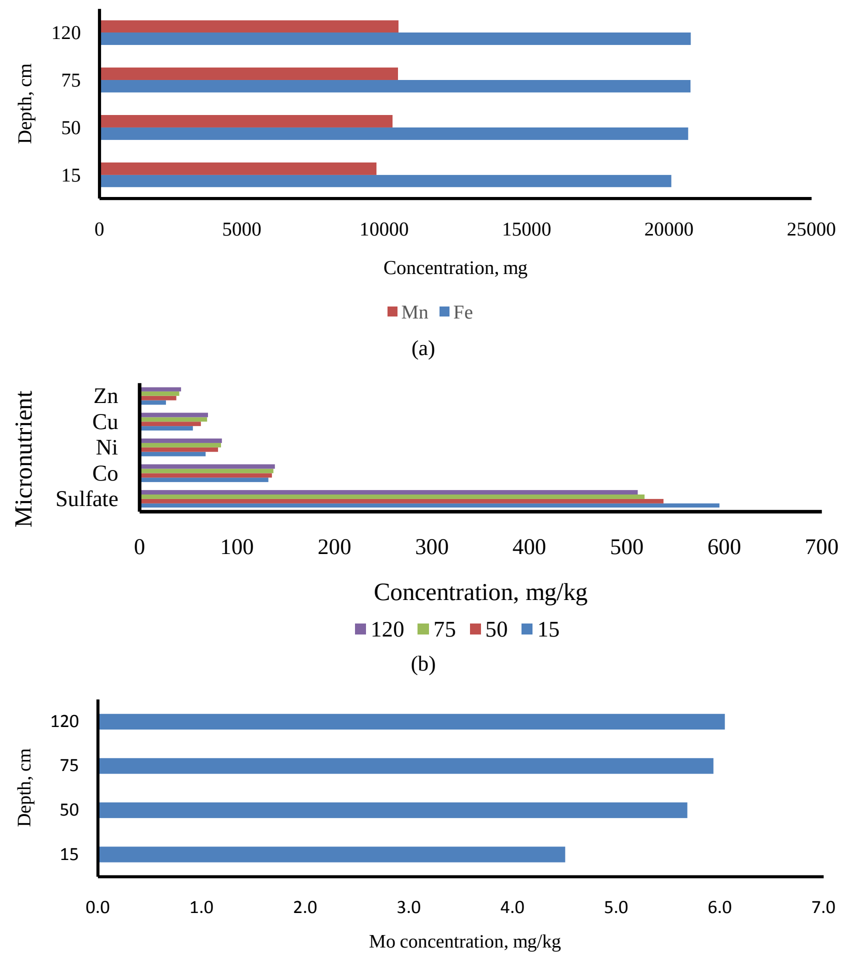
Figure 6. Correlation coefficient of total and available content of micronutrient in surface of Raipur area.





(c)

Figure 7. Depth profile studies of available content of micronutrient in soil of Raipur area.



(c)

Figure 8. Depth profile studies of total content of micronutrient in soil of Raipur area.

3.11. Micronutrient Deficiency and Toxicity

The micronutrients *i.e.* Fe, Mn, Co, Ni, Cu, Zn, Mo and S are used in very small amounts. The presence of micronutrients below critical limit often causes adverse effects in plant growth and in their yields. For each micronutrient, the critical levels, limit of deficiency, toxicity and optimal growth vary with the genotype and are profoundly affected by plant metabolism and by edaphic and environmental factor that affect the absorption of nutrients. In the studied area, five micronutrients *i.e.* Co, Ni, Cu, Mo and S are found in soils at the sufficient levels. Two micronutrients *i.e.* Fe and Mn are present at toxic levels in all types of soils of this region. In some area, the

Zn deficiency in the soils is observed. The iron chlorosis was commonly seen in the plants of this region which may be due to very high amount of Fe content in soil. The brown or purplish spots on leaves, on lower part of the stem and leaf margins are commonly marked in this region that may be due to manganese toxicity.The most visible zinc deficiency symptoms *i.e.* short internodes and a decrease in leaf size were observed in the plants of this region.

3.12. Comparison of Micronutrient Status

The concentration of available maximum amount of Fe, Mn, Zn, SO_4^{2-} and Cu reported was 12234, 269, 121, 70, and 30 mg/kg, respectively [8] [11] [21]. The levels of micronutrients *i.e.* Fe, Mn, and S were found to be at the highest levels in this region. The content of Cu was present at moderated levels similar to other part of country [7]. The Zn content was present low levels as occurred in other parts of the Country [7]. The level of Mo was present at moderate levels but high content of Fe, Mn, and S may cause Mo deficiency.

4. Conclusion

All types of soils in Raipur area are found to be associated with high levels of Fe, Mn, S; moderate levels of Cu and low level of Mo and Zn. The relative abundance of free form of micronutrients (available content/total content) in soils of this region is found in following decreasing order: S >> Mn > Mo > Cu >> Zn ≈ Fe. The adverse effects *i.e.* chlorosis of young leaves, premature fall of fruits, narcotics, stunned growth of plants/crops in plants of this region are frequently seen may be due to either Fe and Mn toxicities or Zn deficiency or their combination. The Zn deficiency could be corrected by application of Zn compounds e.g. Zinc sulfate, Zinc oxide, Zinc phosphate, etc. in the soil.

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