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The Mobility of Trace Metals from Soil to Plant in Irrigation Fields around Tummalapalle Uranium Mine in Kadapa District, Andhra Pradesh

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The present investigation was carried out to assess the Bio-Concentration Factor (BCF) and Transformation Factor (TF) of trace metals from soil to plant in selected irrigation fields around Tummalapalle Uranium mining site, Pulivendula, YSR (Kadapa) district, A.P. Out of five irrigated fields, tomato (*Solanum lycopersicum*) was cultivated in four sites and onion (*Allium cepa)* was cultivated in one site. The soil samples and plant samples including tomato fruits and onion bulbs were analyzed for trace metals using Inductive Coupled Plasma Optical Emission Spectroscopy (ICP-OES). The soil samples were also subjected to the analyses of texture, pH, organic carbon, and electrical conductivity. The BCF and TF of K, P, Mg, B, Ca, Cu, Fe, Mn, Mo, Se, Tl, Zn, As, Cd and Pb from soils to different plant parts (root, stem, leaf and fruits) were calculated. BCF of Pb(172), Cu(85.45), K(47.78), P(14.05), Ca(5.55), B(10.86), Mg(2.92) and Zn(8.22) were found to be > 1, which reveals more accumulation of heavy metals like Pb, Cu and trace metals like K, P, Ca, B, Mg and Zn in plant parts. Recording of BCF of Fe (0.12), Mn(0.04) and Mo(0.14) as < 1 indicates , that these metal ions do not accumulate in the plants.

Key words: Trace metals, Soil, Plant, ICP-OES, Transfer factor, Bio-concentration factor

In recent years, the researcher's evince interest and concern about the uptake of trace metals by plants from agriculture soils, because excess metals getting into the food chain through uptake by plants might be harmful to the human health (Fuliang *et al.,* 1998). Essential trace metals (Bororn (B), Potassium (K), Phosphorous (P), Iron (Fe), Magnesium (Mg), Copper (Cu), Calcium (Ca), Manganese (Mn), Molybdenum (Mo), Selenium (Se) and Zinc (Zn)) and non-essential trace metals (Cadmium (Cd), Thallium (Tl), Arsenic (As) and Lead (Pb)) occur in naturally in rock and soil. High concentrations of these metals are being released into the environment by human activities such as agricultural process (Dickinson *et al.,* 1984; Smuc *et al.,* 2012).

Trace metals are taken up from soil by plant roots and passed to stem, leaves and fruits, which are eventually consumed by animals and humans. Trace metals associated with leaves, roots and fruits originate from two sources, the growth medium of the plant and atmosphere (Haliru and Ajibola, 2009). The roots usually show higher value of metal concentration than shoots, because they are the origin, which comes into roots with the toxic metals present in the soil. The accumulation of metals from soil to vegetables has been studied extensively due to the close relation of vegetables to human health (Alam *et al.,* 2003). The process of metal uptake and accumulation by different plant parts depend on the concentration of available metals in soils, solubility sequences and the vegetable plant species growing on these soils (Andersson, 1977).

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The assessing of soil condition for plant growth, nutrient cycling and biological activity is based on pH and electrical conductivity (EC) parameters. The pH is a good indicator of the balance of available nutrients in soil; Electrical Conductivity can almost be viewed as the quantity of available nutrients in your soil. The soil organic matter (OC) forms from the decomposition process of living or dead plants and animals residues. The organic matter helps from soil erosion and provides better aeration and water movement in soil. Organic matter increases water-retaining power of soil, it improves aeration and produces a better soil structure by increasing granulation (Jitender *et al.,* 2015). The major objective of this work is to investigate the transfer of metals from soil to plant in selective irrigation fields around Tummalapalle uranium mining area in Andhra Pradesh. Experiments were conducted to evaluate the distribution of metals in the sampling area, quantification of the trace metals in different plant parts (root, stem, leaf and fruit).

Material and Methods

Study area

The area selected for the present study was around Tummalapalle uranium mining site, Pulivendula, YSR kadapa District, A.P, India. Total five sites around mining area extending up to10 km have been selected. The site-1 is 6 km, site-2 is 4 km, site-3 is 3 km, site-4 is 5 km and site-5 is 10 km distance from the mining area. The selected sites are shown in Fig.1.

Sampling and analysis

The soil samples were collected from five agricultural fields. Each field was first subdivided into five parts (four corners and one center). The soil samples were collected from a depth of 0-15 cm and transferred into air tight polyethylene bags and brought to the laboratory. The collected soil samples from each field were mixed together to form composite sample which was shade dried in laboratory for two days, followed by oven drying at 110^0 C for about five hours to remove the moisture completely. The dried samples were crushed and ground to pass through 2 mm mesh (Noor-ul and Tauseef, 2015).

According to Sharma *et al.*, (2006), the soil and plant samples were prepared by acid digestion method. The filtered digested sample was taken in 50 ml volumetric flask and made up to the mark with distilled water and blank solution also prepared in the same manner. The prepared soil samples were analyzed by using ICP-Optical Emission Spectrophotometer (model Perkin Elmer 7000DV) for the estimation of trace metals. All the chemicals used were of analytical grade (Merck). The Bio-Concentration Factor (BCF) and Translocation Factor (TF) of trace metals in soil and vegetable samples have been elected. Bio-concentration factor is the ratio of metal concentration in plant tissues (root, stem, leaf and fruit) to the concentration of metal in agriculture field.

$BCF = \frac{C\ plant}{C\ soil}$ Where C_{plant} = metal concentration in plant, C_{soil} = metal concentration in soil.

Translocation factor was calculated as the ratio of metal concentration in the shoot (root-stem, root-leaves and root-fruit) parts of the plant to metal concentration in plant root.

$$TF = \frac{C\ shoot}{C\ root}$$

Results and Discussion

Physicochemical analysis

The collected soil samples from five selected sites were examined by physicochemical analysis and the data is presented in Table.1.

Table 1. Soil physicochemical variables

Properties	Site-I	Site-II	Site-III	Site-IV	Site-V
Texture	Clay loam	Sandy clay loam	Clay loam	Clay loam	Clay loam
pH	8.06	7.95	8.05	8.02	8.08
EC($dS.m^{-1}$)	0.51	0.43	0.43	0.44	0.48
Organic matter %	0.83	0.29	0.36	0.39	0.9

The pH values of five soil samples were found to range from 7.95-8.08 and hence, classified as moderately alkaline. The texture of soil samples of four sites (I, III, IV and V) is clay loam and site-II is sandy clay loam. The electrical conductivity ranged from 0.43-0.51 dSm^{-1}. The organic matter of soil samples ranged from 0.29-0.90 % and higher values were found in site-I and V when compared to other sites.

Table 2. Bio-concentration factor of soil-plant

Metals	B	Ca	Cu	Fe	K	Mg	Mn	Mo	P	Zn	As	Cd	Pb	Se	Tl
Site I	3.76	2.02	64.34	0.02	24.52	0.85	0.01	0.04	14.05	0.86	0	0	1.24	0	0
Site II	4.60	5.55	17.59	0.03	22.91	2.48	0.02	0.03	7.49	8.22	0	0	1.08	0	0
Site III	0.09	2.06	0.34	0.12	5.85	0.80	0.04	0.14	8.32	1.75	0	0	1.06	0	0
Site IV	10.86	4.07	85.45	0.02	47.78	2.92	0	0.04	7.46	4.48	0	0	0.84	0	0
Site V	8.80	1.88	61.39	0.02	15.80	1.26	0	0.05	6.72	0.36	0	0	172	0	0

Bio-concentration factor (BCF)

From the analytical data, Bio-Concentration Factor was evaluated and values were shown in Table.2 and Fig.2.

The BCF for B, Ca, Cu, Fe, K, Mg, Mn, Mo, P, Zn, As, Cd, Pb, Se and Tl transported from soil to crops was calculated. The ratio > 1 indicates higher accumulation of metals in plant parts (Bahemuka and Mubofu, 1999). The BCF for B, Ca, Cu, K, P and Pb (site-I); B, Ca, Cu, K, Mg, P, Zn and Pb (site-II); Ca, K, P, Zn and Pb (site-III); B, Ca, Cu, K, Mg, P and Zn(site-IV) and B, Ca, Cu, K, Mg, P and Pb (site-V) were found to be greater than one, indicating that these trace metals were higher accumulation with plant parts. The BCF values of Cu, K and P in site-I; Cu and P in site-II and Cu and K in site-V, were found to be above 10 and hence, they are hyper accumulated with plant parts. But in site-V, the BCF value of Pb was found to very high. The BCF values of Fe, Mn, Mo, As, Cd, Se and Tl in all the sites were found below one; hence, these were found to be less in plant parts. Similarly, BCF for B, Cu (site-III), Pb (site-IV) and Zn (site-V) were found to be below one resulting in less accumulation of such metals.

Transfer Factor (TF)

The transfer of B, Ca, Cu, Fe, K, Mg, Mn, Mo, P, Zn, As, Cd, Pb, Se and Tl trace metals from root to shoot (stem, leaf and edible part) was evaluated by using translocation factor (TF) and the results are presented in Table .3. Higher TF value indicates the increased level of metal accumulation in the plant body (Baker and Brooks, 1989). The TF > 1 signifies effective translocation of trace metals from the roots to the shoots (Smuc *et al.,* 2012).

Soil-root transfer factor

The higher mobility of calcium (Ca) in site-II (1.18) and III (1.56), potassium (K) and copper in all sites except site-III (0.34) and Zinc in site-II (1.28) and IV (2.02) were found. The soil to root transfer factor of Fe, Mg, Mo, Mn and Pb was less in all sites, except Pb in site-V (171). The boron (B) (0.09) in site-III, phosphorous (P) in site-IV (0.12) and V (0.59) and zinc in site-I (0.32), III (0.73) and V (0.01) were less transfer. The graph is shown in Fig. 3(a).

Table 3. Transfer factor of soil-root, root-stem, root-leaf, and root-edible part

	Metals	B	Ca	Cu	Fe	K	Mg	Mn	Mo	P	Zn	As	Cd	Pb	Se	Tl
Soil to Root	Site I	1.09	0.45	12.34	0	4.53	0.18	0	0	1.74	0.32	0	0	0.26	0	0
	Site II	2.87	1.18	10.61	0.01	3.96	0.44	0	0	1.08	1.28	0	0	0.24	0	0
	Site III	0.09	1.56	0.34	0.12	3.36	0.56	0.04	0.13	4.33	0.73	0	0	0.65	0	0
	Site IV	3.09	0.62	11.75	0.01	4.28	0.33	0	0.02	0.12	2.02	0	0	0.37	0	0
	Site V	2.26	0.39	23.61	0.01	2.35	0.2	0	0.02	0.59	0.01	0	0	171	0	0
Root to Stem	Site I	0.62	0.87	1.38	0.33	1.64	0.11	0	1.64	2.05	0.64	0	0	1.23	0	0
	Site II	0	0.85	0	0.22	1.92	1.63	0	0.66	1.98	0.96	0	0	0.93	0	0
	Site IV	0.75	1.34	2.41	0.11	5.11	3.11	0	0	31.48	0.35	0	0	0.2	0	0
	Site V	0.83	0.86	0.26	0.26	2.5	1.58	0	0.28	4.83	3	0	0	0	0	0
Root to Leaf	Site I	0.93	1.58	1.58	0.33	1.4	2.09	0	0	3.46	0.05	0	0	1	0	0
	Site II	0.1	1.78	0.14	0.57	1.33	1.42	0	1.09	2.38	3.29	0	0	1.33	0	0
	Site IV	0.84	2.7	1.86	0.1	1.37	2.1	0	0.27	8.99	0.11	0	0	0.31	0	0
	Site V	1.07	1.9	0.66	0.22	1.45	1.98	0	0.08	2.81	15	0	0	0	0	0
Root to Fruit	Site I	0.86	1.02	1.23	0.82	1.35	1.48	0	3.12	3.46	0.96	0	0	1.46	0	0
	Site II	0.49	1.04	0.51	0.76	1.5	1.45	0	0.81	1.54	1.13	0	0	1.13	0	0
	Site III	0	0.32	0	0.01	0.73	0.41	0	0.08	0.91	1.37	0	0	0.63	0	0
	Site IV	0.9	1.46	1.99	0.57	3.65	2.6	0	0.83	17.62	0.74	0	0	0.75	0	0
	Site V	0.97	1.03	0.66	0.8	1.74	1.46	0	0.51	2.73	11	0	0	0	0	0

Root-stem transfer factor

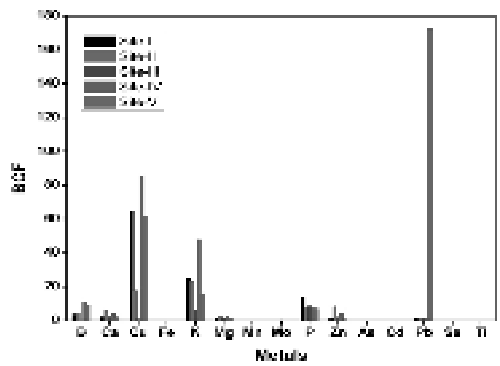
In site-I (1.38) & IV (2.41); Copper (Cu); Potassium (K) & Phosphorous (P) in all sites; Magnesium (Mg) in site-II (1.63), IV (3.11) & V (1.58); Molybdenum (Mo) in site-I (1.64); Zinc (Zn) in site-V (3.0) shows high transfer factor than compared with other sites. The Lead (Pb) is more transferred in site-I (1.23) than rest of the sites. The transfer factor of B, Fe & Mn, less transferred from root-stem in all sites below one. The Calcium (Ca) is less mobility in site-I (0.87), II (0.85) & V (0.86) but the site-IV (1.34) is more transferred. The graph is shown in Fig. 3(b).

Fig.1 : Map showing the mining area and study locations

Root-leaf transfer factor

The root to leaf transfer factor of Fe and B less mobility in all sites, but B shows high mobility in site-V (1.07). The calcium (1.58-2.70), potassium (1.33-1.45), magnesium (1.42-2.10) and phosphorus (2.38-8.99), these metals are highly transferred from root to leaf in all sites. The atmospheric depositions are also influenced to show the higher transfer values in leaf. The zinc exhibit highest transfer values in site-II (3.29) and V (15.0), copper in site-I (1.58), IV (1.86); molybdenum in site-II (1.09) and lead in site-I (1.0) and II (1.33), than other sites. The graph is shown in Fig. 4(a).

Fig. 2: Bio-concentration factor of soil to plant

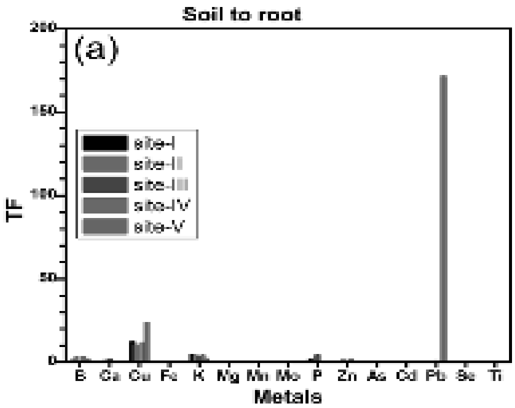


Root-edible part transfer factor

The calcium mobility in site-I (1.02), II (1.04), IV (1.46), and V (1.03); Cu range from (0.0-1.99); potassium (1.35-3.65), magnesium (1.45-2.60) and phosphorous (1.54-17.6) in site-I, II, IV and V; zinc in site-II, III & V (1.13, 1.37 & 11); and Pb in site-I & II (1.46, 1.13) were found to be highest mobility when compared with other trace metals whose TF is less than one. The graph is shown in Fig. 4(b).

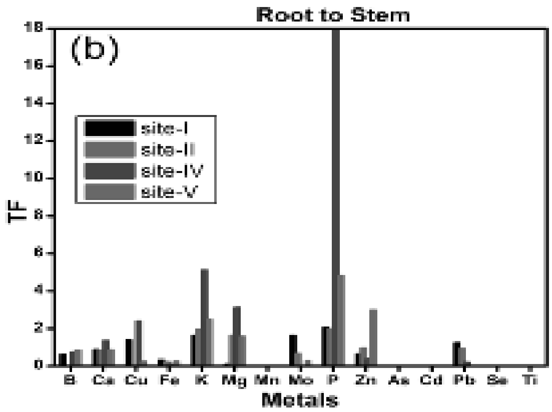
The results indicate that the TF values of all sites showed that the plant species effectively translocate trace metals (Cu, K and P) from soil to total plant, suggesting that they are suitable for phytoextraction. According to BCF all studied plants were accumulate with B, Ca, Mg, Zn and Pb, the Cu, K and P are hyper

Fig: 3 (a) Transfer factor of soil to root



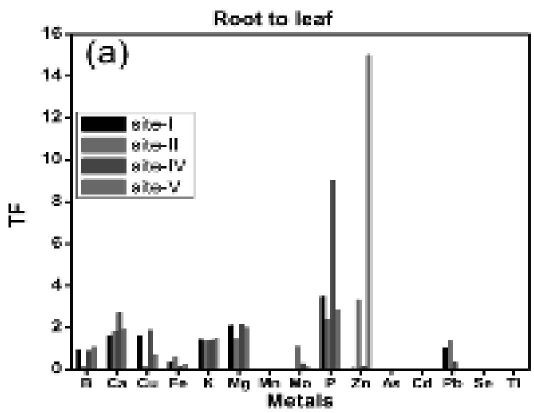
accumulates with plant parts. At high concentration, Cu may become phytotoxic and cause metabolic disorders, although it is an essential nutrient for plant

Fig: 3 (b) Transfer factor of root to stem



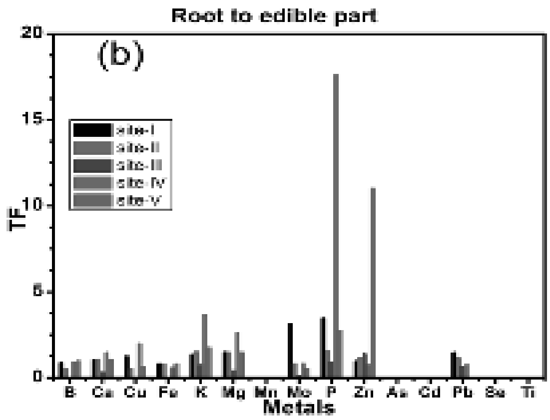
growth and development, and may lead to a potential threat to human health through the food chain (Chang and Page, 2000). The mean concentration of Cu was lower in different plant part samples, indicating no human health impact from the consumption of these plant edible parts.

Fig: 4 (a) Transfer factor of root to leaf



Zn is an essential element to all plants, which acts either as a metal component or enzymes or as a functional, structural or regulatory co-factor of many enzymes (Alloway, 1990). In this study the concentration of zinc was found to be lower the toxic level in all plant species. The macronutrients of K, P, B, Ca and Mg are useful to plants; these elements are sufficiently available in all studied sites. The K and P are highly accumulated with plants and transfer from soil to plant within normal range. The Mg, Ca (cell wall structure component) and B are moderately accumulated with plant parts. The micronutrients of Mo and Fe play an important role in plants. The Mo was essential for nitrogen fixation in legumes and nitrogen metabolism in crucifers, Fe critical for chlorophyll formation and photosynthesis, enzyme systems and respiration in plants. These two metals are less accumulated and translocate within the soil, plant system in all sites (Alberta, 1998).

Fig: 4 (b) Transfer factor of root to edible part



Exposure of human body to high levels of Mn can result in a number of adverse health effects including blood–brain barrier, placental barrier during pregnancy, damage of nervous system, sperm damage and adverse changes in male reproductive performance, inflammation of the kidneys and kidney stone formation (ATSDR, 2012). However, Mn values in this study were lower than the toxic level in soil and plants. The toxic level for plants is between 300 and 500 mg/kg (Nouri et al., 2009).

The concentration of Pb in soil and various parts of the vegetable plants is found in studied areas, in which BCF and TF value of lead shows higher in site V than comparing with other elements and sites. The permissible limit of Pb is 0.30 mg/kg in plants (FAO/WHO, 2007). The Cd, As, Se and Tl metals are not present in all studied sites.

Conclusion

The trace metals were found in soils and vegetable plants around the mining area. It was found to be below the WHO permissible levels. In conclusion, the concentration of trace metals in all sites was found to be within normal range in soils and vegetation, except lead (Pb) in site.5. The vegetable species accumulate different metals, depending on plant available metal species of trace metals rather than the total concentration in the soil. However, the accumulation of trace metals was within the normal range. On the basis of BCF, Cu, K, P, Zn and Mg metals are highly accumulated with vegetable plants.

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