Impact of heavy metal contamination of Bellandur Lake on soil and cultivated vegetation

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The aim of this study is to assess the extent of heavy metal contamination of vegetation due to irrigation with sewage-fed lake water on agricultural land. Samples of water, soil and crop plants have been analysed for seven heavy metals, viz. Fe, Zn, Cu, Ni, Cr, Pb and Cd using atomic absorption spectrophotometry. The results show the presence of some of the heavy metals in rice and vegetables, beyond the limits of Indian standards. Metal transfer factors from soil to vegetation are found significant for Zn, Cu, Pb and Cd. Comparing the results of heavy metals in water, soil and vegetation with their respective natural levels, it is observed that impact of lake water on vegetation was found to be more than the soil.

Keywords: Heavy metals, lake water, transfer factor, vegetation.

THE problem of environmental pollution due to toxic metals has begun to cause concern now in most major metropolitan cities. The toxic heavy metals entering the ecosystem may lead to geoaccumulation, bioaccumulation and biomagnification. Heavy metals like Fe, Cu, Zn, Ni and other trace elements are important for proper functioning of biological systems and their deficiency or excess could lead to a number of disorders[1]. Food chain contamination by heavy metals has become a burning issue in recent years because of their potential accumulation in biosystems through contaminated water, soil and air. Therefore, a better understanding of heavy metal sources, their accumulation in the soil and the effect of their presence in water and soil on plant systems seem to be particularly important issues of present-day research on risk assessments[2]. The main sources of heavy metals to vegetable crops are their growth media (soil, air, nutrient solutions) from which these are taken up by the roots or foliage.

Most of our water resources are gradually becoming polluted due to the addition of foreign materials from the surroundings. These include organic matter of plant and animal origin, land surface washing, and industrial and sewage effluents[3]. Rapid urbanization and industrialization with improper environmental planning often lead to discharge of industrial and sewage effluents into lakes. The lakes have a complex and fragile ecosystem, as they do not have self-cleaning ability and therefore readily accumulate pollutants. Bellandur Lake, the largest one in Bangalore urban area, recently attracted a lot of public attention because of the formation of froth during rainy season due to chemicals (soaps, detergents, etc.) and biosurfactants. For the last few decades, the treated, partially treated and untreated wastewater has been discharged to this lake and the lake water is being used for farming purposes.

It has been reported that sewage effluents of municipal origin contain appreciable amount of major essential plant nutrients and therefore the fertility levels of the soil are improved considerably under sewage irrigation of crop fields[2]. However, studies on the water of Vasai Creek, Maharashtra, reveal that the presence of toxic heavy metals like Fe, Pb and Hg reduce soil fertility and agricultural output[4]. Treated sewage water also contains variable amounts of heavy metals such as Pb, Ni, Cd, Cu Hg, Zn and Cr[2], which have the potential to contaminate crops growing under such irrigation.

Comprehensive studies related to the analyses of water, soil and vegetation around a particular lake are only a few in the country. Therefore, the present study has been undertaken (i) to assess the extent of heavy metal contamination in water, irrigated soil and grown crop (rice), vegetables (spinach, brinjal, beans and radish) and fruit (banana) using sewage-fed Bellandur Lake water, (ii) to investigate the uptake of seven heavy metals in crop plants in order to establish advice regarding consumption of vegetables grown in soils contaminated by heavy metals and (iii) to know the availability of metals (water-soluble) to plants and their accumulation in the food chain, and also to quantify the impact of heavy metals on the vegetation irrigated using lake water.

Study area

Bangalore is located at a lat. of 12°58′N and long. of 77°35′E at an altitude of 921 m above mean sea level[5]. Bellandur Lake is 130 years old and spreads across an area of 892 acres and is located near the Bellandur village towards the south of Bangalore (Figure 1 *a* and *b*). Sewage

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from residential areas near the Bangalore international airport is directly allowed into the lake through the main drain. Dense weeds have occupied a major portion of the lake, thus affecting the photosynthesis process by obstructing penetration of sunlight. Objectionable froth has been developed at the overflow region (southeast end)[6]. Recently, the Lake Development Authority received a nod from the Ministry of Environment and Forests to restore this old lake using bio-remedial techniques at an estimated cost of Rs 5.5 crore[7].

Experimental methodology

Sampling

Samplings had been carried out for two years from March 2003 to February 2005. Grab water samples (number of samples collected, n = 19) were collected in 2 l polyethylene cans at monthly intervals. Vegetables, fruit/crop/milk and plants samples (n = 12) were collected in polyethylene bags once in three months. Soil samples (n = 8) at surface level (0–15 cm in depth) were collected from the same locations where the crop plants were sampled.

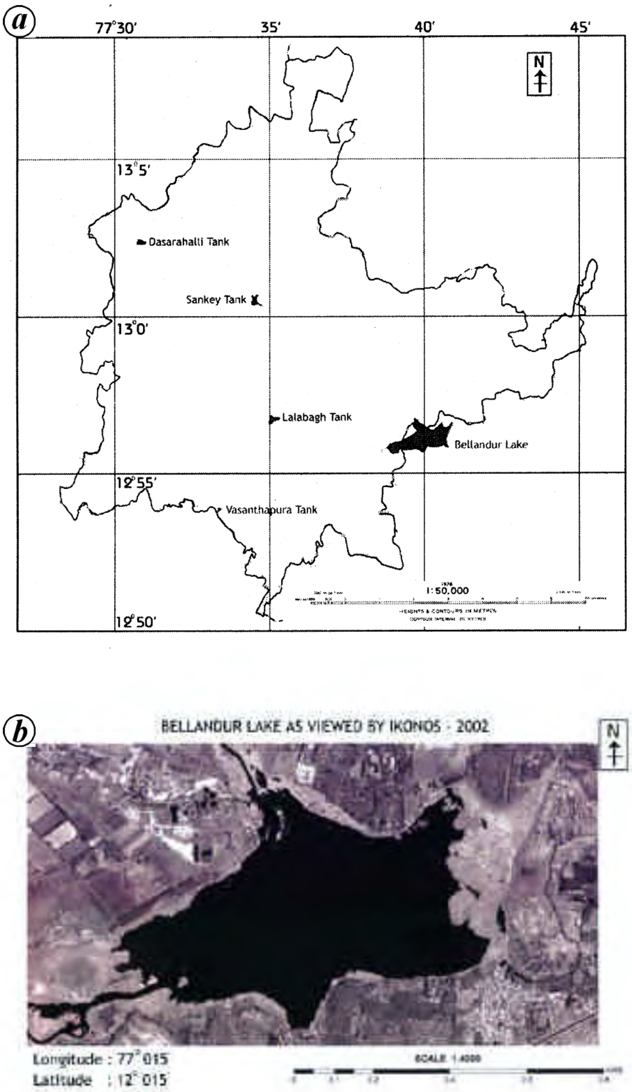

Figure 1. ***a***, Map showing location of Bellandur Lake and ***b***, Satellite view of Bellandur Lake.

Sample preparation

Water samples (500 ml) were filtered using Whatman No. 41 (0.45 μm pore size) filter paper for estimation of dissolved metal content. Filtrate and as-collected water samples (500 ml each) were preserved with 2 ml nitric acid to prevent the precipitation of metals. Both the samples were concentrated to tenfold on a water bath and subjected to nitric acid digestion using the microwave-assisted technique, setting pressure at 30 bar and power at 700 Watts[8,9].

Soil samples were air-dried and ground into fine powder using pestle and mortar and passed through 1 mm sieve. Well-mixed samples of 2 g each were taken in 250 ml glass beakers and digested with 8 ml of aqua regia on a sand bath for 2 h. After evaporation to near dryness, the samples were dissolved with 10 ml of 2% nitric acid, filtered and then diluted to 50 ml with distilled water[10].

Vegetables, fruit, crop and plant samples were thoroughly washed to remove all adhered soil particles. Samples were cut into small pieces, air-dried for 2 days and finally dried at 100 ± 1°C in an hot-air oven for 3 h. The samples were ground in warm condition and passed through 1 mm sieve. Digestion of these samples (2 g each) was carried out using 10 ml nitric acid, according to the procedure used for soil samples[11]. Well-mixed milk samples of 250 ml each were taken in 500 ml glass beakers and digested in 24 ml of aqua regia on a sand bath for 3 days. After evaporation to a lesser volume, the samples were filtered and diluted to 50 ml with distilled water.

Analysis

Heavy metal analyses were carried out using flame atomic absorption spectrophotometer (GBC Avanta version 1.31). The calibration curves were prepared separately for all the metals by running different concentrations of standard solutions. The instrument was set to zero by running the respective reagent blanks. Average values of three replicates were taken for each determination. The detection limits for Fe, Zn, Cu, Ni, Cr, Pb and Cd were 0.05, 0.008, 0.025, 0.04, 0.05, 0.06 and 0.009 (mg l^{-1}) respectively[12]. Powder X-ray diffraction (XRD) pattern of the soil sample (adjacent to lake) was obtained on Philips X'pert PRO X-ray diffractometer with graphite monochromatized CuKα radiation (λ = 1.541 Å) with Ni filter.

Correlation analyses were performed by Pearson's product moment correlation[13]. For samples with values below the detection limit, half of the respective limit of quantification was substituted to perform statistical analysis[14]. The value of $P < 0.05$ was regarded as statistically significant for water and soil measurements.

Transfer factor was calculated for each metal according to the following formula[15,16],

$$\mathrm{TF} = Ps\ (\mu g\ g^{-1}\ \text{dry wt})/St(\mu g\ g^{-1}\ \text{dry wt}),$$

where Ps is the plant metal content originating from the soil and St is the total metal content in the soil.

Results and discussion

Heavy metals in water

Average concentration, desirable limits (fixed by Central Pollution Control Board, Government of India) and natural concentration of metals are presented in Figure 2. From the results, it is found that all seven metals are present in lake water. Average total concentration ($\mu g\ l^{-1}$) of Fe itself is two-fold higher to the limit 1 (total heavy metal concentration $< 0.5\ mg\ l^{-1}$ for irrigation waters[17]), while other metals were within the limit 2 (basic water-quality requirements of metals[17]). It is also observed that the average values of metal concentration ($\mu g\ l^{-1}$) in lake water, i.e. 1087 (Fe), 132 (Zn), 12 (Cu), 3 (Ni), 6 (Cr), 9 (Pb) and 0.7 (Cd) were 2, 9, 4, 6, 6, 9 and 23-fold higher than the natural elemental levels (500 (Fe), 15 (Zn), 3 (Cu), 0.5 (Ni), 1 (Cr), 1 (Pb) and 0.03 (Cd)) in freshwater respectively[1]. This indicates that the heavy metal concentration in lake water is due to the discharge of waste from industrial, municipal and domestic activities in the neighbourhood.

Average metal concentrations found in lake water samples during the rainy (April–October) and dry (November–March) seasons are shown in Table 1. It is observed that Fe, Cr and Pb showed 50% higher concentration during rainy season, while Cd showed higher concentration during dry season. A marginal difference in concentrations is found for Cu and Ni between wet and dry seasons. Zn shows less seasonal variation. Higher concentrations of Fe, Cr and Pb during the rainy season is probably due to rainfall and run-off which cause erosion, thereby introducing into the lake soil, silt and even discarded iron waste besides wastewater from drains nearby[18]. The high level of Cd during dry season might be due to concentration effects.

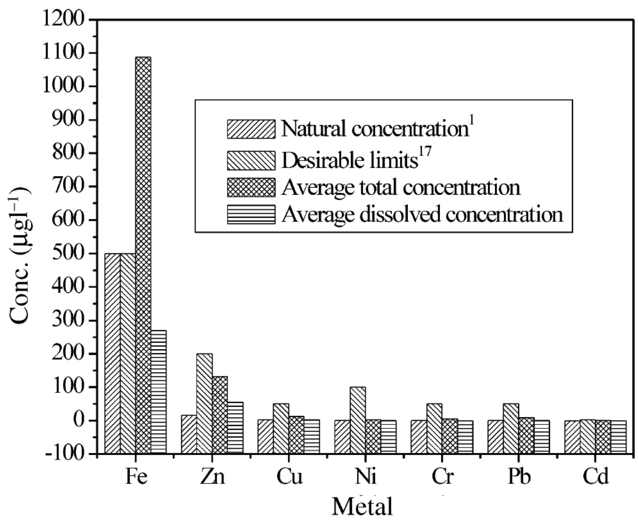

Figure 2. Concentration of metals in lake water.

Bioavailability depends on the concentration of anions and chelating ligands present in water, pH and redox status and the presence of absorbent sediments[19]. The bioavailability (water solubility) of metals (%) with respect to total metal content was found to be: Fe–25, Zn–42, Cu–25, Ni–33, Cr–3, Pb–6 and Cd–19. Zn showed highest bioavailability for plants and animals, and Cr showed the lowest.

Characterization of minerals in soil

Powder XRD studies on soil sample have been carried out as supplementary technique for qualitative identification of elements/metals present in the soil sample of the irrigated land. The powder XRD pattern (Figure 3) of the soil sample exhibits the presence of minerals, namely illite ($KAl_2(Si_3AlO_{10})(OH)_2$), quartz ($SiO_2$) and kaolinite ($Al_2Si_2O_5(OH)_4$), which are in good agreement with the literature data JCPDS No. 31-968, 33-1161 and 29-1488. Minerals present in small quantities such as silhydrite ($Si_3O_6.H_2O$), anatase (TiO_2) and feldspar ($NaAlSi_3O_8$) (JCPDS numbers 25-1332, 21-1272 and 9-466) are also identified from the powder XRD pattern.

A major part of heavy metals is taken up by crops from the soil via roots. Heavy metal transportation from the soil to the roots largely depends on the type and genetic features of soil forming rocks, granuliometric soil composition, amount of organic mater, pH of the soil, sorption capacity, amount of $CaCO_3$, anthropogenic load, and other chemical and physical properties of the soil[20,21]. Adsorption onto oxides has been found to be important for many heavy metals and may significantly affect their mobility in aquatic environments. Laboratory experiments have demonstrated that titanium oxides (TiO_2) are strong sorbents for heavy metals[22]. Hence, presence of TiO_2 (anatase) and aluminium (in combined form) in soil may have an influence on the uptake of heavy metals by plants.

Table 1. Seasonal average heavy metal concentration in lake water ($\mu g\ l^{-1}$)

Season	Fe	Zn	Cu	Ni	Cr	Pb	Cd
Rainy (April–October)	1305	179	17	7	18	13	0.2
Dry (November–March)	777	113	16	6.5	5	6	3.3

Heavy metals in soil

Soil samples of irrigated land used for growing crops and vegetables showed the presence of all seven metals considered in the study. Concentration of Fe, Zn, Cu, Ni, Cr, Pb and Cd (μg g^{-1} dry wt) is represented in Figure 4. These values are higher in soil samples compared to vegetable samples, except for Cd and Zn. The reason might be due to their weak adsorptive nature in the soil[19]. The average total concentration of all metals in soil samples was lower than the permissible limits (limits are based on their effect on animals[23]). However, maximum concentration of Cu and Cd falls within the range of standards. It was found that the average concentration of heavy metals in surface soils, i.e. Cu and Cd was 2.5 and 6-fold higher than the natural concentration[1].

Heavy metals in paddy crop

The paddy crop (*Oryza sativa*) collected during April 2003 was analysed for concentration of metals present in rice, grass and root (μg g^{-1} dry wt) of the plant. The results are presented metal-wise with limits in Figure 5. It is found that Fe, Zn, Cu, Pb and Cd in the roots of the paddy crop are present in high concentration compared to other parts of the plant. Ni and Cr show higher values in soil samples. Since paddy crop is normally planted in flooded soils, the uptake of metals through roots depends on the presence of metal concentration in water as well as in the soil. This uptake mechanism of heavy metals includes both adsorption (from soil) and absorption (from water) and takes place through roots. Hence, Pb concentration in paddy roots is the highest compared to other parts. The distribution of lead subsequently takes place to other parts of the plant from the root. In rice grain, Pb content (3 μg g^{-1}) exceeded the limit, while other metals are within limits. Uptake of Pb in plants is regulated by pH, particle size and cation exchange capacity of the soil as

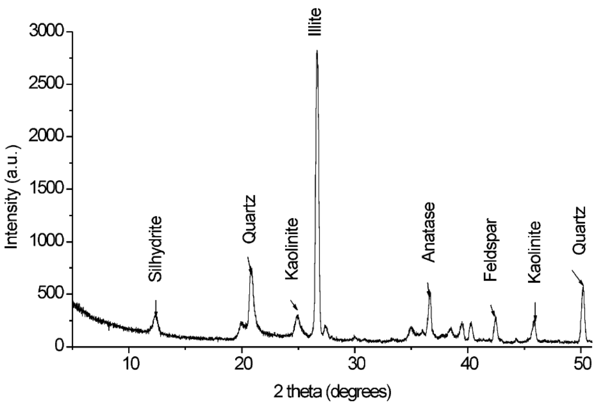

Figure 3. XRD pattern of soil sample collected in the vicinity of Bellandur Lake.

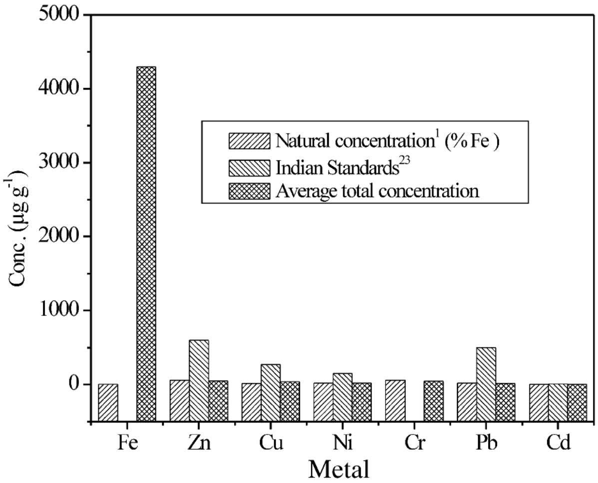

Figure 4. Total concentration of metals in lakeside soil.

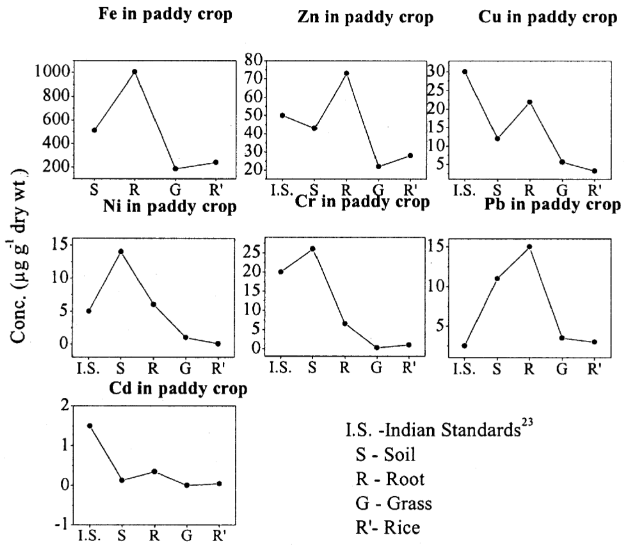

Figure 5. Total concentration of metals in paddy crop.

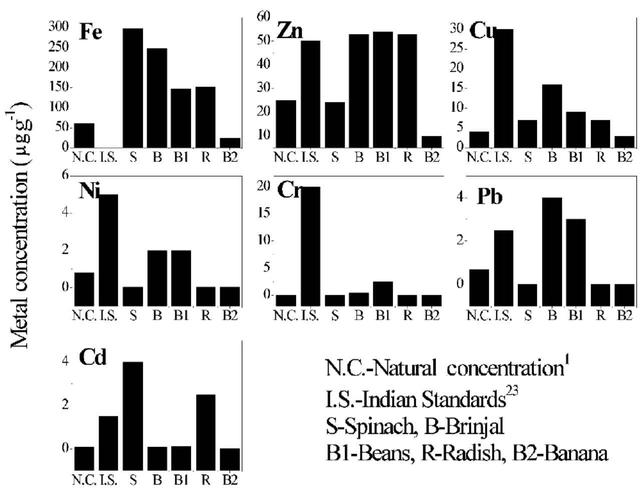

Figure 6. Total concentration of metals in cultivated vegetation.

Table 2. Heavy metal concentration in fodder and milk (mg kg^{-1})

Sample	Fe	Zn	Cu	Ni	Cr	Pb	Cd
Fodder (grass + alligator weed)	312	56	12.3	0.22	BDL	BDL	0.054
Cow milk	0.33	1.83	BDL	BDL	BDL	BDL	0.02
Limit for infant milk substitute and infant food[28]	–	25–50	2.8–15	–	–	0.2	0.1

BDL, Below detection limit.

well as by root exudation and other physico-chemical parameters.

Heavy metals in fruit and vegetables

Most of the laboratory research on biosorption of heavy metals indicates that no single mechanism is responsible for metal uptake. In general, two mechanisms are known to occur, viz. 'adsorption', which refers to binding of materials onto the surface and 'absorption', which implies penetration of metals into the inner matrix[24]. Either one of these or both the mechanisms might take place in the transportation of metals into the plant body. Vegetables – spinach (*Spinacea oleracea*, locally called palak), radish (*Raphanus sativus*), brinjal (*Solanum melongena*), beans (*Phaseolus vulgaris*) and fruits – banana (*Musa X paradisiaca*) are analysed for total metal content. The order of toxic heavy metal contamination in vegetables is as follows: spinach > radish > brinjal > beans (Figure 6). Accumulation of these heavy metals in fruits and vegetables might be due to the use of sewage-fed lake water for their cultivation.

From the results, it is found that the presence of Cd in spinach (4 μg g^{-1}) and radish (2.5 μg g^{-1}) is beyond the limits[25]. The reason for the accumulation is that Cd is relatively easily taken up by food crops and especially by leafy vegetables. Also it may be due to the foliar absorption of atmospheric deposits on plant leaves[19]. Zn is present in appreciable amounts in the vegetables. Radish, brinjal and beans appear to have higher uptake from the continued sewage irrigated land. In case of Pb, maximum concentration is found in brinjal and beans compared to other vegetables. The concentrations of Zn and Cd in food crops increased with the degree of contamination of the soil. Different vegetable species accumulate different metals depending on environmental conditions, metal species and plant available forms of heavy metals. Studies have shown that uptake and accumulation of metals by different plant species depend on several factors, and various researchers have identified several reasons[26,27].

It is found that the average total concentration of metals in plant foodstuff, i.e. Fe, Zn, Cu, Cr, Pb and Cd is 3.5, 2, 2.5, 15, 2.5 and 21-fold higher than the natural concentration[1]. Overall results on comparison reveal that metals in water had more impact on vegetation than the soil itself.

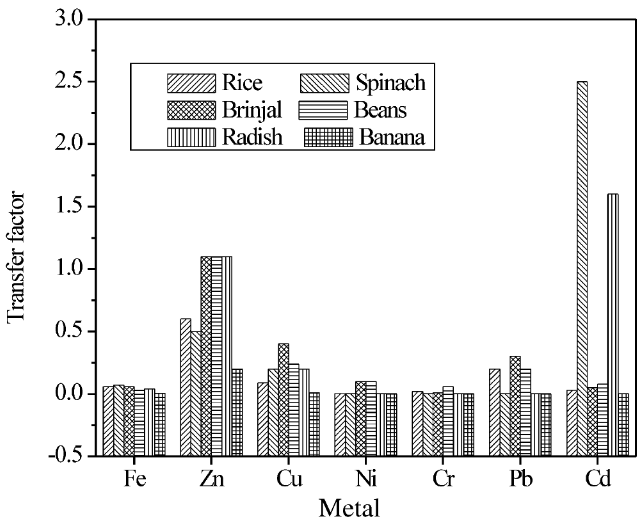

Figure 7. Metal transfer factor for each metal from soil to vegetation.

Heavy metals in fodder and milk

In order to assess the extent of biomagnification of heavy metals from fodder to milk, samples of fodder (grass + alligator weed) and cow milk were analysed. Results are presented with prescribed limits in Table 2. The findings indicate that there is no biomagnification effect of heavy metals in milk. It means that increase in concentration of pollutants from one level to another in the food chain is not observed. However, consumption of milk containing Cd for a long period may affect human health. The presence of Cd in milk may be due to feeding the cows with fodder collected along the lake side. The levels of essential elements in milk are significantly lower than the recommended desirable levels[28], for example, 25–50 mg kg^{-1} for Zn and 2.8–15 mg kg^{-1} for Cu.

Transfer factors for heavy metals

Figure 7 shows the transfer factors (TF) of different heavy metals from soil to vegetation, which is one of the key components of human exposure to metals through the food chain. Highest TF values are obtained for Zn, Cu, Pb and Cd. TF values are below 1, except for those of Zn in brinjal, beans and radish, and Cd in spinach and radish. One of the reasons for these results is that Cd occurs with

Zn in nature and Cd (II) is retained less strongly by the soil than other toxic cations. The highest TF values (2.5 and 1.1 respectively) are found for Cd and Zn because these metals are more mobile in nature. Overall TF values of Zn, Cu, Pb and Cd are found to be significant and it supports the findings that accumulation of Cr, Ni and Pb is comparatively less while that of Cd, Cu and Zn is more in plants[20].

Conclusion

The study reveals that sewage is the main source of pollution of this water body and irrigation with sewage-contaminated water containing variable amounts of heavy metals leads to increase in concentration of metals in the soil and vegetation. Concentration of metals in vegetation will provide baseline data and there is a need for intensive sampling of the same for quantification of the results. Soil, plant and water quality monitoring, together with the prevention of metals entering the plant, is a prerequisite in order to prevent potential health hazards of irrigation with sewage-fed water.

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