INTERNATIONAL JOURNAL OF HIGHER EDUCATION AND RESEARCH
IJHER, Vol., 8(1), 2018, 210-225.
www.ijher.com

IJHER
(ISSN 2277 260X)

CODEN: IJHER

ORIGINAL ARTICLE

# BIOACCUMULATION PATTERN OF HEAVY METALS IN VEGETABLES COLLECTED FROM SELECTED AREAS IN AND AROUND KOLKATA CITY (INDIA)

Ajoy Mallik[1], Joystu Dutta[2], Parvin Sultana[3] and Abhijit Mitra[4]

[1]Department of Zoology, Dinabandhu Mahavidyalaya, Bongaon, West Bengal (India)
[2]Department of Environmental Science, Sarguja University, Ambikapur Chhattisgarh (India) - 497001
[3] Department of Zoology, Vidyasagar University, West Bengal (India)
[4]Department of Marine Science, Ballygunge Science College Campus, Calcutta University, Kolkata-700019, India

**ABSTRACT**

*Bioaccumulation of heavy metals is a burning problem of current times. Considerable studies on heavy metal toxicity at various trophic levels of the ecosystem indicate the serious and far reaching implications of the issue at a global scale. The current paper investigates the bioaccumulation pattern of heavy metals such as Copper, Zinc, Lead in commonly consumed vegetables such as cauliflower, radish and brinjal collected from selected areas in and around the metropolitan city of Kolkata. The bioaccumulation trend shows that Zn>Cu>Pb irrespective of the study areas; Swarupnagar Community Development Block and East Kolkata Wetlands. The pattern of accumulation in vegetables also shows the order Radish>Cauliflower>Brinjal irrespective of the selected areas. A long term survey on the bioaccumulation pattern of heavy metals through seasons may prove the potential of the species to be used as indicator of heavy metal pollution. Such studies are to be repeated with rigorous monitoring of the commonly consumed vegetables in and around Kolkata to prevent the long term effects of such toxic consumption.*

**Keywords: bioaccumulation, heavy metals, vegetables, pollution, Kolkata**

**Introduction:**

Bioaccumulation of toxic heavy metals is one of the burning environmental issues of current times. The mobilization of heavy metals into the biosphere by human activity has become an important process in the geochemical cycling of these metals. Toxic heavy metals such as arsenic (As), lead (Pb), cadmium (Cd), and mercury (Hg) have serious health implications among the heavy metals (Csavina et al., 2012; Sharma et al., 2014; Gupta et al., 2015a). Considerable studies on toxic heavy metals in different trophic levels of the ecosystem are already available as reference scientific literature to understand the magnitude of this problem. Exposure to environmental pollutants is an important problem of environmental toxicology (Zukowska et al., 2008). The rise of ecotoxicology (also termed environmental toxicology) is generally associated with the 1960s and the first formal definition came from Truhaut (1977) who considered ecotoxicology to be the branch of toxicology concerned with the effects of pollutants on the constituents of an ecosystem in an integrated context. A number of variants on this definition have appeared over the years (reviewed in Newman 1998), but all of them embrace much of Truhaut's (1977) original concept (Relya and Hoverman, 2006). Terrestrial and aquatic ecosystems are most vulnerable to pollution due to series of factors including toxic heavy metals that leads to bioaccumulation at different trophic levels (Boran and Altınok, 2010). Any metallic element with a relatively high density and toxicity even at lower concentrations is ascribed to be 'heavy metal' (Lenntech, 2004). The metal distribution in the atmosphere is dependent on various environmental factors (Khlifi and Hamza-Chaffai, 2010). The toxicity of heavy metals is a significant environmental issue in current times (Jaishankar et al., 2013; Nagajyoti et al., 2010). Natural and anthropogenic activities such as solid-waste disposal, atmospheric deposition, and the application of sewage sludge and waste water irrigation on land are the main sources of heavy metal contamination in the environment (Chen, 2007, Cui, et al., 2005, Komarnicki, et al., 2005). Various sources of heavy metals include soil erosion, natural weathering of the earth's crust, mining, industrial effluents, urban runoff, sewage discharge, insect or disease control agents applied to crops, and many others (Morais et al., 2012). Soils may become contaminated by the accumulation of heavy metals and metalloids through emissions from the rapidly expanding industrial areas, mine tailings, disposal of high metal wastes, leaded gasoline and paints, land application of fertilizers, animal manures, sewage sludge, pesticides, wastewater irrigation, coal combustion residues, spillage of petrochemicals, and atmospheric deposition (Khan, et al., 2008, Zhang, et al., 2010). The contamination of aquatic and terrestrial ecosystems with a wide range of pollutants and especially heavy metals has become a matter of concern over the last few decades (Vutukuru, 2005; Dirilgen, 2001; Voegborlo, et al., 1999; Canli, et al., 1998; Velez and Montoro, 1998; Janssen, et al., 1993; Conacher, et al., 1993). Heavy metal contamination has deleterious effects on the ecological balance of the ecosystem irrespective of its nature such as terrestrial, aquatic or marine (Farombi, et al., 2007; Vosyliene and Jankaite, 2006; Ashraj, 2005). Heavy metal accumulation in soil interrupts the normal functioning of soil ecosystems and plant growth (Khan et al., 2008; 2008). Heavy metals such as lead (Pb), cadmium (Cd), mercury (Hg) and chromium (Cr) generally refer to metals having densities greater than 5 $g/cm^3$ (Oves et al., 2012; Järup, 2003; Raut, et al., 2005). An alternative classification of metals based on their coordination chemistry categorizes heavy metals as class B metals that come under non-essential trace elements, which are highly toxic elements such as Hg, Ag, Pb, Ni etc. (Nieboer and Richardson 1980). These heavy metals create toxic effects on human health by forming complexes with organic compounds (Akbulut et al., 2011). Composite effluents stained with different heavy metals are major environmental pollutants of varied wetland ecosystem (Cheung et al., 2003; Chatterjee et al., 2006). Metal toxicity has high impact and relevance to plants and consequently it affects the ecosystem, where the plants form an integral component. Plants growing in metal-polluted sites exhibit altered metabolism, growth reduction, lower biomass production and metal accumulation (Nagajyoti, et al., 2010). Studies have been conducted throughout the world to determine the effects of toxic heavy metals on plants (Reeves and Baker, 2000; Fernandes and Henriques, 1991). Toxicity may result from the binding of metals to sulphydryl groups in proteins, leading to an inhibition of activity or disruption of structure, or from the displacing of an essential element resulting in deficiency effects (Van Assche and Clijsters, 1990). In addition, heavy metal excess may stimulate the formation of free radicals and reactive oxygen species, perhaps resulting in oxidative stress (Dietz et al., 1999). Lead can adversely influence the intelligence development of children, cause excessive lead in blood, and induce hypertension, nephropathy and cardiovascular disease (Ekong, et al., 2006, Goyer, et al., 1993, Navas, et al., 2007). The general body of the literature on lead toxicity indicates that lead exposure in children and adults can cause a wide spectrum of health problems depending on dose of exposures ranging from convulsions, coma, renal failure and death at the high end to subtle effects on metabolism and intelligence loss at the low end exposures (US Agency for Toxic Substances & Disease Registry, 1999). The toxic effects of mercury on edible crops and vegetables are humongous leading to far reaching consequences. Hg and Pb are associated with the development of abnormalities in children (Gibbes and Chen, 1989). Some others heavy metals such as copper (Cu), zinc (Zn), chromium (Cr), manganese (Mn) lie in the narrow 'window' between their essentiality and toxicity, i.e., they are nutritionally essential at lower levels but can also be toxic when certain limits are exceeded (Loutfy et al., 2012). When heavy metals are dispersed into water, soil and air, they could be bio-accumulated by the crops (Fu, et al., 2008, Xiu, et al., 2009) as well as in the fishes via aquatic medium (Lorenzon, et al., 2001, Vutukuru, 2005, Akan, et al., 2012, Mitra, et al., 2014, Arantes, et al., 2016, Dutta et al., 2017).

Vegetables constitute essential diet components by contributing protein, vitamins, iron, calcium and other nutrients, which are usually in short supply (Thompson and Kelly, 1990). Vegetables play important roles in human nutrition and health, particularly as sources of vitamin C, thiamine, niacin, pyridoxine, folic acid, minerals, and dietary fiber (Siegel, et al., 2014). Heavy metal in vegetables is of growing concerns since some soils and irrigation waters are demonstrated to be polluted (Sipter, et al., 2008). Vegetables easily take up heavy metals and accumulate them in their edible parts (Sipter, et al., 2008). Once vegetables containing high levels of heavy metals are consumed by human, such metals can cause several clinical and physiological problems (Khan, et al., 2008, Kumar, et al., 2007). Simple correlation analysis by (Ye, et al., 2015) revealed that there were significantly positive correlations between the metal concentrations in vegetables and the corresponding soils, especially for the leafy and stem vegetables such as pakchoi, cabbage, and celery. This study by (Ye, et al., 2015) further reveals that Bio-concentration factor (BCF) values for Cd are higher than those for Pb and Cr, which indicates that Cd is more readily absorbed by vegetables than Pb and Cr. Therefore, more attention should be paid to the possible pollution of heavy metals in vegetables; especially Cd. Knowledge of acute toxicity of a xenobiotic often can be very helpful in predicting and preventing acute damage to aquatic life in receiving waters as well as in regulating toxic waste discharges (APHA, 1998). The edible vegetables grown in wastewater-irrigated soil shows significant accumulation of heavy metals in their edible parts (Gupta, et al., 2008, Gupta, et al., 2010). A number of excellent reviews of aquatic ecotoxicology have been conducted during the past decade (Brock et al., 2000a, b, Fleeger et al., 2003, Relyea et al., 2005, Dutta et al., 2017). These reviews have provided extensive information on the direct toxic effects of a wide range of contaminants and, in some cases, the indirect effects of pesticides that occur when a given species is eliminated or reduced in number (Relyea and Hoverman, 2006). Soil threshold for heavy metal toxicity is an important factor. It affects the soil environmental capacity of heavy metal and determines cumulative heavy metal loading limits. For soil-plant system, heavy metal toxicity threshold is the highest permissible content in the soil (total or bioavailable concentration) that does not pose any phytotoxic effects or heavy metals in the edible parts of the crops does not exceed food hygiene standards (Islam et al., 2007). Heavy metal accumulation in soils is of concern in agricultural production due to the adverse effects on food quality (safety and marketability), crop growth (due to phytotoxicity) (Ma et al., 1994; Msaky and Calvert, 1990; Fergusson, 1990) and environmental health (soil flora/fauna and terrestrial animals). The mobilization of heavy metals into the biosphere by human activity has become an important process in the geochemical cycling of these metals. Considerable studies on toxic heavy metals in different trophic levels of the ecosystem are already available as reference scientific literature to understand the magnitude of this problem.

In the current paper, considerable concentrations of heavy metal have accumulated in the body tissue of vegetables collected from East Kolkata wetlands area compared to those collected from the Swarupnagar region, a socio-economically prolific hamlet found in Bangaon of North 24 parganas district of West Bengal India. The analysis was carried out through Atomic Absorption Spectrophotometer (AAS) after acid digestion.

**Methodology:**

**a) Description of study areas:**

Swarupnagar is a community development (CD) block that forms an administrative division in Basirhat subdivision of North 24 Parganas district in the Indian state of West Bengal. Headquarters of this block is at Swarupnagar. It is located 30 km from Barasat, the district headquarters. It is located at 22°50′00″N 88°52′00″E. Swarupnagar CD Block is bounded by

Gaighata CD Block in the north, *Kalaroa Upazila* in *Satkhira* District of Bangladesh in the east, Baduria CD Block in the south and west, and Habra I CD Block in the west.

The metropolitan city of Kolkata with its ever expanding urbanscapes lies on the fringes of this area. The huge peri-urban population living in this Community Development Block is majorly dependent on agriculture. The humongous proportions of vegetables grown in this area are transported to Kolkata and outskirts. The agricultural fields in the area and rich variety of fishes grown in the innumerable fish ponds locally termed as *bheries/pukurs* are nourished by water and soils historically rich in toxic heavy metals and hazardous chemicals. The food security challenges and issues associated with population explosion of gangetic West Bengal are fulfilled by the farm productivity of the wetlands. Hence, bioaccumulation studies are of pivotal importance in this area.

The East Kolkata Wetlands (EKW), located on the eastern fringes of Kolkata city is one of the largest assemblages of sewage fed fish ponds spread over an area of 12,500 ha (Fig. 1). These wetlands form a part of the extensive inter-distributory wetland regimes formed by the Gangetic Delta. EKW sustains the world's largest and perhaps oldest integrated resource recovery practice based on a combination of agriculture and aquaculture, and provides livelihood support to a large, economically underprivileged population of around 20,000 families which depend upon the various wetland products, primarily fish and vegetables for sustenance. Based on its immense ecological and socio cultural importance, the Government of India declared EKW as a Wetland of International Importance under Ramsar Convention in 2003. The wetland system currently produces over 15,000 MT per annum from its 264 functioning aquaculture ponds, locally called bheries. Additionally, nearly 150 MT of vegetables are produced daily by subsistence farmers. Needless to say, EKW serves as the backbone of food security of Kolkata City. EKW is a classical example of harnessing natural resources of the wetland system for fisheries and agriculture through ingenuity of local communities with their traditional knowledge.

**Study Area Map:**

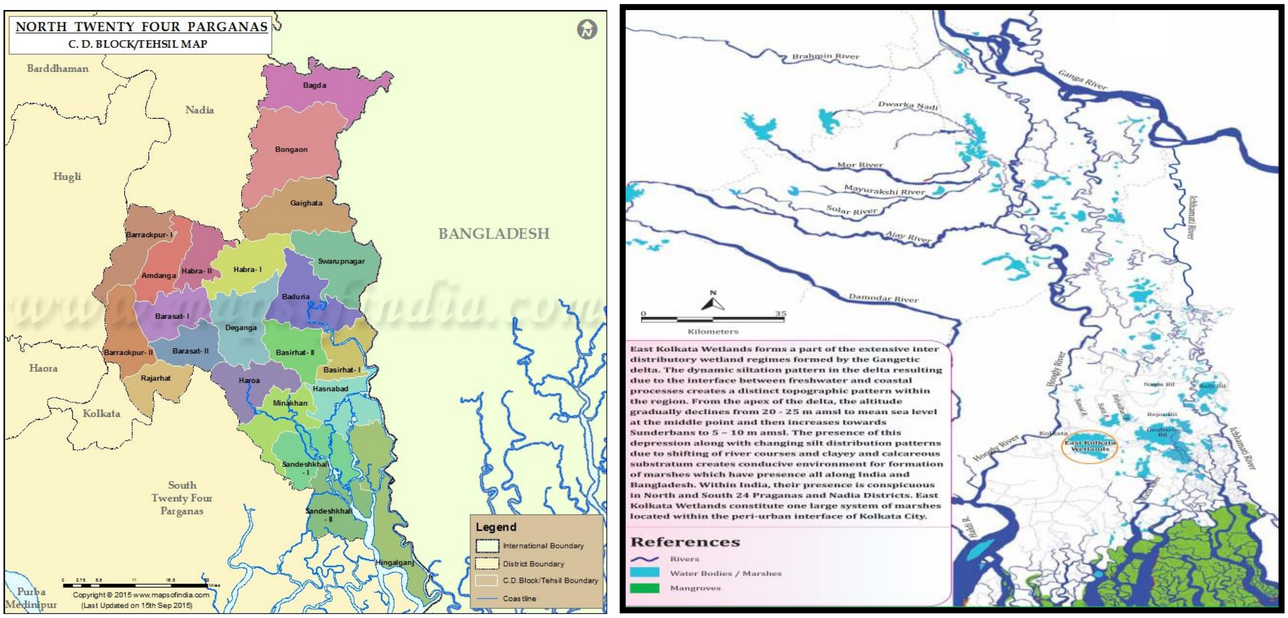



Fig. 1: Swarupnagar Community Block (on left) and East Kolkata Wetlands (on right)

**b) Collection of vegetables:**

The sample collection was carried during November 2017 from the study site. Vegetable samples (Radish, Brinjal and Cauliflower) were collected from the agricultural plots in East Kolkata Wetlands and Swarupnagar.

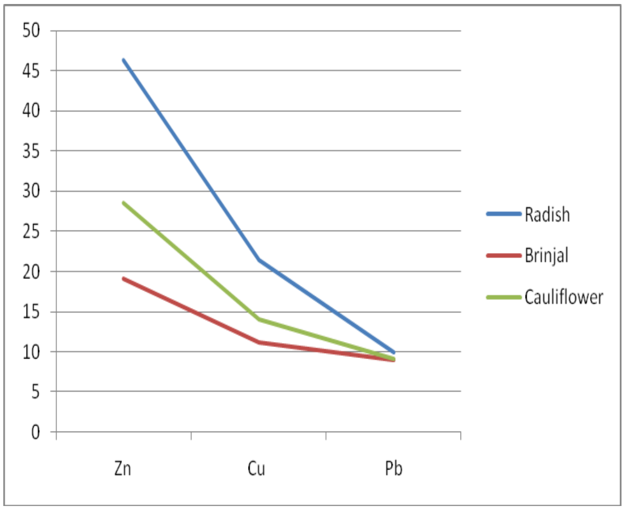
**c) Analysis**

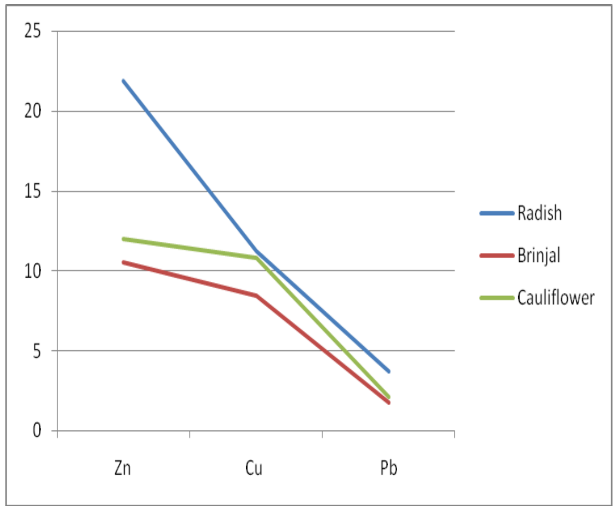
The edible portions of the vegetables were removed separately and oven dried overnight at $105^0$C. After complete drying, the remaining portions were powdered and stored separately by labeling the samples. 1 gm of dried portion (in three replicates) was mixed in 10ml solution of HNO3 and HCl in the ratio 1:3 to form aqua-regia solution. The solution was stirred for few minutes and kept for overnight. The flasks were then placed on a hot plate with tightly corked and allowed to digest until a transparent and clear solution was obtained. This solution was separately aspirated in Atomic Absorption Spectrophotometer with Hydride module (NOVA 350 Model) and the readings were recorded considering the blank correction.

**Results:** The bioaccumulation pattern of heavy metals indicates the trend Zn>Cu>Pb irrespective of the study areas; Swarupnagar Community Development Block and East Kolkata Wetlands. The pattern of accumulation in vegetables also shows the order Radish > Cauliflower > Brinjal irrespective of the selected areas. The results of analysis are detailed in the **Table 1** as under.

**TABLE 1: Selected heavy metal concentrations in vegetables collected from East Kolkata wetlands (A) and Swarupnagar field (B)**

| Species | Metal concentration (mg/kg) dry wt. | | |
|---|---|---|---|
| | **Zn** | **Cu** | **Pb** |
|  **Radish** ***(Raphanus sativus)*** | **A =46.28**<br>**B =21.89** | **A =21.40**<br>**B =11.22** | **A =9.96**<br>**B =3.74** |
|  **Brinjal** **(*Solanum melongena*)** | **A =19.15**<br>**B =10.56** | **A =11.20**<br>**B =8.44** | **A =8.98**<br>**B =1.75** |
|  **Cauliflower** ***(Brassica oleracea)*** | **A =28.48**<br>**B =11.96** | **A =14.05**<br>**B =10.75** | **A =9.13**<br>**B =2.09** |




**A. East Kolkata Wetlands** **B. Swarupnagar Community Block**

**Discussion:**

Vegetables are common diet taken by populations throughout the world, being rich sources of essential nutrients, antioxidants and metabolites by acting as buffering agents for acidic substances produced during the digestion processes (Li et al., 2008). Continuous use of inorganic fertilizers and pesticides although increased the global food production by many folds, have degraded the ecological functioning of agricultural lands, lowered the quality and taste of agricultural produce and have increased the health and environmental risks to human being (Tilman et al., 2001). Vegetables take up heavy metals and accumulate them in their edible (Bahemuka et al., 1991) and inedible parts in quantities high enough to cause clinical problems both to animals and human beings when they consume these metal-rich plants (Alam et al., 2003). The samples chosen for our current research are commonly grown and consumed in the study site. The study stations form one of the major sources of the vegetables and fishes largely consumed by people across Kolkata and outskirts. A major portion is also exported across the country and abroad. Hence, it is extremely essential to monitor and assess the levels of toxic substances, particularly heavy metals that bioaccumulate across the trophic levels of the selected dynamic ecosystems. The present data reveals an issue of concern regarding the consumption of vegetables collected from the selected areas. More such seasonal studies are to be carried out in and around Kolkata on a temporal scale to assess and monitor the vegetables commonly consumed by dense populations living in these areas on a large scale

**Acknowledgements:**

The authors duly acknowledge the unparallel support from Mr. Prasenjit Pramanick and Ms. Arpita Saha, research scholars from Techno India University, Salt Lake City, Kolkata, West Bengal for their technical assistance in this project.

**References:**

Akan, J. C., Mohmoud, S., Bashir, S.Y. and Ogugbuaja, V. O. (2012). Bioaccumulation of Some Heavy Metals in Fish Samples from River Benue in Vinikilang, Adamawa State, Nigeria. American Journal of Analytical Chemistry, Vol. 3, 727-736.

Akbulut, N. E. and Tuncer, A. M. (2011). Environ Monit Assess 173: 387-395. https://doi.org/10.1007/s10661-010-1394-7.

Alam, M. G., Snow, E. T., Tanaka, A. (2003) Arsenic and heavy metal contamination of vegetables grown in Samta village, Bangladesh. Sci Total Environ 308: 83-96.

APHA, AWWA, WPCP. (1998). Standard methods for the examination of Water and Wastewater, 20th ed.American Public Health Association: Washington, DC [.Google Scholar]

Arantes, P. F., Savassi, A. L., Santos, B. H., Gomes, T. V. M. and Bazzoli, N. (2016). Bioaccumulation of mercury, cadmium, zinc, chromium, and lead in muscle, liver, and spleen tissues of a large commercially valuable catfish species from Brazil. Anais da Academia Brasileira de Ciências. (Annals of the Brazilian Academy of Sciences).

Bahemuka, T. E., Mubofu, E. B. (1991). Heavy metals in edible green vegetables grown along the sites of the Sinza and Msimbazi Rivers in Dar es Salaam, Tanzania. *Food Chemistry* 66: 63-66.

Boran, M. and Altinok, I. (2010). A Review of Heavy Metals in Water, Sediment and Living Organisms in the Black Sea. Turkish Journal of Fisheries and Aquatic Sciences, 10, 565-572.

Brock, T.C.M., Lahr, J. & Van den Brink, P.J. (2000a). Ecological risks of pesticides in freshwater ecosystems. Part 1: Herbicides. Alterra-Report 088, Wageningen, The Netherlands

Canli, M., Ay, O. and Kalay, M. (1998). Levels of heavy metals (Cd, Pb, Cu, and Ni) in tissue of Cyprinus Carpio, Barbus Capito and Chondrostoma regium from the Seyhan river. Turk. J. Zool., 22 (3), 149-157.

Chatterjee, S., Chattopadhyay, B., and Mukhopadhyay, S. K. (2006). Trace metal distribution in tissues of Cıchlıds (Orechromıs niloticus and O. mossambicus) collected from wastewater fed fishponds in East Calcutta Wetlands a Ramsar site. Acta Ichthyologica et Piscatoria, 36(2), 119–125.

Chen, J. (2007). Rapid urbanization in China: a real challenge to soil protection and food security. Catena 69, 1-15.

Cheung, K. C., Poon, B. H. T., Lan, C. Y., & Wong, M. H. (2003). Assessment of metal and nutrient concentration in river water and sediment collected from the cities in the Pearl River Delta, South China. Chemosphere, 52, 1431–1440.

Conacher, H. B., Page, B. D. and J. J. Ryan,(1993), Industrial chemical contamination of foods [Review], Food Additive & Contamination, 10 (1), pp129-143.

Csavina J., Field J., Taylor M. P., Gao S., Landázuri A., Betterton E. A., et al. (2012). A review on the importance of metals and metalloids in atmospheric dust and aerosol from mining operations. Sci. Total Environ. 433C, 58–73. 10.1016/j.scitotenv.2012.06.013 [PMC free article] [PubMed] [Cross Ref].

Dietz, K-J; Baier, M.; Krämer, U. (1999). Free radicals and reactive oxygen species as mediators of heavy metal toxicity in plants. In: Prasad MNV, Hagemeyer J, eds. Heavy metal stress in plants: from molecules to ecosystems. Berlin: Springer-Verlag, 73 –97.

Dirilgen, N. (2001). Accumulation of heavy metals in freshwater organisms: Assessment of toxic interactions. Turk. J. Chem., 25 (3), 173-179.

District Human Development Report: North 24 Parganas. Intro Pp 3, 6, 8, 22, 38, 202; Block specific Pp 20, 22, 27, 28, 31, 86, 89, 123, 145, 151, 189. Development & Planning Department, Government of West Bengal, 2010. Retrieved 18 March 2016.

Dutta, J., Roy Choudhary, G. and Mitra, A. (2017). Bioaccumulation of Toxic Heavy Metals in the Edible Fishes of Eastern Kolkata Wetlands (EKW), the Designated Ramsar Site of West Bengal, India. Int J Aquac Fish Sci 3(1): 018-021. DOI: 10.17352/2455-8400.000023

Dutta, J., Zaman, S., Mitra, A. (2017). Bioaccumulation of Toxic Heavy Metals in some commonly edible Vegetables grown in East Kolkata Wetland (EKW), the Designated Ramsar Site of West Bengal, India. Journal of Science, Health, Engineering and Management (JSEHM). Vol 1 Issue 4 Pages: 55-58

Ekong, E.B., Jaar, B.G. and Weaver, V.M. : Lead-related nephrotoxicity: A review of the epidemiologic evidence. Kidney Int. Vol. 70, 2074–2084. (2006). [CrossRef] [PubMed].

Farombi, E. O., Adelowo, O. A., Ajimoko. Y. R. (2007). Biomarkers of oxidative stress and heavy metal levels as indicators of environmental pollution in African Cat fish (Clarias gariepinus) from Nigeria ogun river. Int. J. Environ. Res. Public Health., 4 (2), 158-165.

Fergusson, J.E. The Heavy Elements: Chemistry, Environmental Impact and Health Effects. Oxford: Pergamin Press; 1990. pp. 382–399.

Fernandes, J. C. and Henriques, F. S. (1991). Biochemical, physiological and structural effects of excess copper in plants. Bot Rev 57:247–273.

Fleeger, J.W., Carman, K.R. and Nisbet, R.M. (2003). Indirect effects of contaminants in aquatic ecosystems. Sci. Total Environ., 317, 207–233.

Fu, J. et al. (2008). High levels of heavy metals in rice (Oryza sativa L.) from a typical E-waste recycling area in southeast China and its potential risk to human health. Chemosphere 71, 1269–75. [PubMed]

Gibbes, H., and Chen, C. (1989). Evaluation of issues relating to the carcinogens risk assessment of chromium. Sci. Total Environ. 86, 181–186.

Goyer, R.A. (1993). Lead Toxicity: Current Concerns. Environ. Health Persp. 100, 177–187. [CrossRef]

Gupta, N., Khan, D. K., Santra, S. C. (2008). An assessment of heavy metal contamination in vegetables grown in wastewater-irrigated areas of Titagarh, West Bengal, India. Bull Environ Contam Toxicol. Feb; 80(2):115-8. Epub 2007 Dec 29.

Gupta, S., Satpati, S., Nayek, S., Garai, D. (2010). Environ Monit Assess 165:169–177.

Jaishankar, M.; Mathew, B.B.; Shah, M.S.; Gowda, K.R.S. (2014). Biosorption of Few Heavy Metal Ions Using Agricultural Wastes. Journal of Environment Pollution and Human Health.; 2(1):1–6.

Janssen, M.P.M., Ma, W.C., Van Straalen, N.M. (1993). Biomagnification of metals in terrestrial ecosystems. The Science of the Total Environment, Volume 134, Supplement 1, 1993, Pages 511-524.

Järup, L. (2003). Hazards of heavy metal contamination. Br Med Bull. 68(1):167–182. [PubMed]

Islam, Ejaz ul et al. (2007). Assessing Potential Dietary Toxicity of Heavy Metals in Selected Vegetables and Food Crops." Journal of Zhejiang University. Science. Jan 8.1. Pages 1–13.

Khan, S., Cao, Q., Zheng, Y. M., Huang, Y. Z. and Zhu, Y. G. (2008). "Health risks of heavy metals in contaminated soils and food crops irrigated with wastewater in Beijing, China," Environmental Pollution, vol. 152, no. 3, pp. 686–692.

Khlifi, R. and Hamza-Chaffai, A. (2010). Head and neck cancer due to heavy metal exposure via tobacco smoking and professional exposure: A review. Toxicol Appl Pharmacol. 248:71–88. [PubMed].

Kumar Sharma R., Agrawal M. and Marshall F. (2007). Heavy metal contamination of soil and vegetables in suburban areas of Varanasi, India. Ecotoxicol Environ Saf 66, 258–66, [PubMed]

Lenntech (2004). Heavy metals. Retrieved March 30, 2008 from www.lenntech.com/heavymetals. 34 pp.

Li, T. S. C. (2008) Vegetables and Fruits: Nutritional and Therapeutic Values. CRC Press, Boca Raton. http://dx.doi.org/10.1201/9781420068733.

Lorenzon, S., Francese, M., Smith, V. J., and Ferrero, E. A. (2001). Heavy metals affect the circulating haemocyte number in the shrimp Palaemon elegans. Fish and shellfish immunology, 11: 459–472. doi: 10.1006/fsim.2000.0321.

Loutfy, N., Mentler, A., Shoeab, M., Ahmed, M. T., and Fuerhacker, M. (2012). Analysis and exposure assessment of some heavy metals in foodstuffs from Ismailia city, Egypt. Toxicol. Environ. Chem., 94, 78-90.

Ma, Q. Y., Traina, S. J., Logan, T. J. (1994). Effect of aqueous Al, Cd, Fe(II), Ni and Zn on Pb immobilization by hydroxyapatite. Environ Sci Technol. 28(7):1219–1228. [PubMed].

Mitra, A. and Ghosh, R. (2014). Bioaccumulation Pattern of Heavy Metals in Commercially Important Fishes in and around Indian Sundarbans. Global Journal of Animal Scientific Research. Vol 2, (1):33-44.

Morais, S., Costa, F. G. and Pereira, M. L. (2012). Heavy metals and human health. In: Oosthuizen J, editor. Environmental health – emerging issues and practice. pp. 227–246. [InTech] [Ref list]

Msaky, J. J. and Calvert, R. (1990). Adsorption behavior of copper and zinc in soils: influence of pH on adsorption characteristics. Soil Sci. 150(2):513–522. doi: 10.1097/00010694-199008000-00004. [Cross Ref].

Nagajyoti, P.C.; Lee, K.D. and TVM, Sreekanth. (2010). Heavy metals, occurrence and toxicity for plants: A review. Environmental Chemistry Letters, 8(3), 199-216. Environmental Chemistry Letters. 8(3). 199-216.

Navas-Acien, A., Guallar, E., Silbergeld, E. K., Rothenberg, S. J. (2007). Lead exposure and cardiovascular disease: A systematic review. Environ. Health Perspect. 115, 472–482. [CrossRef] [PubMed]

Nieboer, E. and Richardson, D. H. S. (1980). The replacement of the nondescript term heavy metals by a biologically and chemistry significant classification of metal ions. Environ Pollut Series B 1:3–26.

Oves, M., Khan, M. S., Zaidi, A. and Ahmad E. (2012). Soil contamination, nutritive value, and human health risk assessment of heavy metals: an overview-oxicity of heavy metals to legumes and bioremediation. Springer.

Raut, N.; Charif, G.; Amal, Al-Saadi; Shinoona Al-Aisri, and Abrar Al-Ajmi. (2012). “A Critical Review of Removal of Zinc from Wastewater.” Proceedings of the World Congress on Engineering, London, vol. I, July 4-6, 2012.

Reeves, R.D. and Baker, A.J.M. (2000). Metal-accumulating plants. In: Raskin I, Ensley BD (eds) Phytoremediation of toxic metals: using plants to clean up the environment. Wiley, New York, pp 193–229.

Relyea, R.A., Schoeppner, N.M. and Hoverman, J.T. (2005). Pesticides and amphibians: the importance of community context. Ecol. Appl., 15, 1125–1134

Relyea, R. and Hoverman, J. (2006).Assessing the ecology in ecotoxicology: a review and synthesis in freshwater systems. Ecology Letters, 9: 1157–1171.

Sharma, B., Singh S., Siddiqi N. J. (2014). Biomedical implications of heavy metals induced imbalances in redox systems. Biomed. Res. Int. 2014:640754. 10.1155/2014/640754 [PMC free article] [PubMed] [Cross Ref].

Siegel, K. R., Ali M. K., Srinivasiah A., Nugent R. A. and Narayan K. M. V. (2014). Do we produce enough fruits and vegetables to meet global health need? PloS one 9, e104059 [PMC free article] [PubMed]

Sipter, E., Rozsa E., Gruiz K., Tatrai E. and Morvai V. (2008). Site-specific risk assessment in contaminated vegetable gardens. Chemosphere 71, 1301–7. [PubMed]

Thompson, H.C. and Kelly, W.C. (1990).Vegetable Crops. 5th Ed. New Delhi: MacGraw Hill Publishing Company Ltd.

Tilman, D., Fargione, J., Wolff, B., D’Antonio, C., Dobson, A., Howarth, R., et al. (2001). Forecasting agriculturally driven global environmental change. Science, 292, 281–284.CrossRef. Google Scholar

Truhaut, R. (1977). Ecotoxicology: objectives, principles, and perspectives. Ecotoxicol. Environ. Saf., 1, 151–173.

US Agency for Toxic Substances and Disease Registry. (1999). Lead. Toxicological profiles. Atlanta: Centers for Disease Control and Prevention. PB/99/166704.

Van Assche, F. and Clijsters, H. (1990). Effects of metals on enzyme activity in plants. Plant, Cell and Environment 13, 195 –206.

Velez, D. and Montoro, R. (1998), Arsenic speciation in manufactured seafood products: a review, Journal of food Protection, 61 (9), pp 1240-1245.

Voegborlo, R. B.; Methnani, A. M. E.; Abedin, M. Z. (1999). Mercury, cadmium and lead content of canned Tuna fish. Food Chem., 67 (4), 341 – 345.

Vutukuru, S. S. (2005). Acute effects of Hexavalent chromium on survival, oxygen consumption, hematological parameters and some biochemical profiles of the Indian Major carp, Labeo rohita. Int. J. Environ. Res. Public Health., 2 (3), 456- 462.

Xiu-Zhen H. A. O., Dong-Mei, Z., De-Qian, H., Long, C., Hai-Lin, Z. and Hui, W. (2009). Heavy Metal Transfer from Soil to Vegetable in Southern Jiangsu Province, China. Pedosphere 19(3): 305–311.

Ye, X., Xiao, W., Zhang, Y., Zhao, S., Wang, G., Zhang, Q. and Wang, Q. (2015). Assessment of Heavy Metal Pollution in Vegetables and Relationships With Soil Heavy Metal Distribution in Zhejiang Province, China Environ Monit Assess 187 (6), 378.

Zhang, M. K., Liu, Z. Y. and Wang, H. (2010). "Use of single extraction methods to predict bioavailability of heavy metals in polluted soils to rice," Communications in Soil Science and Plant Analysis, vol. 41, no. 7, pp. 820–831.