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# HEAVY METAL IN THE FOOD CHAIN - CONSEQUENCES OF POLLUTING WATER BODIES

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***Abstract***

**Purpose of the study:** Heavy metals in food (vegetables, etc.) are harmful to humans due to their non-biodegradable nature, long biological half-lives, and their potential to accumulate in different body parts. Prolonged consumption of such heavy metal contaminated vegetables through foodstuffs may lead to chronic accumulation of heavy metals in human beings' kidneys and liver, disrupting numerous biochemical processes, leading to cardiovascular, neural, kidney and bone diseases.

**Method:** The study on heavy metal concentrations in vegetables grown in the command areas of Varthur lake, Bangalore. The collected vegetable samples were analyzed using ICP-OES (Inductively Coupled Plasma-Optical Emission Spectroscopy) technique to assess the level of heavy metal in acid digested samples.

**Main Findings:** The study has shown a significant accumulation of heavy metals in vegetables that correlated well with its concentrations in soil and lake water. The prolonged irrigation of vegetables using contaminated lake water has led to soil contamination, which ultimately resulted in contamination of vegetables due to the uptake and accumulation of heavy metals in edible portions of vegetables.

**Application of the Study:** Urgent attention is needed to devise and implement appropriate means of regular monitoring of the toxic heavy metals from domestic sewage and industrial effluent and provide proper advice and support for the safe and productive use of wastewater for irrigation purposes to prevent excessive buildup of heavy metals in the food chain.

***Keywords:*** *food chain, heavy metals, health, vegetable, wetlands*

## INTRODUCTION

Wetlands are transitional zones between land and water resources and play a significant role in the ecological sustainability of the region, while constituting the most productive ecosystems. A wetland is referred to an area that is periodically or permanently inundated with the surface or groundwater, which supports the growth of diverse aquatic vegetation (Ramachandra *et al*., 2011; Mitsch and Gosselink, 2000). Wetlands play a prominent role in meeting the domestic and irrigation needs of the region apart from being habitats for a wide variety of flora and fauna. The quality and hydrologic regime of the wetlands is directly dependent on the integrity of its watershed (catchment or basin). Wetlands function as kidneys of the landscape and help as a sink to myriads of toxic compounds and pollutants. However, an excess inflow of nutrients and other contaminants beyond the treatment capability results in changes in the water quality, impairing the ecological functions and hampering the ecological integrity of aquatic ecosystems. The sustained inflow of untreated or partially treated sewage to water bodies leads to the enrichment of nutrients such as nitrogen (N) and phosphorus (P), which is evident from the algal blooms and profuse growth of macrophytes. This has led to eutrophication of the surface water. This has also contaminated nearby groundwater sources via leaching affecting human health.

Unplanned rapid urbanization in recent years has led to the deterioration of wetlands. The sustained inflow of untreated or partially treated sewage to wetlands leads to the enrichment of nutrients such as nitrogen (N) and phosphorus (P), which is evident from the algal blooms and profuse growth of macrophytes. This has led to eutrophication of the surface water. This has also contaminated nearby groundwater sources via leaching, which affects human health. Nitrogen as nitrate-N pollution leads to physiological disorders including blue baby syndrome (methemoglobinemia) and the persistent assimilation of nitrate rich water leads to carcinogenic symptoms (as nitrosamines, which are carcinogens) (Ramachandra *et al.*, 2014; Mahapatra et al., 2011; 2013). The movement of chemicals through biological systems due to toxicokinetic behavior. The heavy metal content in vegetables exceeded the safe limits in India. The continued consumption of heavy metal contaminated food can seriously deplete some essential nutrients in the body causing a decrease in immunological defenses, intra-uterine growth retardation, impaired physico-social behavior, malfunctioning of kidneys, disabilities associated with malnutrition and a high prevalence of upper gastrointestinal cancer.

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The prevalence of chronic kidney disease (CKD) is increasing, evident from the number of kidney patients in the city. The number of kidney failures has increased from 1 in 1 lakh population (in early 2000) to 1 in 5000 people. In this regard, the diverse and emerging issues of food security and healthy youth would be of serious concern considering the changes in the climate with global warming. Hence, it needs to stop the contamination of food by regulating the polluters by implementing the 'Polluter pays' principle. This entails stringent action against polluters (erring industries and inefficient regulatory agencies) for indiscriminately discharging pollutants in the environment.

Heavy metals are elements with atomic number >20 that possess higher density (>5 g/cm³) and metallic properties and mainly include cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), lead (Pb), cobalt (Co), iron (Fe), nickel (Ni), manganese (Mn), zinc (Zn) and arsenic (As). These heavy metals are mainly released from industrial processes, industrial discharges, mining operations, etc.

Heavy metals are one of the most toxic chemicals that have been posing challenges to decision-makers. Heavy metals are elements with atomic number >20 that possess higher density (>5 g/cm³) and metallic properties and mainly include cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), lead (Pb), cobalt (Co), iron (Fe), nickel (Ni), manganese (Mn), zinc (Zn) and arsenic (As). These heavy metals are mainly released from industrial processes; industrial discharges, mining operations, and acid mine drainage (Rungwa *et al.*, 2013). These heavy metals move through various biogeochemical cycles and enter the food chain resulting in bioaccumulation and consequent bio-magnifications. The non-biodegradable nature and long biological half-life of heavy metals, when compared to other xenobiotics, are the reasons for various environmental problems. The primary sources of heavy metals into the environment are; fertilizers, pesticides, untreated or partially treated wastewater, leachates from mining sites, industrial wastes (e-wastes), wastes from smelting ores, and sewage sludge.

## LITERATURE REVIEWS

Cultivation of vegetables and other food crops in heavy metal contaminated sites or irrigation with heavy metal contaminated water may result in uptake of such contaminants from soil, ultimately resulting in its accumulation in edible portions of vegetables (Sun *et al.*, 2016). Vegetable like Pudina (*Mentha spicata*), Coriander, (*Coriandrum sativum*), Spinach (*Spinacia oleracea*), etc. grown in tropical India contained various heavy metals (e. g. Pb, Zn, Cd, Cr, Cu, and Ni) with concentrations exceeding their safe limits (Gupta *et al.*, 2012). Concentrations of Pb, Zn, Cd, and Cr in all the sewage-fed vegetables were beyond the safe limits of FAO/WHO and Indian standards. The concentration of zinc was higher in the vegetables than other metals ranging from 90.87 to 148.02 mg/Kg. Daily intake values of Pb, Cd, and Ni through consumption of sewage-fed vegetables exceeded the recommended oral dose of metal for adults and children. Paddy grown in arsenic-contaminated soil accumulated Dimethyl arsenic acid (DMA), a carcinogenic substance (Ye *et al.*, 2011).

Heavy metal analysis in vegetables grown near an e-waste recycling facility in China (Luo *et al.*, 2011) showed that the soils of former incineration sites had high concentrations of Cd, Cu, Pb, and Zn with mean values of 17.1, 11,140, 4500, and 3690mg/kg, respectively. In the edible tissues of vegetables, the concentrations of Cd and Pb in most samples exceeded the maximum level permitted for food in China. Sequential leaching tests revealed that the Cu, Pb, and Zn were predominantly associated with the residual fraction, followed by the carbonate/specifically adsorbed phases except for Cd, which was mainly in the extractable form in paddy fields and vegetable soils.

Uptake of heavy metals by some edible vegetables irrigated using wastewater revealed a mean concentration in the order of Fe (183.11±161.2)>Zn (5.38±3.50)>Ni (3.52±1.27)>Pb (2.49±1.81)>Cr (1.46±0.51)>Co (0.66±0.25)>Cd (0.36±0.15). The water samples used for irrigation were found to be unsuitable for irrigation due to high SAR values (Ackah *et al.*, 2014). Transportation and marketing systems of vegetables play a significant role in elevating the contaminant levels of heavy metals pose a threat to the quality of the vegetables with health consequences for the consumers of locally produced foodstuffs (Sharma *et al.*, (2009). Heavy metal analysis in vegetables grown in an industrial area in Dhaka, Bangladesh the contaminations in the order of metal contents Fe > Cu > Zn > Cr > Pb > Ni >Cd in contaminated irrigation water, and a similar pattern Fe > Zn > Ni > Cr > Pb > Cu > Cd was also observed in arable soils. Metal levels observed in different sources were compared with WHO, SEPA, and established permissible levels. The mean concentration of Cu, Fe, and Cd in irrigation water and Cd content in soil were much above the recommended level. Accumulation of the heavy metals in vegetables studied was lower than the recommended maximum tolerable levels proposed by the Joint FAO/WHO Expert Committee on Food Additives (1999), except Cd, which exhibited elevated content.

Vegetables with protein, vitamins, iron, calcium, and other essential micro-nutrients constitute essential diet components. Contamination of vegetables grown with the city effluents has been posing a serious threat to humans evident from the enhanced episodes of various health disorders in the catchment. Heavy metals in vegetables are harmful to human beings due to their non-biodegradable nature, long biological half-lives, and their potential to accumulate in different body parts (Monu *et al.*,

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2008). Prolonged consumption of such heavy metal contaminated vegetables through foodstuffs may lead to chronic accumulation of heavy metals in human beings' kidney and liver, disrupting numerous biochemical processes, leading to cardiovascular, neural, kidney and bone diseases. Furthermore, heavy metal contamination can seriously deplete some essential nutrients in the body, causing a decrease in immunological defenses, intra-uterine growth retardation, impaired physico-social behavior, disabilities associated with malnutrition, and a high prevalence of upper gastrointestinal cancer. The nature of the effect can be toxic (acute, chronic or sub-chronic), neurotoxic, carcinogenic, mutagenic or teratogenic (European Union, 2002). Considering the serious health threat, there is an urgent need to remove the heavy metals to minimize its interventions in humans' food chain. Wetlands plants can uptake heavy metals and allow the water through them (before letting into crop or vegetable fields) would help in the remediation, and this process is often termed as 'Phytoremediation'.

Phytoremediation takes advantage of the natural processes of plants and is a cost-effective treatment technique for the removal of both organic and inorganic contaminants (Meagher, 1996; Passatore *et al.*, 2014; Campos *et al.*, 2008; Ahalya and Ramachandra, 2006). These processes include water and chemical uptake, metabolism within the plant, exudate released into the soil that leads to contaminant loss, and the physical, biochemical impacts of the plant roots. More than 400 plant species have been identified to have the potential for soil and water remediation (Brook R. R., 1998).

The heavy metal removal mechanisms in plants include (i) uptake, (ii) translocation, and (iii) storage. The absorption of metals (for e.g., Pb) by roots occurs via the apoplastic pathway or via $Ca^{2+}$ permeable channels. The behaviour of metals in soil and uptake by plants is controlled by its speciation and soil pH, soil particle size, cation-exchange capacity, root surface area, root exudation, and degree of mycorrhizal transpiration (Hopkins and Huner, 2009; Dhir, 2010,2013). Before the metal can move from the soil solution into the plant, it must pass the surface of the root. This can either be the movement of metal ions passing through the porous cell wall of the root cells, by which metal ions move symplastically through the cells of the root (Ali *et al.*, 2013, Hopkin and Huner, 2009).

Special plant membrane proteins bind with specific metals and become ready for uptake and transport. Root to shoot transport - elements are transported via the vascular system to the above-soil biomass (shoots). Different chelators are involved in the translocation of metal cations through the xylem, such as organic acid chelators - malate, citrate, histidine, or nicotianamine (Ali *et al.*, 2013). Since the metal is complexed within a chelate, it can be translocated upwards in the xylem without being adsorbed by the high cation exchange capacity of the xylem. The transported metals are stored in the plant cell's vacuoles (Taiz and Zeiger, 2003). Heavy metals like arsenic (as arsenate) might be taken up by plants due to the similarities to the plant nutrient phosphate, while Selenium (Se) replaces the nutrient sulphur in compounds taken up by a plant (Brooks, 1998).

## AIM OF THE STUDY

The Objective of the current study is to assess the heavy metal accumulation in vegetables.

## MATERIAL AND METHODS

Bangalore is the principal administrative, cultural, commercial, industrial and knowledge capital of the state of Karnataka. Greater Bangalore spatial extent was expanded to 741 km² including the city, neighboring municipal councils, and outgrowths, in December 2006. The field sampling was done in the vicinity of Varthur Lake.

**Varthur Lake:** Varthur Lake is situated in the eastern periphery of Bangalore City and a part of the internationally famous Whitefield Township. Varthur is a Hobli and part of Bruhat Bangalore Mahanagara Palike (BBMP). The lake ecosystem is an integral part of Bangalore, although unplanned urbanization and industrialization have led to the contamination of these water bodies. Varthur Lake, with a spatial extent of 216 ha, is the second largest lake in Bangalore city. Recently, siltation and encroachment, the spatial extent of the lake has been reduced to 165.75 ha and also one of the most polluted lakes in Bangalore due to (i) the sustained inflow of untreated and partially treated domestic sewage, (ii) discharge of untreated industrial effluents (through stormwater drains and through trucks (who discharge untreated effluents), (iii) dumping of solid waste in the lake, drains and in the buffer zone. The wetland water accounts to irrigate 625 ha of agricultural fields in the command area for growing crops like rice, ragi millet, coconut, flowers, and various fruits and vegetables. Earlier reports have indicated the possible uptake of trace elements by plants grown in the command area of the lake (Ramachandra *et al.*, 2011; Jumbe and Nandini, 2009). Field samples of vegetables grown using the lake water in the command area of Varthur Lake (Varthur) were collected to assess the level of heavy metal uptake (figures 1 - 3).

**Heavy metal analysis:** The collected vegetable samples were analyzed using ICP-OES (Inductively Coupled Plasma-Optical Emission Spectroscopy) technique to assess the level of heavy metal in acid digested samples.

**Digestion procedure**: For the water sample, the digestion was carried out with an acid combination of nitric and sulfuric acids at a ratio of 10:1. The plant samples were digested using nitric, sulfuric, and perchloric acids combinations of 5:1:1. Nitric and

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sulfuric acid combination 5:1 was used for the digestion of soil samples. A temperature range of 60-70˚C was maintained during digestion of samples and additional volumes of acids were added till the sample became transparent. The digested samples were transferred into a 50 ml standard and made up to the mark using distilled water. The samples were then transferred into small plastic (tarsons) bottles, capped and labelled (APHA, 1999).

**Preparation of standards**: A stock solution of 1000 ppm was prepared for the analysis of heavy metals such as Cd, Cu, Pb, Cr, and Ni. The chemicals used for standard preparation are; Cadmium sulphate (Cd), Potassium dichromate (Cr), Copper sulfate (Cu), Lead nitrate (Pb), and Nickel sulfate (Ni). Standards were prepared in a range of 1, 10, and 20 ppm from the stock solution in 2% $HNO_3$. The prepared standards were then fed into ICP-OES to obtain a calibration curve.

**ICP-OES**: Emission spectroscopy using ICP was developed in the mid-1960's as a rapid, sensitive, and convenient method for the determination of metals in water and wastewater samples. Dissolved metals are determined in filtered and acidified samples. Total metals are determined after appropriate digestion. Care must be taken to ensure that potential interferences are dealt with, especially when dissolved solids exceed 1500 mg/L.

**Principle**: ICP source consists of a flowing stream of argon gas ionized by an applied radiofrequency field typically oscillating at 27.1 MHz. This field is inductively coupled to the ionized gas by a water-cooled coil surrounding a quartz ''torch'' that supports and confines the plasma. A sample aerosol is generated in an appropriate nebulizer and spray chamber and is carried into the plasma through an injector tube located within the torch. The sample aerosol is injected directly into the ICP, subjecting the constituent atoms to temperatures of about 6000 to 8000°K. Significant reduction in chemical interferences is achieved with the almost complete dissociation of molecules. The light emitted from the ICP is focused onto the entrance slit of either a monochromator or a polychromator that affects dispersion. A precisely aligned exit slit is used to isolate a portion of the emission spectrum for intensity measurement using a photomultiplier tube. The monochromator uses a single exit slit/photomultiplier and may use a computer-controlled scanning mechanism to examine emission wavelengths sequentially. The polychromator uses multiple fixed exit slits and corresponding photomultiplier tubes; it simultaneously monitors all configured wavelengths using a computer-controlled readout system (APHA, 1999).

**Procedure**: Initially, the instrument was calibrated using blank. After calibration with blanks, standards of three different concentrations were fed alternating with blank to obtain a calibration curve. The samples were fed into the instrument in a similar way to standards. At the end of the analysis, blank was again fed into the instrument. The results were obtained via a computerized readout system.

**Calculations**: Dilution correction factor = Final weight or vol. / Initial weight or vol.

Interference correction factor, K = Apparent conc. of element / Actual conc. of an interfering element.

## RESULTS AND DISCUSSIONS

**Heavy metals in vegetables (Varthur):** The heavy metal content was high in most vegetables and exceeded their safe limits in India (Awasthi *et al*., 2000). The concentration of metals in vegetables grown in the command area of Varthur lake is presented in Table 1 and heavy metal-wise discussed below.

**Lead (Pb):** In this study *Amaranthus* sp. showed the highest concentration of Pb, i. e., 148±4.2 mg/Kg, and maize showed the lowest concentration, i. e., 24 mg/Kg that is far exceeding the Indian safe limit of 2.5 mg/Kg (table 1). The Pb contamination in vegetables was found to be due to prolonged irrigation of vegetables using Pb-containing lake water. Discharges from battery industries are the prime sources of Pb contamination. However, plants have the ability to accumulate high levels of Pb without any impact on their appearance or yield (Suruchi and Pankaj, 2011). Due to the high bioaccumulation properties of Pb in plants, its accumulation can exceed several hundred times of the threshold levels permitted for human consumption (Wierzbica, 1995; Suruchi and Pankaj, 2011). Accumulation of lead is mainly due to a large number of small-scale industries, vehicular emissions, resuspended road dust, and diesel generator sets (Ramesh and Murthy, 2012). The uptake of lead in plants is regulated by pH, particle size, and CEC (cation exchange capacity) of soil as well as by root exudation and other physicochemical parameters (Lokeshwari and Chandrappa, 2006). A higher Pb content of 28.4 to 149.5 mg/Kg was found in Palak and 54.69 to 75.5 mg/Kg in Coriander grown near Varthur lake (Ramesh and Yokananda Murthy, 2012).

Similarly, Varalakshmi and Ganeshamurthy (2010), also found elevated levels of Pb in Varthur vegetables. Lead is very toxic to plants and humans; hence high levels recorded in this study are quite alarming. Todd (1996) noted that when lead is accumulated in the human body, it gets sequestered in the bones and teeth, resulting in brittle bones and weakness in the wrists and fingers. Furthermore, lead stored in bones can re-enter the bloodstream during periods of increased bone mineral recycling, causing further anomalies (i.e., pregnancy, lactation, menopause, advancing age, etc.). Mobilized lead can be re-deposited in

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the body's soft tissues and can cause musculoskeletal, renal, ocular, immunological, neurological, reproductive, and developmental effects (ATSDR, 1999b).

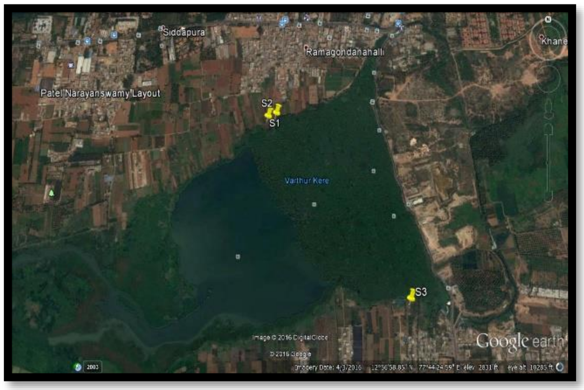


**Figure 1: Varthur lake and sampling sites**

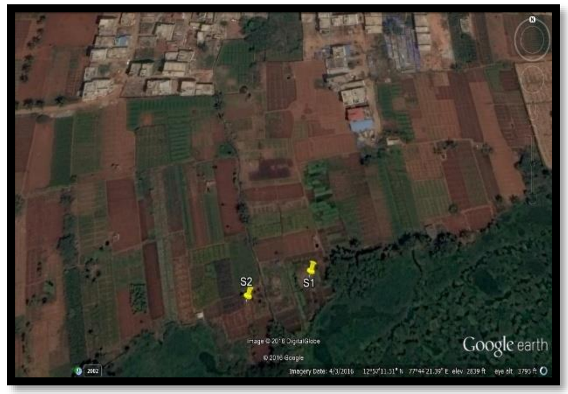


**Figure 2: Sampling sites 1 and 2 (N: 12.95247, E: 077.73963 and N:12.95277, E: 077.73876)**

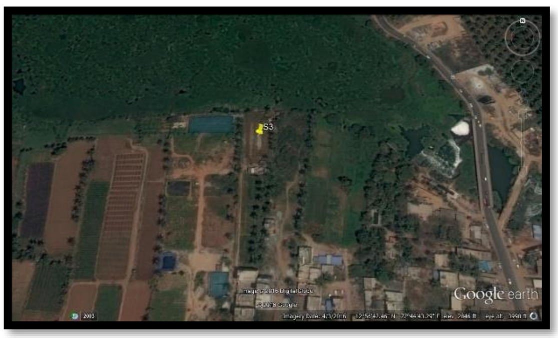


**Figure 3: Sampling site 3 (N: 12. 94473, E: 077.74554)**

**Table 1: Mean heavy metal content in vegetable samples collected from Varthur**

| Vegetables analyzed | Heavy metal content (mg/Kg) | | | | |
|---|---|---|---|---|---|
| | **Cd** | **Cr** | **Cu** | **Pb** | **Ni** |
| Pudina | 9.6±0.4 | 50.17±54 | 79.7±27 | 54±27 | 7.2±2.8 |
| Palak | 9.7±0.2 | 141±34 | 183±17 | 37±1.4 | N/D |
| Spinach | 9.5±0.2 | 79.8±0.2 | 177±45 | 41.6±6 | 1.4±0.3 |
| Amaranths | 6.8±3.8 | 98±20 | 122±53.7 | 148±4.2 | 90.5±7.7 |
| Turnip | 9.5±0.3 | 93±11 | 41.7±22 | 14.3±3.6 | 11.5±1.5 |
| Maize (Corn) | 9.7±0.07 | 74±29 | 75±3.4 | 24 | N/D |
| Coriander | 9.55±1 | 93 | 41.6±12 | 14.3 | 0.5 |
| **Indian safe limits*** | **1.5** | **20** | **2.5** | **30** | **1.5** |
| Lake water (mg/L) | 0.6±0.07 | 0.5±0.14 | 1.4±0.1 | 0.2±0.007 | N/D |
| **Safe limits*** | **0.01** | **0.1** | **0.5** | **0.2** | **0.2** |
| Soil (mg/Kg) | 20.55±3.4 | 208±101 | 21.3±12.3 | 246.5±19 | 189.5±71 |
| **Indian Safe limits*** | **3-6** | *N/A | **250-500** | **135-270** | **75-150** |

*(*Note: Safe limits- Pescod, 1992; Indian safe limits- Awasthi et al., 2000; N/D- Not detectable; N/A- Not available).*

**Cadmium (Cd):** The Cd content in palak and corn was highest i. e., 9.7±0.07 9.7±0.2 mg/Kg and lowest in *Amaranthus* sp. i. e., 6.8±3.8 mg/Kg (table 1). A maximum Cd concentration of 4 mg/Kg was found in spinach grown near Bellandur lake,

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Bangalore. (Lokeshwari and Chandrappa, 2006). Acute doses (10–30 mg/kg/day) of cadmium can cause severe gastrointestinal irritation, vomiting, diarrhea, and excessive salivation, and doses of 25 mg of Cd/Kg body weight can cause death (cadmium exposure in humans, 2011)). The use of contaminated water for irrigation, fertilizers, sewage, and compost can remarkably increase the Cd uptake into plant tissues (Jackson and Alloway, 1991). Farooq *et al*., (2008) revealed that plants could readily absorb Cd from the soil where their ingestion will enter into the human food chain based on plant species, their physical and chemical properties. Low-level chronic exposure to Cd can cause adverse health effects, including gastrointestinal, hematological, musculoskeletal, renal, neurological, and reproductive effects (table 2). The most vulnerable organ system affected by Cd exposure is the kidney (ATSDR, 1999a).

**Copper (Cu):** The Cu content was highest in palak, i. e., 183± 18 mg/Kg and lowest in coriander, i. e., 41.6±12 mg/Kg (table 1). The average content of Cu in plant tissue is ten µg/g dry weight (Baker and Senef, 1995). Typical symptoms of Cu deficiency appear first at the tips of young leaves and then extend downward along the leaf margins. The leaves may also be twisted or malformed and show chlorosis or even necrosis (Marschner, 1995). Demirezen and Ahmet (2006) reported that Cu concentration (22.19-76.50 mg/kg) was found higher in leafy vegetables when compared to non-leafy vegetables in Turkey, and it may be due to the richness of chlorophyll. Chronic exposure to Cu can cause Vineyard sprayer's lung (if inhaled) and Wilson disease (hepatic and basal ganglia degeneration).

**Chromium (Cr)**: The Cr content in vegetables was highest in palak, i. e., 141±34 mg/Kg and lowest in pudina, i. e., 50.3±54 mg/Kg (table 1). The exposure route of Cr to humans is through nonpoint sources. In fact, Cr can be found in common cereals/grains, vegetables, red wine, beans, fish, lean meat, etc. Naturally, Cr is present in the soil in the form of minerals. A higher Cr content of 127.27 mg/Kg was found in coriander grown in urban districts of Karnataka (Ramesh and Murthy, 2012). Chromium enhances the actions of insulin, a key enzyme that is vital to the metabolism and the storage of carbohydrates, fats, and protein. Chromium (III) is an essential trace element that aids in the metabolism of glucose and fats (Morgan, 2010). Chromium (VI) compounds are carcinogenic as classified by the International Agency for Research on Cancer, whereas chromium (III) compounds are not (Guertin *et al*., 2004).

**Nickel (Ni):** The Ni content is maximum in *Amaranthus* sp. i. e., 90.5±7.7 mg/Kg. Ni was not detectable in palak and maize (Table 1). The Ni was also not detectable in lake water; however, it was high in the soil. A maximum concentration of 14.9 mg/Kg Ni was obtained for *Spinach* sp. grown near Vrishabhavathi River, Bangalore, Karnataka (Jayadev and Puttaih, 2012). Ni is an essential metal in the diet of humans but at low concentrations. Excess levels of Ni in humans can lead to various forms of cancer. Ni is mainly found in the soil as an ore together with iron. Other anthropogenic sources are dust/gases released by power plants which settle on the soil or precipitate with raindrops (table 2). When the soil pH is acidic, Ni becomes immobile and is taken up by plants.

In a similar study in West Bengal, the heavy metal content in vegetables like Pudina, Spinach, and Coriander were found to exceed their Indian safe limits (Gupta *et al*., 2012). The average Cd content in vegetables ranged from 9.4 to 13.2, Cu content from 25 to 32.1, Pb from 21 to 47.7, Cr from 44.1 to 95.8and Ni from 51 to 68.6 mg/Kg. The heavy metal content in *Amaranthus* sp. grown near Vrishabhavathi River, Bangalore, were observed to be 6.1 mg/Kg for Pb, 16 mg/Kg for Cu, 11.9 mg/Kg for Ni, and 10 mg/Kg dry weight of Cr (Jayadev and Puttaih, 2013).

**Heavy metals in lake water and soil from the vegetable farm at Varthur**

Among the metals analyzed, Ni was not detectable in the lake water sample (table 3). The concentration of Cd was found to be 0.6±0.07 mg/L exceeding the safe limits for irrigation, i.e., 0.01 mg/L. Cr level in water was observed to be 0.5±0.14 mg/L and exceeded the safe limits (0.1 mg/L). Similarly, high Cu levels were observed (1.4±0.1 mg/L), exceeding the safe limits (0.5 mg/L). Pb content in water was found to be within the limit, i.e., 2.0 mg/L. Heavy metal analysis by Jumbe and Nandini (2009) reveals metals like Cd, Cr, Cu, Pb, and Ni at a concentration of 0.12, 2.13, 0.32, 2.72, and 1.03 ppm. A study by Varalakshmi and Ganeshamurthy (2010) in Varthur lake reported undesirable concentration of heavy metals as Cd (0.03 mg/L), Pb (0.07 mg/L), Cr (0.28 mg/L), and Ni (0.03 mg/L). A similar study conducted by Lokeshwari and Chandrappa (2006) in Bellandur lake, showed reasonably high values of Cu (12 mg/L), Ni (3 mg/L), Cr (6 mg/L), Pb (9 mg/L), and Cd (0.7 mg/L), respectively.

In the case of soil 20.5±3.4, mg/Kg and 189±71 mg/Kg of Cd and Ni were observed, respectively. They were found to exceed the safe limits, i.e., 3-6 mg/Kg and 135-270 mg/Kg (Pescod, 1992). Varalakshmi and Ganeshamurthy (2010), reported that the soil near Varthur lake contained metals like Cd, Pb, Cr, and Ni with concentrations of 2.9, 68.12, 56.5, and 57.3 mg/Kg. Similarly, investigations by Ramesh and Murthy (2012), showed substantially high heavy metal content in soil at Ramagondanahalli (in Varthur), i.e., 35.32 mg/kg for Cu, 45.33 for Pb and 116.94 mg/Kg Cr. Moreover, Lokeshwari and Chandrappa (2006) analyzed heavy metals in surface soils, i.e., Cu and Cd were 2.5 and 6-fold higher than the natural concentration, respectively. Unequal distribution of heavy metals could be because of myriads of factors depending on the type and genetic features of soil-forming rocks, granulometric soil composition, amount of organic matter, pH, absorption capacity, amount of $CaCO_3$, and other physical and chemical properties of soil (Naser *et al*., 2009).

**Table 2: The sources and effects of heavy metals exposure**

| Heavy metals | Sources | Toxic effects |
|---|---|---|
| Cu | Electroplating industry, smelting and refining, mining, biosolids. | Vineyard sprayer's lung (inhaled); Wilson disease (hepatic and basal ganglia degeneration). |
| Cd | Geogenic sources, anthropogenic activities, metal smelting and refining, fossil fuel burning, application of phosphate fertilizers, sewage sludge. | Lung cancer, osteomalacia. |
| Cr | Electroplating industry, sludge, solid waste, tanneries. | Pulmonary fibrosis, lung cancer (inhalation). |
| Ni | Volcanic eruptions, land fill, forest fire, bubble bursting and gas exchange in the ocean, weathering of soils and geological materials. | Occupational (inhaled): pulmonary fibrosis, reduced sperm count, nasopharyngeal tumors. |
| Pb | Mining and smelting of metalliferous ores, burning of leaded gasoline, municipal sewage, industrial wastes enriched in Pb, paints. | Anemia, abdominal pain, nephropathy. |

(Jarup L., 2003; Ali *et al*., 2013; Xu *et al*., 2014; Wang *et al*., 2010)

**Sodium adsorption ratio (SAR) of Varthur lake water:** The wastewater quality for irrigation was determined using the sodium absorption ratio (SAR). The SAR is commonly used as an index for evaluating the sodium hazard associated with an irrigation water supply (Rajendra *et al*., 2009). The SAR is defined as the square root of the ratio of the sodium to calcium & magnesium ions (Ca+Mg).

$$SAR = Na^{+}/\sqrt{(Ca^{2+} + Mg^{2+})}$$

The SAR recorded for Varthur lake water of the two sampling periods was found to be 28.6 (table 3), which poses a very severe degree of restriction for irrigation purposes (FAO, 1985). A SAR of 14.9 was observed in a study conducted by Ackah *et al.* (2013) in Accra, Ghana. Irrigation waters having higher SAR could lead to build-up of high soil Na levels over time, which in turn can adversely affect soil infiltration and percolation rates (due to soil dispersion). Additionally, excessive SAR levels can lead to soil crusting, poor seedling, emergence, and poor aeration. This problem is also related to factors such as the salinity rate and the type of soil. For example, sandy soils may not get damaged as easily as other heavier soils when it is irrigated with high SAR water. It means excess sodium in irrigation water, relative to calcium and magnesium or total salt content, can affect soil structure, soil aeration, flow rate, permeability, infiltration, etc.

## CONCLUSION

The study on heavy metal concentrations in vegetables grown near Varthur lake, Bangalore, has shown significant accumulation of heavy metals in vegetables that correlated well with its soil and lake water concentrations. The prolonged irrigation of vegetables using such contaminated lake water has led to soil contamination, which ultimately resulted in contamination of vegetables due to the uptake and accumulation of heavy metals in edible portions of vegetables. The heavy metal content in vegetables exceeded the safe limits in India. Thus, urgent attention is needed to devise and implement appropriate means of regular monitoring of these toxic heavy metals from domestic sewage and industrial effluent and provide proper advice and support for the safe and productive use of wastewater for irrigation purposes in order to prevent excessive build-up of heavy metals in the food chain. The higher SAR is another important factor that highlights the lake water is unsuitable for irrigation purposes.

## RECOMMENDATIONS

- Treating sewage at decentralized levels to prevent eutrophication of water bodies;
- Ensuring zero discharge of industrial effluents;
- Removal of heavy metals (through adsorption) and recovery (desorption)

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- Development of a self-sustaining bioremediation-based wetland systems are;
  1. Nutrient removal through selected wetland plants, preferably native species (such as *Alternanthera* sp., *Ludwigia* sp.) for efficient wastewater treatment and resource recovery.
  2. Removal of heavy metals dual-mode cation/anion-based natural resins at the treatment locations or through natural porous beds with high cation exchange capacity.
  3. Further screening of macrophytes to check their efficiencies in nutrient and heavy metal removal.
  4. Design of a suitable treatment to treat municipal and agro-industrial wastewater.
  5. Regular de-sludging of algal ponds for maintaining critical depths for optimal algal photosynthesis.

**Table 3: Water quality of Varthur lake**

| Sl no. | WQ Parameters | Sampling sites | |
|---|---|---|---|
| | | 1 | 3 |
| 1 | pH | 6.45 | 6.4 |
| 2 | TDS (mg/l) | 765 | 627 |
| 3 | EC (µS/cm) | 1202 | 1054 |
| 4 | ORP | -183 | +102 |
| 5 | WT (˚C) | 23 | 25 |
| 6 | Total alkalinity (mg/l) | 560 | 520 |
| 7 | BOD (mg/l) | 39.25 | 42.37 |
| 8 | Sodium (mg/l) | 157 | 179.5 |
| 9 | Potassium (mg/L) | 44 | 37.5 |
| 10 | Chlorides (mg/l) | 141.8 | 113.4 |
| 11 | Ca Hardness (mg/l) | 160 | 112 |
| 12 | Total Hardness (mg/l) | 300 | 260 |
| 13 | Phosphates (mg/l) | 12.02 | 4.77 |
| 14 | Nitrates (mg/l) | 0.13 | 0.07 |
| 15 | COD (mg/l) | 160 | 112 |
| 16 | Sodium Adsorption Ratio | 24.7 | 32.5 |

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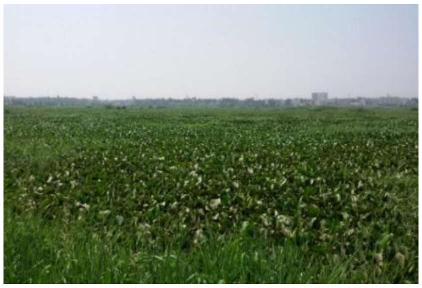
**HOTOGRAPHS -FIELD (VARTHUR)**



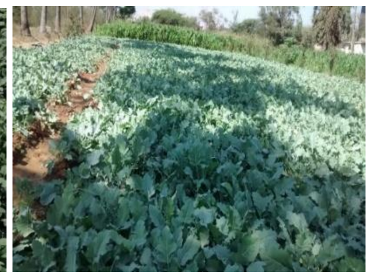
Varthur lake

Pudina

Palak

Spinach

Amaranthus



Turnip

Maize

Coriander

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