Dietary Intake of Potentially Toxic Elements from Vegetables

M. Azizur Rahman Graduate School of Natural Science and Technology
Kanazawa University, Kakuma, Kanazawa 920-1192, Japan

M. Mahfuzur Rahman Department of Botany, Jahangirnagar University, Savar,
Dhaka-1342, Bangladesh

Ismail M. M. Rahman Graduate School of Natural Science and Technology
Kanazawa University, Kakuma, Kanazawa 920-1192, Japan
&
Department of Chemistry
University of Chittagong, Chittagong 4331, Bangladesh

H. Hasegawa Graduate School of Natural Science and Technology
Kanazawa University, Kakuma, Kanazawa 920-1192, Japan

ABSTRACT:

Toxic elements e.g. arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), and zinc (Zn) are the chief environmental pollutants which can cause deleterious health effects in humans. Inhalation and consumption of metal-contaminated food are the major pathways of metal entrance into human body. Cultivation of crop plants in the metal-contaminated soils induces the bioaccumulation of toxic elements in the food chain. Among different food items, vegetables have major contribution in the daily diet, and the heavy metal contamination of vegetables poses a threat to human health with the prevalence of skin and gastrointerestinal cancer.

The uptake and bioaccumulation of toxic elements in vegetables are influenced by a number of factors such as atmospheric deposition, metal concentrations in soil, soil characteristics, and duration of cultivation. Cultivation areas near highways are exposed to atmospheric pollution in the form of metal containing aerosols which can be deposited on leaves of vegetables and then absorbed. The magnitude of heavy metal deposition on vegetable surfaces varied with morpho-physiological nature of the vegetables. Post-harvest activities, such as transportation, marketing, cooking, etc., may also influence the deposition of toxic elements in vegetables. Incorporation of toxic elements during transportation and marketing of vegetable can be occurred due to the use of contaminated water. Higher heavy metal content in vegetables from urban area then those from rural areas may be due to the contribution of urban activities which elevates heavy metal loads in atmospheric deposition and consequently in the edible part of the vegetables. Cooking has definite influence to the content of toxic elements in cooked items if the heavy metal concentrations in the cooking water are high.

Vegetable consumption varies with age group, food habit, as well as vegetable availability. For example the mean daily vegetable consumption among the European people is 153 g (ranged between 109-241 g) while it is around 250g among the South Asian people. Vegetables occupy a substantial proportion of the daily diet for the South-East Asian people, especially the Japanese, Korean and Chinese people. Thus, whatever the metal contents in vegetables are, their intake in

human is, off course, dependent on the total vegetable consumption. In this review, the contribution of vegetables in dietary intake of toxic elements has been discussed from a common platform.

INTRODUCTION:

Metals comprise about 75% of the known elements and have been used from the beginning of ancient human civilization. Since the beginning of the Industrial Age, metals have been emitted to and deposited in the environment [1]. In some cases, metals have accumulated in terrestrial and aquatic environments in high concentrations and cause harm to animals and humans via ingestion of soil and/or dust, food, and water; inhalation of polluted air; and absorption via the skin from polluted soils, water and air [2]. Increasing use of metals with the boom of population and economy, especially in the developing countries, could contaminate the soil and water causing the deterioration of environmental quality and posing threat to human health. [1].

Metals can be classified in to light, heavy, semimetal (i.e. metalloids), toxic, and trace, depending on several physico-chemical characteristics [3]. Certain metals and metalloids, commonly known as micronutrients, are essential for plant growth and animal health. Micronutrients include B, Cu, Fe, Zn, Mn, Mo. In addition, As, Co, Cr, Ni, Se, Sn, and V are especially essential in animal nutrition. Micronutrients are also known as “trace elements” since they are needed in only small quantities. In excess, trace elements can be toxic to living beings though their deficiency is also a problem to the normal growth of plant, microbes, and animals [1]. Important trace elements in the environment are As, Ag, B, Ba, Be, Cd, Co, Cr, Cu, Hg, Mn, Mo, Ni, Pb, Se, and Zn. However, the trace elements are also essential for organisms at low concentrations in most of the cases [4].

The trace elements can be derived from both natural and anthropogenic sources. Natural (geogenic) sources includes parent rocks and metallic minerals, and the anthropogenic sources include agriculture (fertilizers, pesticides, herbicides, and animal manures), mining, smelting, and sewage sludge and scrap disposal [4]. Anthropogenic deposition is a major mechanism for heavy metal input in the environment. Soil is the major recipient of trace elements in terrestrial environment, while sediments are the major sink in aquatic environment. Leaching of heavy metals or transport via mobile colloids can contaminate groundwater. On the other hand, runoff and drainage of the heavy metals via sediments can contaminate freshwater environment [2, 4].

Bioaccumulation of toxic elements in the food chain can be especially dangerous to human health. The toxic metals can enter into the human body by either inhalation or by ingestion; and ingestion is the main route of exposure to these elements [5]. For most of the people the main route of exposure to trace elements is diet except occupational exposures at related industries [6]. The exposure of heavy metal through the food chain has been reported in many countries, particularly in developing countries, and received huge attention from the governmental and non-governmental agencies [7-10]. The concern by environmentalists of the accumulation of toxic metals in the food chain, and the harmful effects on the environment by those metals has escalated in recent years. Once these metals enter into the biological systems they disturb the normal biochemical processes, and in some cases it can be fatal [11]. Regulations have been set up for the industries and other structures that discharging pollutants into the environment in many countries to control the emission of trace elements and their subsequent health effects.

Vegetables constitute essential components of the diet, by contributing proteins, vitamins, iron, calcium, and other nutrients. A constant supply of essential bioavailable trace elements is necessary and highly recommended for daily life [12]. Vegetables also act as buffering agents for acid substances obtained during the digestion process and contain both essential and toxic elements over a wide range of concentrations [13]. Vegetable is one of the major diets for the populations of many countries. A Bangladeshi individual, regardless of gender, consumes an average of 130 g vegetables per day (leafy and non-leafy) and in the total diet, the proportion varied from 12 - 21% [14, 15]. However, the recommended requirement of vegetables in daily diets is 200 g person^{-1} day^{-1} [16]. The Japanese diet is substantially high in vegetables, fish and soy products, and low in saturated fats and sugar [17]. A large proportion of the adult United States population eats no vegetables (0.17) or fruit (0.41) on any given day [18]. Based on a comprehensive literature review, the National Academy of Sciences (NAS) concluded that diet influences the risk of several major chronic diseases and recommended eating five or more daily servings of a combination of vegetables and fruit, especially green and yellow vegetables and citrus fruit [19]. The US Department of Agriculture (USDA) and the Department of Health and Human Services (DHHS) recommend as part of their food guidance system that the daily diet include two to three servings of fruit and three to five servings of vegetables [20, 21]. But about 45 percent of the population had no servings of fruit or juice and 22 percent had no servings of a vegetable on the recall day. Only 27 percent consumed the three or more servings of vegetables and 29 percent had the two or more servings of fruit recommended by the US Departments of Agriculture and of Health and Human Services; 9 percent had both [22]. The people of Mediterranean countries consume about 248 g (113-456 g) of vegetables a day [23]. On the other hand, vegetable is neglected in the daily diet of Arabian countries.

Recently, vegetable becomes popular in daily diet of health conscious people because of its antioxidant properties. A wide number of vegetables are consumed by the population of different countries worldwide. Heavy metal uptake in vegetables and other food crops due to soil, water, and atmospheric contamination is a great threat to the food quality and food safety [5]. The uptake and bioaccumulation of trace elements in vegetables are influenced by a number of factors such as climate, atmospheric depositions, the concentrations of trace elements in the soils, the nature of soils on which the vegetables are grown, and the exposure time [24, 25]. Trace elements from air may also be deposited on vegetables during post-harvest activities such as transportation, marketing, etc. [6]. Vegetables accumulate trace elements from contaminated soils and store them in their edible and inedible parts with various concentrations, as well as from deposits on parts of vegetables exposed to the air from polluted environment [26].

Dietary intake of trace elements from vegetables is an important concern because of their potential health risks, and detrimental effects on the environment. It has been reported that nearly half of the mean ingestion of lead, cadmium, and mercury through food is of plant origin (fruits, vegetables, and cereals) [5]. Previously, a large scale study on trace elements in vegetables and fruits from the Valparaiso region of Chile has been conducted by Pinochet et al. [27]. Trace elements in various common vegetables collected from two typical growing areas of northwestern Greece were studied by Stalikas et al. [28]. Ursinyova et al. [29] reported the contents of cadmium, lead, and mercury in crops, vegetables from selected regions of Slovakia and compared to the provisional tolerable weekly intake as recommended by the world health organization (WHO) [30]. The cadmium and lead were determined in lettuce, potato, soy beans, and wheat in the United States [31, 32]. The trace elements in some vegetables, fruits, and cereals in Egypt were also reported in literatures [33]. The trace elements in vegetables grown in the greater industrial areas of North Greece (Thessaloniki) was investigated too and elevated concentrations, in some cases exceeding the maximum permissible limit of human consumption, was observed, particularly for Pb, Cd, Zn and As [25, 34]. In this review, the contribution of vegetables in dietary intake of some important trace elements such as arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), and zinc (Zn), and their effects to human health has been discussed for different countries as reported in literatures.

DIETARY INTAKE OF TOXIC ELEMENTS FROM VEGETABLES

Arsenic (As)

Sources of human exposure:

Arsenic is a naturally occurring element that is widely distributed in the Earth's crust. Arsenic is classified chemically as a metalloid, having both properties of a metal and a nonmetal; however, it is frequently referred to as a metal [35]. However, arsenic is usually found in the environment combined with other elements such as oxygen, chlorine, and sulfur. Arsenic combined with these elements is called inorganic arsenic. Arsenic combined with carbon and hydrogen is referred to as organic arsenic. Arsenic occurs naturally in soil and minerals and it therefore may enter the air, water, and land from wind-blown dust and may get into water from runoff and leaching. Volcanic eruptions are another source of arsenic. Arsenic is associated with ores containing metals, such as copper and lead. Arsenic may enter the environment during the mining and smelting of these ores. Small amounts of arsenic also may be released into the atmosphere from coal-fired power plants and incinerators because coal and waste products often contain some arsenic [35].

Many common arsenic compounds can dissolve in water. Thus, arsenic can get into lakes, rivers, or underground water by dissolving in rain or snow or through the discharge of industrial wastes. Some of the arsenic will stick to particles in the water or sediment on the bottom of lakes or rivers, and some will be carried along by the water. Ultimately, most arsenic ends up in the soil or sediment.

Health effects:

Inorganic arsenic has been recognized as a human poison since ancient times. Perhaps the single-most characteristic effect of long-term oral exposure to inorganic arsenic is a pattern of skin changes. These include patches of darkened skin and the appearance of small "corns" or "warts" on the palms, soles, and torso, and are often associated with changes in the blood vessels of the skin. Skin cancer may also develop. Swallowing arsenic has also been reported to increase the risk of cancer in the liver, bladder, and lungs. The Department of Health and Human Services (DHHS) has determined that inorganic arsenic is known to be a human carcinogen (a chemical that causes cancer). The International Agency for Research on Cancer (IARC) has determined that inorganic arsenic is carcinogenic to humans. EPA also has classified inorganic arsenic as a known human carcinogen [35]. Chronic arsenic poisoning associated with groundwater contamination has been reported in many countries, often where poor nutritional status is concomitantly found, and it has been suggested that the poor nutritional status affects the toxicity and metabolism of arsenic [36-

41]. A case-control study conducted in Bangladesh showed that malnourished individuals are more often found among patients with arsenicosis than among the non-exposed population [42].

Dietary intake:

As reported in the literatures, the total arsenic contents in vegetable products were < 0.004 to 0.303 mg kg^{-1} fresh weight [43-46], which is within the range of values found in the samples of Bangladesh (Table 1). The average arsenic concentration in the vegetables collected from some arsenic prone areas of Bangladesh was 0.28 mg kg^{-1} fresh weight (ranging between 0.25 and 0.38 mg kg^{-1} fresh weight), which was higher than that of the United Kingdom, 0.003 mg kg^{-1} fresh weight [47], and Croatia, 0.0004 mg kg^{-1} fresh weight [48]. However, string beans collected from Bangladesh were found to have highest mean arsenic content (between 0.88±0.04 and 1.26±0.06 mg kg^{-1} fresh weight). Arsenic content in vegetables of some other countries have also been reported in literatures. Voutsa et al. [25] investigated the arsenic content in vegetables of Greece and found the lowest in *Daucas carota* L. (Carrots) (0.02-0.05 mg kg^{-1} dry weight) while the highest in *Cichorium endivia* (Endive) (0.13-0.19 mg kg^{-1} dry weight) (Table 3).

A Bangladeshi individual, regardless of gender, consumes an average of 130 – 200 g of vegetables per day (leafy and non-leafy) [14, 15]. Thus, the average dietary intake of total arsenic from vegetables by the inhabitants of arsenic prone area in Bangladesh was estimated to be 0.015 – 0.161 mg day^{-1}. In another study Rahman et al. [49] reported that the average dietary intake of arsenic from vegetables by the inhabitants of Bangladesh was 0.0147 mg day^{-1}.

However, the recommended daily dietary intake of vegetables is 200 g person^{-1} day^{-1}, though the availability of vegetables is only about 1/5th of the suggested requisite in Bangladesh [15]. If we consider that every person is able to fulfill the recommended amount of vegetables in their daily diets, the estimated average daily dietary intake of arsenic from vegetables in Bangladesh would be 0.0758 mg day^{-1}. The average intake of total arsenic from vegetable by an adult has been reported as 0.012 mg day^{-1} in Belgium [50], 0.015 mg day^{-1} in Netherlands [51], 0.0592 mg day^{-1} in Canada [43], 0.060 mg day^{-1} in Sweden [52], 0.160–0.280 mg day^{-1} in Japan [53], and 0.291 mg day^{-1} in Spain [45]. Per capita vegetable consumption by a Greek adult is reported to be about 240 g (the mean total daily availability of main foods, except water and beverages, per capita in Greece is 1575 g in which vegetables represent 15.3% of the total daily diet) [54]. On the basis of this calculation diet, daily dietary intake of arsenic via fresh vegetables in Greece has been reported as 0.02-0.63 µg day^{-1} from cabbage, 0.01-0.04 µg day^{-1} from carrot, 0.004-0.06 µg day^{-1} from leek, 0.04-0.26 µg day^{-1} from lettuce, 0.31-0.46 µg day^{-1} from Endive. If the mean daily consumption availability of these five vegetables was 61 g (as reported in literature), a total of 0.38-1.5 µg of As would be taken day^{-1} by a Greek adult. Moreover, assuming the similar content of arsenic in most vegetables in the Greek diet and considering the mean daily vegetable consumption availability as 241 g (as reported in literature), the total daily intake of arsenic would be 1.5-5.9 µg [54]. Thus, the total dietary intake of arsenic via vegetables in Greece was calculated to be 1.7% of the provisional tolerable daily intake (PTDI) according to the WHO [30, 55].

As found in the literature, the inorganic arsenic species content in diets ranges between 40% [56], 65% [43], 95-96% [57] and 100% [58]. Based on those reports, we can assume that at least 50% of the total arsenic in the vegetable samples is inorganic. Therefore, the daily dietary intake of inorganic arsenic from vegetables in Chittagong areas of Bangladesh would be at least 0.288 mg to 0.047 mg. From a toxicological point of view, inorganic arsenic compounds are the most toxic, and according to the WHO [59], a daily intake of 2 µg of inorganic arsenic per kg body weight should not be exceeded to minimize the health risk.

Cadmium (Cd)

Sources of human exposure:

Cadmium is one of six substances banned by the European Union's Restriction on Hazardous Substances (RoHS) directive, which bans certain hazardous substances in electronics [60]. Cadmium is also a potential environmental hazard. Human exposures to environmental cadmium are primarily the result of the burning of fossil fuels and municipal wastes [61], and the production of nickel-cadmium batteries, pigments, plastics, and other synthetics. Cadmium occurs in the earth's crust at a concentration of 0.1–0.5 mg kg^{-1} and is commonly associated with zinc, lead, and copper ores. It is also a natural constituent of ocean water with average levels between <5 and 110 ng L^{-1}. The cadmium concentration of natural surface water and groundwater is usually <1 μg L^{-1} [62]. Non-ferrous metal mining and refining, manufacture and application of phosphate fertilizers, fossil fuel combustion, and waste incineration and disposal are the main anthropogenic sources of cadmium in the environment. Water sources near cadmium-emitting industries, both with historic and current operations; have shown a marked elevation of cadmium in water sediments and aquatic organisms. Concentrations of cadmium in these polluted waters have ranged from <1.0 to 77 μg L^{-1}. Cadmium from polluted soil and water can accumulate in plants and organisms, thus entering the food supply [62].

Smoking greatly increases exposure to cadmium, as tobacco leaves naturally accumulate high amounts of cadmium. It has been estimated that tobacco smokers are exposed to 1.7 μg cadmium per cigarette, and about 10% is inhaled when smoked. A geometric mean blood cadmium level for a heavy smoker has been reported as high as 1.58 μg L^{-1}, compared to the estimated national mean of 0.47 μg L^{-1} for all adults [62]. The largest source of cadmium exposure for nonsmoking adults and children is through dietary intake. The estimated daily intakes of cadmium in nonsmoking adult males and females living in the United States are 0.35 and 0.30 μg Cd kg^{-1} day^{-1}, respectively. In general, leafy vegetables such as lettuce and spinach and staples such as potatoes and grains contain relatively high values of cadmium [62]. Peanuts, soybeans, and sunflower seeds have naturally high levels of cadmium.

Health effects:

The primary route of exposure in industrial settings is inhalation [63]. Current research has found that cadmium toxicity may be carried into the body by zinc binding proteins; in particular, proteins that contain zinc finger protein structures. Zinc and cadmium are in the same group on the periodic table, contain the same common oxidation state (+2), and when ionized are almost the same size. Due to these similarities, cadmium can replace zinc in many biological systems, in particular, systems that contain softer ligands such as sulfur. Cadmium can bind up to ten times more strongly than zinc in certain biological systems, and is notoriously difficult to remove. In addition, cadmium can replace magnesium and calcium in certain biological systems, although these replacements are rare [64].

However, there have been notable instances of toxicity as the result of long-term exposure to cadmium in contaminated food and water. In the decades following World War II, Japanese mining operations contaminated the Jinzu River with cadmium and traces of other toxic metals. As a consequence, cadmium accumulated in the rice crops growing along the riverbanks downstream of the mines. The local agricultural communities consuming the contaminated rice developed Itai-itai disease and renal abnormalities, including proteinuria and glucosuria [65].

Acute inhalation exposure to high levels of cadmium in humans may result in effects on the lung, such as bronchial and pulmonary irritation. A single acute exposure to high levels of cadmium can result in long-lasting impairment of lung function [61, 62]. Chronic inhalation and oral exposure of humans to cadmium results in a build-up of cadmium in the kidneys that can cause kidney disease, including proteinuria, a decrease in glomerular filtration rate, and an increased frequency of kidney stone formation [61]. Other effects noted in occupational settings from chronic exposure of humans to cadmium in air are effects on the lung, including bronchiolitis and emphysema.

Dietary intake:

Cadmium content has been reported in various common vegetables of many countries. In a study Bahemuka and Mubofu [13] reported that the cadmium content in vegetables of Tanzania ranged between 0.1 and 0.6 mg kg^{-1} dry weight. The highest content of cadmium was in African spinach (*Spinacia oleracea* L.) (0.3-0.6 mg kg^{-1} dry weight) while the lowest was in Leafy cabbages (*Brassica oleracea var. capitata* L.), about 0.1 mg kg^{-1} dry weight) (Table 4). Cadmium contents have also been reported in vegetables of Saudi Arabia (the lowest in Cucumber (*Cucumis sativa* L.) and Cabbage (*Brassica oleracea* var. *capitata* L.), about 0.59 mg kg^{-1} dry weight and the highest in Watercress (*Nasturtium officinale*, *N. microphyllum*), about 1.22 mg kg^{-1} dry weight) (Table 2) [12]; Greece (the lowest in Carrots (*Daucas carota* L.), about 0.17-0.41 mg kg^{-1} dry weight and the highest in Cabbages (*Brassica oleracea* L.), about 0.26-1.03 mg kg^{-1} dry weight) (Table 3) [25, 54]; India (the lowest in Chinese onion (*Allium cepa* L.), about 5.7-25.0 mg kg^{-1} dry weight and the highest in Spinach (*Spinacia oleracea* L.), about 6.5-32.0 mg kg^{-1} dry weight) (Table 5) [66].

The above data reveal that cadmium content in same vegetable differs from country to country. According to above reports, cadmium content in vegetables of India is many folds higher than those of other countries. It might be because the metal uptake in vegetables is influenced by several factors such as metal concentrations in agricultural soils, soil pH, physico-chemical characteristics of the soil, soil classification, etc. Moreover, vegetable consumption (per person per day) is not same for the residents of different regions. It was reported that the average consumption of leafy vegetables is 108 g per person per day in the coastal region of Tanzania [13] while it is 130-200 g per person per day in rural Bangladesh [14, 15]. Thus, dietary intake of cadmium would very from region to region. It was estimated that if the mean content of cadmium in vegetables of Tanzania was 0.20 mg kg^{-1} and if the average vegetable consumption was 108 g per person per day, the contribution of green vegetable to daily dietary intake of cadmium would be 0.02 mg. In contrast, if the vegetable consumption is 130-200 g per person per day by the Indian people (as a neighboring country of Bangladesh, the food habit and food consumption of the Indian people is almost same), the estimated contribution of vegetables to daily dietary intake would be 0.74-5.00 mg. Voutsa and Samara [54] reported dietary intake of Cd from five vegetable species from Greece as 0.4-1.8 μg day^{-1} from cabbage, 0.2-0.3 μg day^{-1} from carrot, 0.1-0.2 μg day^{-1} from leek, 0.4-0.6

µg day^{-1} from lettuce, 1.1-1.7 µg day^{-1} from Endive, with a total of 2.2-4.6 µg day^{-1} (if the mean daily consumption availability of five listed vegetables is considered to be 61 g as reported in literature). Assuming the similar content of cadmium in most vegetables in the Greek diet and considering the mean daily vegetable consumption availability as 241 g (as reported in literature) [55], the total daily intake of cadmium would be 8.7-18 µg which represents 15.7% of the provisional tolerable daily intake (PTDI) according to the WHO [30, 55]. Other estimates made from various countries have shown that the daily dietary intake of cadmium from vegetables is between 10-20 mg [67].

Chromium (Cr)

Sources of human exposure:

Chromium (Cr) is the seventh most abundant element on earth crust [68]. Due to its wide industrial use, chromium is considered a serious environmental pollutant. Chromium is found in all phases of the environment, including air, water and soil. Human can be exposed to chromium by breathing air, drinking water, or eating food containing chromium or through skin contact with chromium or chromium compounds. The level of chromium in air and water is generally low. The concentration of total chromium in air (both Cr(III) and Cr(VI)) generally ranges between 0.01 and 0.03 µg m^{-3}. Chromium concentrations in drinking water (mostly as Cr(III)) are generally very low, less than 2 µg l^{-1}. For the general population, eating foods that contain chromium is the most likely route of Cr(III) exposure. Cr(III) occurs naturally in many fresh vegetables, fruits, meat, yeast, and grain [69].

Chromium compounds are highly toxic to plants and are detrimental to their growth and development [70]. Although some crops are not affected by low Cr concentration (3.8×10^{-4} µM) [71, 72], Cr is toxic to most higher plants at 100 µM kg^{-1} dry weight [73, 74]. Contamination of soil and ground water due to the use of chromium in various anthropomorphic activities has become a serious source of concern to plant and animal scientists over the past decade. The stable forms of chromium are the trivalent Cr(III) and the hexavalent Cr(VI) species, although there are various other valence states which are unstable and short-lived in biological systems [75].

Health effects:

Chromium can be both beneficial and toxic to animals and humans depending on its oxidations state and concentration. At low concentration, Cr(III) is essential for animal and human health that helps the body use sugar, protein, and fat [68]. In general, Cr(VI) is absorbed by the body more easily than Cr(III), but once inside the body, Cr(VI) is changed to Cr(III). Although Cr(III) in small amounts is a nutrient needed by the body, swallowing large amounts of Cr(III) may cause health problems [69]. An intake of 50–200 μg of Cr(III) per day is recommended for adults. Without chromium(III) in the diet, the body loses its ability to use sugars, proteins, and fat properly, which may result in weight loss or decreased growth, improper function of the nervous system, and a diabetic-like condition [69].

Chromium(VI) is considered the most toxic form of chromium which usually occurs in association with oxygen as chromate (CrO_4^{2-}) or dichromate ($Cr_2O_7^{2-}$) oxyanions. Chromium(III) is less mobile, less toxic, and is mainly found bound to organic matter in soil and aquatic environments [70]. The health effects resulting from exposure to Cr(III) and Cr(VI) are fairly well described in the literature. Chromium(VI) is believed to be primarily responsible for the increased lung cancer rates observed in workers who were exposed to high levels. The EPA has determined that Cr(VI) in air is a human carcinogen. The EPA has also determined that there is insufficient information to determine whether Cr(VI) in water or food and Cr(III) are human carcinogens [69].

Dietary intake:

However, chromium content in leafy vegetables has been reported in many countries. In a study Voutsa et al. [25] reported 0.08-9.72 mg kg^{-1} dry weight of Cr in different vegetables of Greece (Table 3). Voutsa et al. [25] found 0.86-9.72 mg kg^{-1} dry weight of Cr in Lettuce (*Lactuca* *sativa*) while its content was about 0.13-3.42 mg kg^{-1} dry weight in Leek (*Allium ampeloprasum* var. *porrum* L.) (Table 3). Chromium in vegetables of India has also been reported by Gupta et al. [66]. The content of Cr in Indian vegetables ranged between 40.3-115.4 mg kg^{-1} dry weight (Table 5). The highest Cr content was found in Spinach (*Spinacia oleracea* L.), about 74.0-115.4 mg kg^{-1} dry weight and the lowest was found in Chinese onion (*Allium cepa* L.), about 40.3-53.2 mg kg^{-1} dry weight. Cr content in Pakistani vegetables ranged between 0.1±0.00 mg kg^{-1} dry weight (in Mustard (*Brassica juncea*)) and 1.2±0.01 mg kg^{-1} dry weight (in Coriander (*Coriandrum sativum*)) (Table 6) [76].

Chromium is usually found in its trivalent form in biological and food samples [77] while the hexavalent form is the most toxic. The average dietary intake of chromium as estimated by Biego et al. [78] was 98 µg day^{-1}, which is between those recommended by the United States (50-100 µg day^{-1}) [79]. Anderson et al. [80] reported that chromium contents of grain products, fruits, and vegetables vary widely, with some foods providing >20 g/serving. Van Cauwenbergh et al. [81] reported that the mean Cr intake Belgium was 53±31 µg day^{-1}, which is similar to levels found for most other countries and is situated at the lower end of the recommended range for a safe and adequate daily dietary intake. The mean total daily availability of main foods, except water and beverages, per capita in Greece is 1575 g in which vegetables represent 15.3% of the total daily diet [54]. Daily dietary intake of chromium via fresh vegetables in Greece has been reported as 0.3-13 µg day^{-1} from cabbage, 0.06-6 µg day^{-1} from carrot, 0.05-1.4 µg day^{-1} from leek, 0.6-8.7 µg day^{-1} from lettuce, 1.2-13 µg day^{-1} from Endive, with a total of 2.2-42.0 µg day^{-1} from these five vegetables (if the mean daily consumption availability of the five vegetables was considered to be 61 g, as reported literature [54]). Assuming the similar content of chromium in most vegetables in the Greek diet and considering the mean daily vegetable consumption availability as 241 g (as reported in literature [55]), the total daily intake of Cr would be 8.7-166 µg.

Copper (Cu)

Sources of human exposure:

Copper is among the major toxic elements contaminants in the environment with various anthropogenic and natural sources. A range of Cu based products have been historically and are currently used as fungicides [82]. Copper may also deposit in agricultural soils from wastewater, mine, and industrial discharges. Although it is an essential micronutrient for normal plant metabolism, playing an important role in a large number of metalloenzymes, photosynthesis-related plastocyanin, and membrane structure, copper has been reported to be among the most toxic of toxic elementss [83, 84]. People may be exposed to copper by breathing air, drinking water, eating food, and by skin contact with soil, water and other copper-containing substances [85].

Health effects:

Copper is an essential mineral for human health and at the same time can be toxic, depending upon the amounts ingested. However, exposure to higher doses can be harmful. Long term exposure to copper dust can irritate your nose, mouth, and eyes, and cause headaches, dizziness, nausea, and diarrhea. Intentionally high intakes of copper can cause liver and kidney damage and even death. We do not know if copper can cause cancer in humans. EPA does not classify copper as a human carcinogen because there are no adequate human or animal cancer studies [85]. There are numerous reports of acute gastrointestinal effects in humans after ingestion of large amounts of copper in drinking water or beverages. The most prevalent effects are nausea and vomiting, which typically occur shortly after ingestion and are not persistent [86-90].

Copper is associated with bone health, immune function and increased frequency of infections, cardiovascular risk and alterations in cholesterol metabolism. Its metabolism is tightly intertwined with other microminerals and its deficiency is known to impair iron mobilisation, resulting in secondary iron deficiency [91].

Dietary intake:

Copper uptake by vegetable plants from soils and sewage used for irrigation has been reported in literatures [5, 13, 47, 50, 53, 82, 92, 93]. In a study Mohamed et al. [12] reported that the copper content in vegetables of Saudi Arabia ranged between 0.43 mg kg^{-1} (in cabbages (*Brassica oleracea* var. *capitata* L.)) and 4.49 mg kg^{-1} (in green pepper (*Capsicum frutescens*)) (Table 2). Copper content in vegetables from Greece has been reported as 0.89-3.89 mg kg^{-1} in lettuce (*Lactuca sativa*), 0.17-0.41 mg kg^{-1} in carrots (*Daucas carota* L.), 0.26-1.03 mg kg^{-1} in cabbages (*Brassica oleracea* L.), 0.29-0.49 mg kg^{-1} in leek (*Allium ampeloprasum* var. *porrum* L.), and 0.44-0.72 mg kg^{-1} in endive (*Cichorium endivia*) (Table 3) [25]. A market basket survey showed that the copper content in vegetables from Pakistan ranged between 1.0±0.00 mg kg^{-1} (in radish (*Rapnus sativus* L.)) and 3.3±0.01 mg kg^{-1} (in mustard (*Brassica juncea*)) (Table 6) [76]. In Nigerian vegetables, copper content has been reported as 0.41 mg kg^{-1} in cabbage, 0.07 mg kg^{-1} in pumpkin leaves, 0.72 mg kg^{-1} in lettuce, 0.20 mg kg^{-1} in bitter leaf, 0.40 mg kg^{-1} in carrot, 0.36 mg kg^{-1} in tomatoes, 5.47 mg kg^{-1} in garden egg (*Solanum melongena*), 6.95 mg kg^{-1} in okra, and onion 7.30 mg kg^{-1} [94]. Onianwa et al. [94] reported that among different food groups in Nigeria the highest variation in Cu level was observed in leafy and fruity vegetables (about 169%), and the average level of Cu in this food group was 1.6±2.7 mg kg^{-1} (ranged between 0.07 and 7.30 mg kg^{-1}). However the Indian vegetables contain much higher amount of copper compared to other countries reported. Gupta et al. [66] reported that copper content in some common vegetables of India ranged between 13.4 mg kg^{-1} (in lettuce (*Lactuca sativa*)) and 48.6 mg kg^{-1} (in spinach (*Spinacia oleracea* L.)) (Table 5).

The recommended daily allowance for dietary copper is 2.5 mg day^{-1} [94-96]. Voutsa et al. [54] estimated the daily dietary intake of trace elements by the Greek population on the basis of the concentration of vegetable contaminants (dry weight), the percent moisture of vegetables (ranged between 90 and 95%), and of the daily availability of the specific vegetable species (the mean total daily availability of main foods, except water and beverages, per capita in Greece is 1575 g day^{-1} in which vegetables contribute about 15.3% (241 g day^{-1}) [97]). Voutsa et al. [54] determined trace elements in five common vegetables in Greece which account for 25.3% of the mean total vegetable consumption, that is 3.9% of the total food consumption. Accordingly the total dietary intake of Cu from those five vegetables was estimated to be 11-20 µg day^{-1} (mean daily availability of those five vegetables was 61 g), and if most of the vegetable in Greek diet have similar Cu content the total daily intake of Cu from vegetables was estimated to be 43-79 µg day^{-1} (mean daily availability of vegetables in Greek diet was 241 g (15.3% of the total diet) [97]).

Dietary intake of Cu in some countries of Asia, Europe, and North America has been reported in literature [94]. In Britain, Germany, and Hungary the daily dietary intake of Cu from all food sources were 1.51 mg (ranged between 1.25 and 3.1 mg), 2.7 mg (ranged between 0.6-12.3 mg), and 1.23 mg, respectively. In India and Japan the amount were 5.8 and 3.6 mg day^{-1}, respectively. In Russia, USA, and Canada the daily dietary intake of Cu were reported as 1.3-4.3, 0.76-1.7, and 2.2 mg, respectively [94]. But how much was the contribution of vegetables in total dietary intake of Cu for these countries is not clear. If we consider the contribution of vegetables in total daily diet for an adult in all countries as 15.3% (the daily availability of vegetables for a Greek adult in total diet is 241 g, which is 15.3% of total diet [54]), at least 0.23, 0.41, 0.88, 0.55, 0.19, and 0.34 mg of Cu day^{-1} would be consumed from vegetables by an adult in Britain, Germany, India, Japan, Russia, USA, and Canada, respectively.

The adult human body contains about 1.5±2.0 mg kg^{-1} of Cu which is essential as a constituent of some metalloenzymes and is required in haemoglobin synthesis and in the catalysis of metabolic oxidation [94]. The critical food Cu threshold for human health is 10 mg kg^{-1} [5]. Symptoms of copper deficiency in humans include bone demineralisation, depressed growth, depigmentation, and gastro-intestinal disturbances, among others, while toxicity due to excessive intake has been reported to cause liver cirrhosis, dermatitis and neurological disorders [98-100].

Lead (Pb)

Sources of human exposure:

Lead is commonly found in soil especially near roadways, older houses, old orchards, mining areas, industrial sites, near power plants, incinerators, landfills, and hazardous waste sites. People living near hazardous waste sites may be exposed to lead and chemicals that contain lead by breathing air, drinking water, eating foods, or swallowing dust or dirt that contain lead [101]. People living in areas where there are old houses that have been painted with lead paint may be exposed to higher levels of lead in dust and soil. Similarly, people who live near busy highways or on old orchard land where lead arsenate pesticides were used in the past may be exposed to higher levels of lead. People may also be exposed to lead when they work in jobs where lead is used or have hobbies in which lead is used, such as making stained glass [101].

One major source of environmental lead and of lead exposure to humans, both through direct inhalation and from ingestion following contamination of food chains, has been from the combustion of leaded petrol. Leafy fresh vegetables grown in lead-containing soils may have lead-containing dust on them. Lead may also enter foods if they are put into improperly glazed pottery or ceramic dishes and from leaded-crystal glassware [101].

Health effects:

In the human body, lead inhibits porphobilinogen synthase and ferrochelatase, preventing both porphobilinogen formation and the incorporation of iron into protoporphyrin IX, the final step in heme synthesis. This causes ineffective heme synthesis and subsequent microcytic anemia. At lower levels, it acts as a calcium analog, interfering with ion channels during nerve conduction. This is one of the mechanisms by which it interferes with cognition.

The main target for lead toxicity is the nervous system, both in adults and children. Long-term exposure of adults to lead at work has resulted in decreased performance in some tests that measure functions of the nervous system. Lead exposure may also cause weakness in fingers, wrists, or ankles. Lead exposure also causes small increases in blood pressure, particularly in middle-aged and older people. Lead exposure may also cause anemia. At high levels of exposure, lead can severely damage the brain and kidneys in adults or children and ultimately cause death. In pregnant women, high levels of exposure to lead may cause miscarriage. High level exposure in men can damage the organs responsible for sperm production [101].

Dietary intake:

Lead is generally considered to be only sparingly taken up and translocated to the edible tissues of vegetable crops [102]. Chumbley and Unwin [103] measured the Pb content in some common vegetable in Britain and reported that lettuce, cabbage, leek, onion, spinach, cauliflower, potato, radish, and sweet corn content 2.3-10.1, 0.3-0.8, 0.8-6.0, 0.6-1.5, 3.7-7.0, 2.0-7.1, 0.2-0.3, 2.9-4.9, and 0.1-0.2 mg kg^{-1} dry weight of Pb, respectively. Lead content in vegetables from Saudi Arabia has also been reported (Table 2) which show that the highest was 14.37 mg kg^{-1} in watercress (*Nasturtium officinale*, *N. microphyllum*) and the lowest was 2.59 mg kg^{-1} in tomato (*Lycopersicon esculentum* L.) [12]. In Greek vegetables, the Pb content ranged between 0.08-24.20 mg kg^{-1} dry weight (Table 3). It was reported that the lead contents in some common Greek vegetables; leek, carrot, lettuce, endive, and cabbage were 0.31-16.50, 0.08-0.71, 0.17-15.30, 1.42-24.20, and 0.49-15.50 mg kg^{-1} dry weight, respectively [25]. Bahemuka and Mubofu [13] reported lead content in some common leafy vegetables in Tanzania (Table 4) among which the highest was in cowpea leaves (6.6 mg kg^{-1} dry weight) and the lowest was in cabbage (1.90 mg kg^{-1} dry weight). Indian vegetables content much higher amount of lead compared to other countries. The lead content was highest in radish (50.0-63.5 mg kg^{-1} dry weight) while the lowest was in pudina (*Mentha arvensis*) (15.3-26.5 mg kg^{-1} dry weight) [66]. This amount was several times higher than the safe limit of Pb for human consumption (2.5 mg kg^{-1}).

Sapunar-Postruznik et al. [104] reported that the lead content in vegetables in the Republic of Croatia was 94 µg kg^{-1}. The general population of Croatia consumes an average of 274 g of vegetable day^{-1} and the intake of lead from vegetables was calculated to be about 25.85 µg $person^{-1}$ day^{-1}. Lead intake by a Greek adult has been reported as 0.8-26 µg day^{-1} from cabbage, 0.1-0.5 µg day^{-1} from carrot, 0.1-6.6 μg day^{-1} from leek, 0.2-14 μg day^{-1} from lettuce, and 3.4-58 μg day^{-1} from endive. Notably, the mean daily availability of cabbage, carrot, leek, lettuce, and endive for a Greek adult was estimated to be 17, 7, 4, 9, and 24, respectively [54]. It was estimated that the average daily dietary intake of lead from these five vegetables was 4.6-105 μg day^{-1}, and if all other Greek vegetables contain the similar amount of lead the total daily intake of the metal would be 18-415 μg day^{-1} (the mean daily vegetable availability for a Greek adult was 241 g [97]). However, the total intake of Pb from vegetables represents about 23.6% of the provisional tolerable daily intake [55]. Dietary intake of lead among the general population in Korea was reported to be 20.5 μg day^{-1} [105].

Zinc (Zn)

Sources of human exposure:

Zinc is one of the most common elements in the Earth's crust. Zinc is found in the air, soil, and water and is present in all foods. Zinc enters the air, water, and soil as a result of both natural processes and human activities. Most zinc enters the environment as the result of mining, purifying of zinc, lead, and cadmium ores, steel production, coal burning, and burning of wastes. These activities can increase zinc levels in the atmosphere. Waste streams from zinc and other metal manufacturing and zinc chemical industries, domestic waste water, and run-off from soil containing zinc can discharge zinc into waterways. The level of zinc in soil increases mainly from disposal of zinc wastes from metal manufacturing industries and coal ash from electric utilities. Sludge and fertilizer also contribute to increased levels of zinc in the soil [106].

Exposure of the general population to zinc is primarily by ingestion. The average daily intake of zinc from food in humans is 5.2–16.2 mg zinc/day; assuming a 70-kg average body weight, this corresponds to 0.07–0.23 mg zinc/kg/day [106]. Zinc is widespread in commonly consumed foods, but tends to be higher in those of animal origin, particularly some sea foods. Meat products contain relatively high concentrations of zinc, whereas fruits and vegetables have relatively low concentrations. Other possible pathways for zinc exposure are water and air. Individuals involved in galvanizing, smelting, welding, or brass foundry operations are exposed to metallic zinc and zinc compounds [106].

Health effects:

Zinc is an essential trace element, necessary for sustaining all plants and animals and is thought to protect plants from drought and disease. Zinc constitutes about 33 mg kg^{-1} of adult body weight and is essential as a constituent of many enzymes involved in a number of physiological functions, such as protein synthesis and energy metabolism [94]. Zn plays a fundamental role in expression of the genetic potential; the synthesis, repair and structural integrity of nucleic acids require Zn. Therefore, it is not surprising that deficiency of Zn reduces growth in almost all biological systems via decreased cell replication [107]. Zinc deficiency, resulting from poor diet, alcoholism and malabsorption, causes dwarfism, hypogonadism and dermatitis, while toxicity of zinc, due to excessive intake, may lead to electrolyte imbalance, nausea, anaemia and lethargy [107, 108]. Even though zinc is a very essential requirement for a healthy body, excess zinc can be harmful. Excessive absorption of zinc can also suppress copper and iron absorption. The free zinc ion in solution is highly toxic to plants, invertebrates, and even vertebrate fish. The Free Ion Activity Model (FIAM) is well-established in the literature, and shows that just micromole amount of the free ion kills some organisms. A recent example showed 6 micromole killing 93% of all *Daphnia* in water [109].

Dietary intake:

Although a variety of human diets contribute to the intake of Zn, however, vegetables are reported to be one of the important sources. Zinc contents in common vegetables of many countries have been reported by researchers. Mohamed et al. [12] investigated Zn content in some common vegetables in Saudi Arabia which show that watercress (*Nasturtium officinale, N. microphyllum*) had the highest amount of Zn (105.20 mg kg^{-1} dry weight) while the potato (*Solanum tuberosum* L.) had the lowest (4.50 mg kg^{-1} dry weight) (Table 2). Among the Greek vegetables about 20.10-140.00 mg kg^{-1} dry weight of Zn was found in endive (*Cichorium endivia*) while it was 8.90-40.50 in leek (*Allium ampeloprasum* var. *porrum* L.) (Table 3) [25]. In Tanzania, Zn contents were reported as 37.6-41.8 mg kg^{-1} in leafy cabbage (*Brassica oleracea var. capitata* L.), 14.8-15.9 mg kg^{-1} in lettuce (*Lactuca sativa*), 40.8-48.1 mg kg^{-1} in African spinach (*Spinacia oleracea* L.), 23.8-49.3 mg kg^{-1} in Chinese cabbage (*Brassica chinensis* L.), and 27.7-36.7 mg kg^{-1} in pumpkin leaves (*Cucurbita moschata* L.) (Table 4) [13]. Among south Asian countries Zn content in Pakistani vegetables have lower than that in Indian vegetables. The Zn content in Pakistani vegetables ranged between 0.1±0.00 and 1.2±0.01 mg kg^{-1} dry weight (Table 6) [76] while its content in Indian vegetables ranged between 82.6 and 193.7 mg kg^{-1} dry weight (Table 5) [66]. Among the Indian vegetables the highest content of Zn (136.5-181.0 mg kg^{-1} dry weight) was observed in spinach (*Spinacia oleracea* L.) and the lowest (82.6-123.0 mg kg^{-1} dry weight) in cauliflower (*Brassica oleracea var. botrytis* L.). However, these values are much higher than the safe limit for human consumption (50.0 mg kg^{-1}) [66].

Recommended dietary allowances for Zn have been set at a level of 15 mg for adult males and 12 mg for adult non-pregnant and non-lactating women, based on an average requirement of 2.5 mg day^{-1} for absorbed Zn and an absorption efficiency of 20%, to meet the needs of all healthy persons, including those who consume diets with low Zn bioavailability [110]. High level of Zn in vegetables of many countries, especially in India, might contribute its intake in human through daily diet significantly. In Egyptian diet the average vegetable consumption is about 238±21.6 g (between 43.6 and 351 g) a day [110]. Hussein et al. [110] estimated that Zn content in Egyptian vegetables was 41.9 mg kg^{-1} and thus the daily dietary intake of Zn from vegetables would be 0.84-9.8 mg. This value is lower than the safe limit daily Zn intake (15 mg and 12 mg for adult male and female, respectively [110]).

Voutsa and Samara [54] investigated the Zn content in some common vegetables in Greece and estimated the daily dietary intake of the element in human. According to their estimation the mean daily dietary intake of Zn is 109 µg day^{-1} from cabbage, 15 µg day^{-1} from carrot, 9 µg day^{-1} from leek, 35 µg day^{-1} from lettuce, 59 µg day^{-1} from endive. Voutsa and Samara [54] also estimated that every day 61 g of these five vegetables are consumed by a Greek adult which contribute 227 µg of Zn. Moreover, the total daily vegetable consumption by Greek population is 241 g, and if all vegetables content similar amount of Zn the daily Zn intake would be 897 µg only from vegetables.

The vegetable consumption by Indian and other south Asian population is between 200 and 300 g day^{-1}. On the basis of Zn content in some common Indian vegetables reported in literature [66], the daily dietary intake of Zn by Indian population would be 16.52-58.11 mg. This amount is above the permissible limit of total Zn in daily diet (15 mg and 12 mg for adult male and female, respectively [110]).

CONCLUSION

Dietary intakes of toxic elements not only depend on the concentration of the elements in the vegetables but also evidently associated with the food habit and consumption rate by the population of a certain geographical area. Concentrations of some potentially toxic elements in a variety of vegetable species from different region of the world are compiled within the scope of the present article, and the dietary intake of the toxic elements in the vegetables for the corresponding region or country are discussed. Emphasis was given on data in available literatures and personal communication. Vegetables of south Asian countries like Bangladesh, India, and Pakistan have found to contain high level of toxic elements compared to other areas. Especially arsenic could be a major threat to the health of the population of this sub-continent. The food habit as well as the pattern of food consumption by the population of this area is also favorable in the dietary intake of toxic metals. Excessive use of contaminated groundwater in cooking and drinking could present a new dimension in health risk from arsenic in south Asia through the inclusion of arsenic in the food chains.

The contents of toxic elements in vegetables of some European countries were significantly lower then those in vegetables of south Asian and African countries. A detail discussion of the content of toxic elements in some common vegetables of Greece has been found in literatures which represents the European countries in this discussion. Data of Tanzania is considered as representative of African countries. Toxic elements in vegetables of Saudi Arabian markets have also been included in this discussion which might give an idea about the dietary intake of metals from vegetables of other Arabian countries. Considering the contents of toxic elements in vegetables of different areas worldwide, it can be concluded that vegetables could be a potential route for the dietary intake of those elements for the populations of highly contaminated areas.

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Table 1: Arsenic content in common vegetables collected from arsenic-prone villages of Bangladesh (Personal communication).

Vegetables (Scientific Name)	Arsenic Content (mg kg^{-1} Fresh Weight)
Bean (*Lablab niger)*	0.44±0.02 - 0.40±0.21
Bitter gourd (*Momordica charantia)*	0.37±0.05
Bottle gourd (*Lagenaria siceraria)*	BDL
Brinjal (*Solanum melongena)*	0.24±0.01 - 0.26±0.07
Chilli (*Capsicum frutescens*)	0 - 0.87±0.48
Green papaya (*Carica papaya)*	0.08±0.03
Mint (*Mentha viridis)*	0.59±0.07 - 0.56±0.04
Okra (*Abelmoschus esculentus)*	BDL
Palwal (*Trichosanthes dioica)*	BDL
Potato (*Solanum tuberosum)*	0.12±0.07
Pumpkin leaf (*Cucurbita maxima)*	0.41±0.07
Red amaranth (*Amaranthus gangeticus)*	0.16±0.03
String bean (*Vigna sesquipedalis)*	1.26±0.06 - 0.88±0.04
Sweet gourd (pumpkin) (*Cucurbita maxima)*	0.11±0.01 - 0.12±0.02
Tomato (*Lycopersicon esculentum)*	0.08±0.01 - 0.54±0.31

Data are presented as mean ± SD (n = 3). 'BDL' = below detection limit.

Table 2: Heavy metal concentrations in some common vegetables of Saudi Arabia [12].

Vegetables (Scientific Name)	Heavy metal contents (mg kg^{-1})			
	Cd	Cu	Pb	Zn
Cucumber (*Cucumis sativa* L.)	0.59	2.48	4.26	32.30
Egg-plant (*Solanum melongena* L.)	0.69	2.93	4.57	50.70
Carrots (*Daucas carota* L.)	0.81	0.98	7.94	9.60
Lettuce (*Lactuca sativa)*	1.04	0.90	3.70	42.00
Spinach (*Spinacia oleracea* L.)	0.77	2.71	9.44	9.60
Green pepper (*Capsicum frutescens)*	0.80	4.49	1.90	8.51
Onion (*Allium cepa* L.)	0.76	1.07	10.29	17.60
Watercress (*Nasturtium microphyllum)*	1.22	1.96	14.37	105.20
Cabbages *Brassica oleracea* L.)	0.59	0.43	-	14.90
Potatoes (*Solanum tuberosum* L.)	0.84	0.88	2.81	4.5
Tomato (*Lycopersicon esculentum* L.)	0.77	4.47	2.59	14.40

Table 3: Heavy metal concentrations in some common vegetables of Greece [25].

Vegetables (Scientific name)	Heavy metal contents (mg kg^{-1} dry weight)					
	As	Cd	Cu	Cr	Pb	Zn
Leek (*Allium ampeloprasum* L.)	0.01-0.16	0.29-0.49	1.65-2.19	0.13-3.42	0.31-16.50	8.90-40.50
Carrots (*Daucas carota* L)	0.02-0.05	0.17-0.41	1.75-2.37	0.08-8.62	0.08-0.71	11.90-113.00
Lettuce (*Lactuca sativa*)	0.04-0.29	0.40-0.64	0.89-3.89	0.86-9.72	0.17-15.30	13.10-75.00
Endive (*Cichorium endivia*)	0.13-0.19	0.44-0.72	2.62-4.49	0.50-5.50	1.42-24.20	20.10-140.00
Cabbages (*Brassica oleracea* L.)	0.01-0.37	0.26-1.03	1.01-1.87	0.20-7.73	0.49-15.50	13.70-258.00

Table 4: Heavy metal concentrations in some common vegetables of Tanzania [13].

Vegetables (Scientific Name)	Heavy metal content (mg kg^{-1})			
	Cd	Cu	Pb	Zn
Leafy cabbages (*Brassica oleracea* L.)	0.1	5.0-5.6	1.90-3.10	37.6-41.8
Cowpea leaves (*Vigna sinensis* L.)	0.2-0.6	8.5-9.1	2.8-6.6	33.6-34.6
Lettuce (*Lactuca sativa)*	0.3-0.4	2.5-5.8	3.6-3.8	14.8-15.9
African spinach (*Spinacia oleracea* L.)	0.3-0.6	7.2-13.7	3.0-5.9	40.8-48.1
Chinese cabbages (*Brassica chinensis* L.)	0.2	4.9-7.5	3.2-6.1	23.8-49.3
Pumpkin leaves (*Cucurbita moschata* L.)	0.2	9.4-16.0	3.4-3.9	27.7-36.7

Table 5: Heavy metal concentrations in some common vegetables of India grown in waste-water irrigated agricultural soil [66].

Vegetables (Scientific Name)	Heavy metal Content (mg kg^{-1})				
	Cd	Cu	Cr	Pb	Zn
Pudina (*Mentha arvensis)*	5.4-31.0	18.7-30.7	58.4-75.3	15.3-26.5	110.9-153.0
Cauliflower (*Brassica oleracea* L.)	7.0-30.0	13.4-18.1	74.8-103.0	28.3-35.6	82.6-123.0
Lettuce (*Lactuca sativa)*	10.3-28.0	17.6-37.8	50.4-70.5	33.1-38.0	149.4-193.7
Spinach (*Spinacia oleracea* L.)	6.5-32.0	22.1-48.6	74.0-115.4	41.9-60.5	136.5-181.0
Chinese onion (*Allium cepa* L.)	5.7-25.0	16.3-18.9	40.3-53.2	22.8-41.4	110.9-150.0
Radish (*Rapnus sativus* L.)	11.8-28.6	18.7-35.1	69.8-100.0	50.0-63.5	125.4-157.3

Table 6: Concentration of heavy metals in vegetables procured from local markets of Pakistan [76].

Vegetable (Scientific Name)	Heavy metal Content (mg kg^{-1})		
	Cu	Zn	Cr
Lady finger (*Abelmoschus esculantus* L.)	1.8 ± 0.01	8.6 ± 0.04	0.7 ± 0.01
Pumpkin (*Cucurbita moschata* L.)	1.7 ± 0.01	4.1 ± 0.02	0.8 ± 0.02
Tomato (*Lycopersicon esculentum* L.)	1.3 ± 0.01	4.4 ± 0.03	0.5 ± 0.04
Brinjil (*Solanum melongena)*	3.1 ± 0.02	7.1 ± 0.05	0.7 ± 0.02
Potato (*Solanum tuberosum* L.)	1.2 ± 0.00	2.6 ± 0.01	0.3 ± 0.00
Beet (*Beta vulgaris)*	1.9 ± 0.01	3.6 ± 0.02	0.7 ± 0.02
Radish (*Rapnus sativus* L.)	1.0 ± 0.00	3.4 ± 0.02	0.5 ± 0.01
Carrot (*Daucas carota* L.)	1.2 ± 0.00	5.2 ± 0.04	0.8 ± 0.01
Turnip (*Brassica rapa* var. *rapa)*	1.1 ± 0.01	4.1 ± 0.02	0.4 ± 0.00
Mustard (*Brassica juncea)*	3.3 ± 0.01	5.4 ± 0.03	0.1 ± 0.00
Cabbage (*Brassica oleracea* L.)	1.1 ± 0.00	3.8 ± 0.02	0.4 ± 0.00
Spinach (*Spinacia oleracea* L.)	2.9 ± 0.01	6.1 ± 0.03	0.7 ± 0.02
Coriander (*Coriandrum sativum)*	1.8 ± 0.00	3.7 ± 0.04	1.2 ± 0.01