Health Risk Associated with Copper Intake through Vegetables in Different Countries

Nitika Sharma1*, Akanksha Bakshi1, Ashita Sharma2, Inderpreet Kaur3, Avinash Kaur Nagpal1#
1 Department of Botanical and Environmental Sciences, Guru Nanak Dev University, Amritsar
2 Civil Engineering Department, Chandigarh University, Mohali
3 Department of Chemistry, Guru Nanak Dev University, Amritsar

Abstract. Sustainable development goals aim to attain food security by 2030. To attain food security, it becomes extremely important to target various aspects of food security where safety of food is a major factor. In order to meet the growing population demand, efforts are being made to increase production of food and thus the safety aspect is often ignored. Irrational anthropogenic activities have impacted and deteriorated the ambient environment. Degradation of soil and water has resulted in buildup of contaminants in these spheres and further transfer of contaminants into the food chain. Increase in heavy metals in our surroundings is reported in many parts of the world. Further, increase in concentration of metals in soil and water result in the transfer of these metals into food chain. Unlike other metals copper is although is an essential element for living organisms but excessive consumption of copper is known to cause toxic impacts to living organisms. Green leafy vegetables are considered as hyperaccumulators for copper. The excessive concentration of copper in vegetables is not limited to any one region of the world. The present review summarizes the reports of copper content in vegetables in various parts of the world and health effects associated with it.

1. INTRODUCTION
Sustainable development goals target to achieve food security for all by 2030. In order to meet with the demands of growing population, the focus of agriculture is to increase the production of food and thus the quality and safety of the food is neglected [1], [2]. Cultivation of crops using wastewater and on polluted lands result in the uptake of contaminants. Increase in heavy metal content in various food crops have been reported in various parts of the world [3]–[5]. Among all food crops, many
vegetables are considered hyperaccumulators for various metals. Vegetables are an important component of a balanced diet, since they provide not only energy in the form of carbohydrates, proteins, and lipids, but also vitamins, minerals and enzymes. Beneficial effects of vegetable for human well-being are well known. The health promoting effects of vegetables have been associated with antioxidative potential of variety of compounds like ascorbic acid, carotenoids, tocopherols, glutathione, phenolic acids, and flavonoids found in them. Vegetables are typically grown on soil, which is the ultimate source of crop nutrients. Contaminated soils, on the other hand, are a source of various pollutants like heavy metals, pesticides etc. that are directly taken up by the plant root system and accumulate in tissues. Post-harvest vegetables may also be at risk from air pollution during transportation and marketing, resulting in higher levels of heavy metals in the produce [6]–[8].

One of the primary and most often discussed ecotoxicological issues is heavy metal poisoning of ecosystem. Among inorganic pollutants (heavy metals, non-metallic salts, acids and bases), heavy metals are the most common inorganic pollutants, and their severe toxicity, non-biodegradability, and high mobility and availability have made them an increasing source of concern around the world a [9]–[12], posing a potential threat to the environment and human health. Despite their poor mobility in soil, these elements alter biochemical processes in organisms, impacting physiological functions even at low concentrations. When present in trace amounts, some heavy metals (Cu, Fe, Zn, Mn, etc.) are necessary for plant growth and development, but at high concentrations, they are hazardous. Essential elements have a very different physiology and behaviour than non-essential elements. In risk assessment approaches for essential metals, it is critical to take these processes into account, which include homeostasis, baseline and normative nutritional requirements, and bioavailability. Copper is one such metal. Copper is essential for plants and being a micronutrient, it plays an important role in number of physiological processes [13]–[16]. Cu in high concentrations pollutes the environment and is hazardous to plants, animals and humans.

2. CONTAMINATION SOURCES

Heavy metal poisoning of soil is becoming a global problem due to its negative effects on environmental safety. The increase in heavy metal levels in the environment can be attributed to both natural and manmade activities. Parent geologic rock material, volcanic eruptions, spontaneous contributions, or forest fires are natural sources of contamination in soil. Heavy metals accumulate in soil mostly as a result of anthropogenic activity, particularly the application of agrochemicals. Cu is found in nature as native copper [17]–[20], copper sulphides, copper sulfoalts, copper carbonates, and copper (I) and copper (II) oxides. Batteries, pigments and paints, fuel, alloys, catalysts, pesticides and fertilisers are all possible industrial and agricultural sources of copper. Tailings, overburden boulders, and abandoned mines are the main sources of heavy metal contamination in the mining zone. They're all sulfide-rich, and while the metal content isn't high enough to extract economically,
it's high enough to pollute the environment. On exposure to oxygen and water, sulphides in tailings, overburden rocks, and abandoned mines produce acid metal drainage. The extraction of low-grade ore is expanding in tandem with the rising demand for Cu. More trash is produced during the extraction of low-grade ore. From 2012 to 2017, global copper (Cu) production increased from 16,692 to 20,029 thousand metric tonnes. With total Cu output of 11,042 thousand metric tonnes, the American continent leads, followed by Asia with 4246.5 thousand metric tonnes.

3. COPPER IN VEGETABLES
Copper is an important redox active transition metal and exists as Cu\(^{2+}\) and Cu\(^{+}\) in physiological conditions. In plants, copper (Cu) is involved in photosynthetic electron transport, mitochondrial respiration, oxidative stress responses, cell wall metabolism, hormone signalling and as a structural element in regulatory proteins. As a result, plants require Cu as an essential element for appropriate growth and development; when this ion is deficient, plants exhibit distinct symptoms, majority of which harm reproductive organs and young leaves (Copper participates in numerous physiological processes, however, problems arise when excess copper is present in cells). The redox characteristics that contribute towards the essentiality of Cu also make it a toxic element. The generation of highly harmful hydroxyl radicals can be catalysed by redox cycling between Cu\(^{2+}\) and Cu\(^{+}\), causing damage to biomolecules like proteins, DNA, lipids, and protein

In some soils, Cu is naturally present in higher concentrations while in others, the toxic level of Cu is due to human activities like agriculture, smelting, mining and manufacture. Cu has been proven to impede growth and interfere with critical cellular activities including photosynthesis and respiration at concentrations above those required for optimal function.

4. UPTAKE MECHANISM
Vegetables planted near industrial set ups and busy roads, as well as crops exposed to municipal and agricultural effluents, have a higher concentration of certain elements. Bedrock is the natural source of metals in soil. Some quantity of metal is introduced in the agricultural soil by fertilizers. Surface and ground water, soil, and eventually crop plants may be contaminated with metals. The toxic potential of heavy metals is due to their ability to form stable coordinated compounds with a variety of organic and inorganic ligands, so even at low concentration they serve as biological poisons. Growing plants absorb toxic elements, stored in organic matter in soils, in the form of cations and these cations are harmful when bound to short chains of carbon atoms in plant cells. The methods by which vegetables absorb important elements from the soil are extremely well-organized. Even at very low concentration of micronutrients, the root system of vegetables, in combination with chelating agents and redox reactions, can solubilize and assimilate them. Deposition of air particles on leaf
surface also leads to accumulation of heavy metals. This is especially true for vegetables like lettuce, spinach, and endive.

5. HEALTH RISK DUE TO COPPER IN VEGETABLES

Depending on growth stage and fertiliser treatment, plant species have different capacities for accumulating Cu. Because Cu is quickly absorbed by plant roots and not readily translocated to aboveground portions of the plant, the effect of Cu toxicity is mostly on root growth and shape. Cu transfer into aboveground plant parts is effectively controlled by the substantial concentration of Cu in roots. Some earlier studies on *Amaranthus spinosus*, *Boehmeria nivea* L., *Eclipta alba*, *Oryza sativa*, *Phyllostachys pubescens*, *Triticum aestivum*, *Trigonella foenum-graecum*, and Willows(*Salix* spp.), have shown Cu to have a tendency for getting accumulated in root tissues with little upward migration towards shoots. Copper tolerance is related to a plant’s ability to store copper in its roots and effectively prevent it from being translocated to photosynthetic regions.

Despite the fact that the plants had an enhanced copper content and had suffered some damage as a result of the Cu treatment, they appeared to be in good health. It was proposed that Chinese cabbage with high Cu level but no obvious signs of damage could pose a risk to human health due to transfer of metal to food.

There is a little difference between the necessary, beneficial, and harmful concentrations of Cu in living systems, which varies significantly depending on Cu speciation and the form of living organisms. As a result, monitoring its bioavailability, speciation, exposure levels, and pathways in live organisms is critical. The main source of heavy metal toxicity in humans is the consumption of Cu-laced food crops.

An overview of the global scenario for contamination of vegetables with Cu is given in Table 1 which summarises recent research on copper contents in different vegetables mainly from 2011 – 2021, however a few earlier reports are also included. A study conducted by in Romania (Baia Mare, the mining district) showed that copper accumulated in higher quantities in root vegetables like carrot (2.7 – 8.6 mg/kg fw), kohlrabi (0.9 – 25.9 mg/kg fw) and parsley (3.3 – 49.3 mg/kg fw). Lettuce (0.8 – 4.5 mg/kg fw) proved to be a high copper accumulator among leafy vegetables. [2]reported that Copper is present in higher concentration in leafy vegetables (33.22 – 6.76μg/g), also showed that leafy and tuberous vegetables accumulate higher level of copper as compared to fruity vegetables.

Copper is reported in bulbs (onion, ginger), fruits (brinjal, pumpkin, ladyfinger), roots (carrot, radish) tubers (potato), stem (lotus). reported the concentration of copper, in vegetables grown in rural areas of Multan, Pakistan, is below the permissible limits as proposed by FAO/WHO (2001). Most of the studies have reported copper in leafy vegetables. Highest concentration of copper was reported in Cucumber (95.31 mg/kg of dry weight) by, see table 1.
Table 1. Summary of literature on content of copper in different vegetables grown in diverse parts of the globe.

| Sr. No. | Botanical name of the vegetable (Common name) | City/State/Country | Description of Site (Method of irrigation/Type of area/Collection from market) | Part of plant | Content of Copper (mg/kg) |
|---------|-----------------------------------------------|--------------------|--------------------------------------------------------------------------------|---------------|--------------------------|
| 1       | *Abelmoschus esculentus* (Okra)               | Multan, Pakistan   | Irrigated with Canal water, Waste water, Tubewell water                      | Fruits        | 1.09                     |
| 2       | *Allium cepa* (Onion)                         | Tabuk, Riyan, Damam, Jazan, Saudi Arabia | Collected from farms                                                          | Stems         | 4.91                     |
|         |                                                | Baia Mare, Romania | Urban                                                                        | Leaf bases    | 1.35                     |
|         |                                                | Liaoning Province, China | Farms irrigated with wastewater                                            | Roots         | 0.537                    |
|         |                                                | Bushehr, Iran      | Farms irrigated with groundwater                                            | Leaf bases    | 2.81                     |
| 3       | *Allium sativum* (Garlic)                     | Baia Mare, Romania | Urban                                                                        | Bulbs         | 2.2                      |
|         |                                                |                                                | Rural                                                                        |              | 2.5                      |
| 4       | *Allium fistulosum* (Scallion/spring onion)   | Malaysia           | Collected from field stalls, wholesaler outlets, supermarkets and farmer market | Leaves        | 0.033                    |
|         |                                                | Beijing, China     | Cameron highlands, Sepang highlands                                          |              | 0.138                    |
| 5       | *Allium tuberosum* (Leek)                     | Beijing, China     | Collected from field stalls, wholesaler outlets, supermarkets and farmer market | Leaves        | 0.51                     |
|         |                                                | Southern Jiangsu, China | Industrial zone                                                       |              | 0.72                     |
| 6       | *Amaranthus paniculatus* L.                   | Dhaka, Bangladesh  | Riverside fields                                                              | Leaves        | 19.35                    |
| 7       | *Amaranthus viridis* L.                       | Dhaka, Bangladesh  | Riverside fields                                                              | Leaves        | 15.60                    |
| 8       | *Anethum graveolens* (Dill)                   | Baia Mare, Romania | Urban                                                                        | Leaves        | 1.3                      |
|         |                                                |                                                | Rural                                                                        |              | 1.9                      |
| 9       | *Artemisia dracunculus* (Tarragon)            | Baia Mare, Romania | Urban                                                                        | Leaves        | 2.3                      |
|         |                                                |                                                | Rural                                                                        |              | 2.4                      |
| 10      | *Apium graveolens* (Celery)                   | Liaoning Province, China | Farmland near smelters                                                      | Leaves        | 1.039                    |
| 11      | *Benincasa hispida* (Wax)                     | Beijing, China     | Collected from field stalls, wholesaler outlets, Fruits                      |              | 0.19                     |
| No. | Species | Location | Exposure Area | Control Area | Leaves | Roots |
|-----|---------|----------|---------------|--------------|--------|-------|
| 12  | *Beeta vulgaris* L. (Chard, Beet root) | Puchuncavi, Chile | Control area | Exposure area | Control area | Leaves | Roots |
| 13  | *Brassica campestris var. communis* (Pakchoi) | Liaoning Province, China | Farmland near smelters | | | | 0.485 |
| 14  | *Brassica campestris pekinensis* Olsson | Liaoning Province, China | Farmland near smelters | | | | 0.163 |
| 15  | *Brassica chinensis* Linn./green cabbage | Southern Jiangsu, China | Industrial area | | | | 0.48 |
| 16  | *Brassica chinensis* L. (Shanghai green cabbages) | Shanghai, China | Industrial area | | | | 0.23 |
| 17  | *Brassica juncea* (Leaf mustard) | Dehradun, India | Site I (irrigated with wastewater) | Site II (irrigated with tube well water) | | | |
| 18  | *Brassica oleracea* (Kohlrabi) | Baia Mare, Romania | Urban | Rural | | | |
| 19  | *Brassica oleracea var. acephala* (Kale) | Thika, Kenya | Irrigated with wastewater | Makongeni market | | | |
| 20  | *Brassica oleracea var. botrytis* (Cauliflower) | Dehradun, India | Site I (irrigated with wastewater) | Site II (irrigated with tube well water) | | | |
|     |         | Multan, Pakistan | Irrigated with | Canal water | Waste water | Tubewell water | | |
|     |         | Liaoning Province, China | Farmland near smelters | | | | 0.337 |
| No. | Species                          | Location                  | Irrigation Source       | Crop Part       | Concentration (μg/kg) |
|-----|---------------------------------|---------------------------|-------------------------|-----------------|-----------------------|
| 21  | *Brassica oleracea* var. *capitata* (Cabbage) | Tabuk, Saudi Arabia | Ground water            | Inflorescence  | 0.006                 |
|     |                                 | Riayadh, Saudi Arabia    | Ground water            | Inflorescence  | 0.40                  |
|     |                                 | Damam, Syria             | Ground water            | Inflorescence  | 2.76                  |
|     |                                 | Jazan, Syria             | Ground water            | Inflorescence  | 6.85                  |
|     |                                 | Baia Mare, Romania       | Urban                    | Leaves         | 4.24                  |
|     |                                 | Liaoning Province, China | Urban                    | Leaves         | 3.88                  |
|     |                                 |                          | Rural                    | Leaves         | 0.9                   |
|     |                                 |                          | Farmland near smelters  | Leaves         | 0.287                 |
|     |                                 |                          |                          |                 |                       |
| 22  | *Brassica rapa* (Turnip)         | Tabuk, Saudi Arabia      | Ground water            | Root            | 11.80                 |
|     |                                 | Riayadh, Saudi Arabia    | Ground water            | Root            | 14.27                 |
|     |                                 | Damam, Syria             | Ground water            | Root            | 6.21                  |
|     |                                 | Jazan, Syria             | Ground water            | Root            | 7.45                  |
|     |                                 | Baia Mare, Romania       | Ground water            | Root            | 0.003                 |
|     |                                 | Liaoning Province, China | Ground water            | Root            | 0.18                  |
| 23  | *Brassica rapa* subsp. *chinensis* (Bok Choy) | Beijing, China | Collected from field stalls, wholesaler outlets, supermarkets and farmer market | Leaves | 0.56 |
| 24  | *Brassica rapa* subsp. *pekinensis* (Chinese Cabbage) | Beijing, China | Collected from field stalls, wholesaler outlets, supermarkets and farmer market | Leaves | 0.29 |
|     |                                 | Southern Jiangsu, China  | Industrial zone         | Leaves         | 0.46                  |
| 25  | *Capsicum annuum* (Capsicum/Green pepper/ Bell pepper) | Dhaka, Bangladesh       | Riverside fields        | Fruits          | 24.18                 |
|     |                                 | Baia Mare, Romania       | Urban                    | Fruits          | 0.3                   |
|     |                                 |                          | Rural                    | Fruits          | 0.3                   |
|     |                                 | Liaoaning Province, China | Farmland near smelters  | Fruits          | 2.262                 |
|     |                                 | Bushehr, Iran            | Farm s irrigat ed        | Fruits          | 5.87                  |
|     |                                 |                          | Ground water            | Fruits          | 4.12                  |
| No. | Species | Location | Condition | Product | Concentration |
|-----|---------|----------|-----------|---------|---------------|
| 26  | Capsicum frutescens (Chillies) | Dhaka, Bangladesh | Industrial area | Fruits | 11.18         |
| 27  | Chrysanthemum coronarium (Garland Chrysanthemum) | Liaoning Province, China | Farmland near smelters | Leaves | 1.073        |
| 28  | Cichorium endivia (Endive) | Liaoning Province, China | Farmland near smelters | Leaves | 0.626        |
| 29  | Corchorus olitorius (Jew's mallow) | Tabuk, Saudi Arabia | Collected from farms | Leaves | 15.3         |
|     |       | Riyadh, Saudi Arabia |                      |        | 33.22        |
|     |       | Damam, Saudi Arabia |                      |        | 9.07         |
|     |       | Jazan, Saudi Arabia |                      |        | 24.38        |
| 30  | Coriandrum sativum (Coriander) | Thika, Kenya | Irrigated with wastewater | Leaves | 1.37         |
|     |       | Makongeni market |                      |        | 1.68         |
| 31  | Cucumis sativus (Cucumber) | Tabuk, Saudi Arabia | Collected from farms | Fruits | 3.95         |
|     |       | Riyadh, Saudi Arabia |                      |        | 7.18         |
|     |       | Damam, Saudi Arabia |                      |        | 3.21         |
|     |       | Jazan, Saudi Arabia |                      |        | 5.65         |
|     |       | Boumerdes, Algeria | Irrigated with reclaimed water | Fruits | 95.31         |
|     |       |                      | Collected from markets |        | 94.56         |
|     |       | Baia Mare, Romania | Urban                  | Fruits | 0.8          |
|     |       |                    | Rural                  |        | 0.7          |
|     |       | Liaoning Province, China | Farmland near smelters | Fruits | 0.636        |
|     |       | Golestan Province, Iran | Gonbad            | Fruits | 4.1          |
|     |       |                      | Gorgan                |        | 3.7          |
| 32  | Cucurbita maxima | Dhaka, Bangladesh | Riverside fields | Fruits | 11.44        |
| 33  | Cucurbita pepo (Zucchini) | Baia Mare, Romania | Urban                  | Fruits | 0.7          |
|     |       |                      | Rural                  |        | 0.6          |
| 34  | Cucurbita pepo var. pepo (Pumpkin) | Multan, Pakistan | Irrigated with Canal water | Fruits | 0.29         |
|     |       |                      | Waste water            |        | 0.19         |
| 35  | Daucus carota (Carrot) | Tabuk, Saudi Arabia | Collected from farms | Roots | 4.44         |
|     |       | Riyadh, Saudi Arabia |                      |        | 4.49         |
|     |       | Damam, Saudi Arabia |                      |        | 3.69         |
|     |       | Jazan, Saudi Arabia |                      |        | 7.82         |
|     |       | Baia Mare, Romania | Urban                  | Roots  | 7.1          |
|     |       |                      | Rural                  |        | 4.5          |
|     |       | Liaoning Province, China | Farmland near smelters | Roots  | 1.038        |
| Province, Country                        | Region                          | Cultivar                         | Source                                      | Sample Type        | Concentration (mg/kg) |
|----------------------------------------|---------------------------------|----------------------------------|---------------------------------------------|--------------------|-----------------------|
| Sahiwal, Pakistan                      |                   | Ground water                   | Roots                                       | 0.007              |
| Puchuncavi, Chile                      | Control area                   | Ground water                   | Roots                                       | 0.62               |
| Puchuncavi, Chile                      | Exposure area                  | Ground water                   | Roots                                       | 9                  |
| Puchuncavi, Chile                      | Collectors from farms          | Ground water                   | Leaves                                      | 6.81               |
| Jazan                                  |                                 | Ground water                   | Leaves                                      | 9.07               |
| Jazan                                  |                                 | Ground water                   | Leaves                                      | 6.03               |
| Jazan                                  |                                 | Ground water                   | Leaves                                      | 6.76               |
| Guangzhou, South China                 | Site I (close to waste incinerator) | Ground water                   | Leaves                                      | 8.67               |
| Guangzhou, South China                 | Site II (less contaminated area) | Ground water                   | Leaves                                      | 2.4                |
| Shanghai, China                        | Industrial areas               | Ground water                   | Leaves                                      | 0.79               |
| Guangzhou, South China                 | Site I (close to waste incinerator) | Ground water                   | Leaves                                      | 14.43              |
| Guangzhou, South China                 | Site II (less contaminated area) | Ground water                   | Leaves                                      | 6.29               |
| Shanghai, China                        | Industrial areas               | Ground water                   | Leaves                                      | 12.99              |
| Guangzhou, South China                 | Farmland near smelters         | Ground water                   | Leaves                                      | 6.42               |
| Guangzhou, South China                 | Urban                           | Ground water                   | Leaves                                      | 2.1                |
| Guangzhou, South China                 | Rural                           | Ground water                   | Leaves                                      | 2.2                |
| Liaoning, Liaoning, China              | Farmland near smelters         | Ground water                   | Leaves                                      | 0.727              |
| Shanghai, China                        | Industrial areas               | Ground water                   | Leaves                                      | 0.46               |
| Bushehr, Iran                          | Farms irrigated with           | Ground water                   | Leaves                                      | 5.12               |
| Puchuncavi, Chile                      | Control area                   | Ground water                   | Leaves                                      | 2.81               |
| Guangzhou, South China                 | Site I (close to waste incinerator) | Ground water                   | Leaves                                      | 7.67               |
| Guangzhou, South China                 | Site II (less contaminated area) | Ground water                   | Leaves                                      | 2.1                |
| Dhaka, Bangladesh                      | Riverside fields               | Ground water                   | Leaves                                      | 10.42              |
| Multan, Pakistan                       | Irrigated with                 | Ground water                   | Leaves                                      | 0.27               |
| Multan, Pakistan                       | Irrigated with                 | Ground water                   | Leaves                                      | 0.42               |
| Multan, Pakistan                       | Irrigated with                 | Ground water                   | Leaves                                      | 0.22               |
| No. | Species                  | Location                        | Type                               | Sampling Site                        | Parameter   | Concentration (mg/kg) |
|-----|--------------------------|---------------------------------|------------------------------------|--------------------------------------|-------------|----------------------|
| 43  | *Luffa cylindrica* (Sponge Gourd) | Southern Jiangsu, China          | Industrial zone                    | Fruits                               |             | 0.43                 |
| 44  | *Mentha* (Mint)          | Rajasthan, India                 | Irrigated with Wastewater          | Leaves                               |             | 12.7                |
| 45  | *Momordica charantia* (Bitter gourd) | Multan, Pakistan                | Irrigated with Canal water          | Fruits                               | 0.10        | 1.26                 |
|     |                          |                                 |                                    | with Tube well water                  |             | 0.08                 |
| 46  | *Nelumbo adans*          | Beijing, China                   | Collected from field stalls, wholesaler outlets, supermarkets and farmer market | Roots                               |             | 1.62                 |
| 47  | *Nelumbo nucifera*       | Rajasthan, India                 | Irrigated with Wastewater          | Stems                                |             | 13.7                |
| 48  | *Petroselinum crispum* (Parsley) | Tabuk, Saudi Arabia              | Collected from farms               | Leaves                               | 6.28        | 7.07                 |
|     |                          |                                 |                                    |                                      |             | 7.82                 |
|     |                          |                                 |                                    |                                      |             | 9.10                 |
|     |                          |                                 |                                    |                                      |             |                     |
|     |                          |                                 |                                    |                                      |             |                     |
| 49  | *Phaseolus vulgaris* (French beans/ Green bean) | Dehradun, India                | Site I (irrigated with wastewater) | Fruits                               | 11.61       |                     |
|     |                          |                                 | Site II (irrigated with tube well water) |                                     |             | 11.89                |
|     |                          |                                 | Urban                              | Fruits                               | 0.8         |                     |
|     |                          |                                 | Rural                              |                                      |             | 0.7                  |
|     |                          |                                 |                                    |                                      |             |                     |
|     |                          |                                 |                                    |                                      |             |                     |
| 50  | *Raphanus sativus* (Radish) | Liaoning Province, China         | Farmland near smelter              | Fruits                               | 0.975       |                     |
|     |                          |                                 |                                    |                                      |             |                     |
|     |                          |                                 |                                    |                                      |             |                     |
| 51  | *Solanum lycopersicum* (Tomato) | Tabuk, Saudi Arabia              | Collected from farms               | Fruits                               | 3.57        | 7.46                 |
|     |                          |                                 |                                    |                                      |             | 5.80                 |
| Location                  | Cultivation Method                      | Product     | Quantity |
|---------------------------|-----------------------------------------|-------------|----------|
| Jazan                     | Riverside fields                        | Fruits      | 7.30     |
| Dhaka, Bangladesh         |                                        |             | 17.50    |
| Boumerdes, Algeria        | Irrigated with reclaimed water           | Fruits      | 89.39    |
|                           | Collected from market                    |             | 91.10    |
| Baia Mare, Romania        | Urban                                    | Fruits      | 1.3      |
|                           | Rural                                    |             | 2.1      |
| Liaoning Province, China  | Farmland near smelters                  | Fruits      | 0.822    |
| Bushehr, Iran             | Farms irrigated with Waste water         | Fruits      | 5.09     |
|                           | Ground water                             |             | 2.61     |
| Golestan Province, Iran   | Gonbad                                  | Fruits      | 0.85     |
|                           | Gorgan                                   |             | 1.7      |

**52. Solanum melongena (Brinjal)**

| Location                  | Cultivation Method                      | Product     | Quantity |
|---------------------------|-----------------------------------------|-------------|----------|
| Dhaka, Bangladesh         | Riverside fields                        | Fruits      | 17.04    |
|                           |                                        |             | 17.04    |
| Multan Pakistan           | Irrigated with Canal water              | Fruits      | 2.45     |
|                           | Waste water                             |             | 1.52     |
| Tabouk, Saudi Arabia      | Collected from farms                    | Roots       | 2.06     |
|                           |                                         |             | 2.06     |
| Riyadh, Saudi Arabia      |                                         | Roots       | 6.41     |
|                           |                                         |             | 6.41     |
| Damam, Jazan              |                                         | Roots       | 6.08     |
|                           |                                         |             | 6.08     |
| Boumerdes, Algeria        | Irrigated with reclaimed water           | Roots       | 84.17    |
|                           | Collected from market                    |             | 80.42    |
| Baia Mare, Romania        | Urban                                    | Roots       | 2.9      |
|                           | Rural                                    |             | 3.0      |
| Liaoning Province, China  | Farmland near smelters                  | Roots       | 1.405    |
| Bushehr, Iran             | Farms irrigated with Waste water         | Roots       | 4.06     |
|                           | Ground water                             |             | 3.11     |
| Puchuncavi, Chile         | Control area                             | Roots       | 10       |
|                           | Exposure area                            |             | 10       |

**53. Solanum tuberosum (Potatoes)**

| Location                  | Cultivation Method                      | Product     | Quantity |
|---------------------------|-----------------------------------------|-------------|----------|
| Jazan                     | Riverside fields                        | Fruits      | 10.00    |
| Multan, Pakistan          | Irrigated with Canal water              | Leaves      | 10.00    |
| Tabouk, Saudi Arabia      | Collected from farms                    | Leaves      | 7.82     |
|                           |                                         |             | 7.82     |
| Riyadh, Saudi Arabia      |                                         | Leaves      | 14.07    |
|                           |                                         |             | 14.07    |
| Damam, Jazan              |                                         | Leaves      | 11.38    |
|                           |                                         |             | 11.38    |
| Jazan                     |                                         | Leaves      | 10.00    |
|                           |                                         |             | 10.00    |

**54. Spinacia oleracea (Spinach)**

| Location                  | Cultivation Method                      | Product     | Quantity |
|---------------------------|-----------------------------------------|-------------|----------|
| Jazan                     | Riverside fields                        | Leaves      | 1.34     |
| Multan, Pakistan          | Irrigated with Canal water              | Leaves      | 1.13     |
|                           | Waste water                             |             | 1.13     |
|                           | Tube well water                         |             | 0.94     |
| Location                  | Type of Irrigation                        | Part of Plant | Concentration (ppm) |
|---------------------------|-------------------------------------------|---------------|---------------------|
| Liaoning Province, China  | Farmland near smelters                    | Leaves        | 0.695               |
| Bushehr, Iran             | Farms irrigated with wastewater           | Leaves        | 7.31                |
|                           | Farms irrigated with groundwater          |               | 3.16                |
| Sahiwal, Pakistan         | Irrigated with groundwater                | Leaves        | 0.02                |
|                           | Irrigated with wastewater                 |               | 0.87                |
| Machakos, Kenya           | Site I                                    | Leaves        | 4.79                |
|                           | Site II                                   |               | 14.5                |
|                           | Site III                                  |               | 3.07                |
| Rajasthan, India          | Irrigated with Wastewater                 | Leaves        | 18.2                |

*Trigonella foenum-graecum* (Fenugreek/Methi)
6. Regulatory Authorities

Metal industry associations and scientists worldwide, as well as regulatory bodies in Canada, Europe, and the United States, are examining the environmental risks of metals in soils and creating techniques to set protective soil recommendations and quality criteria. Regulations have been established in several countries and for various industrial settings to limit the emission of heavy metals. Food and Drug Administration (FDA), National Institute for Occupational Safety and Health (NIOSH), Occupational Safety and Health Administration (OSHA), Bureau of Indian Standards (BIS) and United States Environmental Protection Agency (EPA) are the organisations responsible for heavy metal regulation in food items. The FDA monitors, tests, and sets regulations for metals in foods to help ensure the safety of the food supply. (https://www.fda.gov/food/chemicals-metals-pesticides-food/metals-and-your-food). In BIS, toxic material (heavy metals) release limitations are applied to ceramic ware, vitreous enamelware, glassware, and glass-ceramic ware intended for food and beverage preparation, storage, cooking, or serving. US EPA is involved in the Ecological Soil Screening Level (ECO-SSL), which provides an overview of the contaminant (heavy metals) present in soil (https://www.epa.gov/chemical-research/ecological-soil-screening-level). OSHA and NIOSH are two government entities which are involved in the regulation of workplace safety.
References

[1] J. Huang et al., “A novel electrochemiluminescence aptasensor based on copper-gold bimetallic nanoparticles and its applications,” Biosens. Bioelectron., vol. 194, 2021, doi: 10.1016/j.bios.2021.113601.

[2] N. K. Singh et al., “Performance of CuO nanoparticles as an additive to the chemically modified Nicotiana Tabacum as a sustainable coolant-lubricant during turning EN19 steel,” Wear, vol. 486–487, 2021, doi: 10.1016/j.wear.2021.204057.

[3] U. Sarker and S. Oba, “Color attributes, betacyanin, and carotenoid profiles, bioactive components, and radical quenching capacity in selected Amaranthus gangeticus leafy vegetables,” Sci. Rep., vol. 11, no. 1, 2021, doi: 10.1038/s41598-021-91157-8.

[4] F. S. Tariq, “Heavy metals concentration in vegetables irrigated with municipal wastewater and their human daily intake in Erbil city,” Environ. Nanotechnology, Monit. Manag., vol. 16, 2021, doi: 10.1016/j.ennm.2021.100475.

[5] Y. Wu, X. Li, F. Tan, X. Zhou, J. Mu, and X. Zhao, “Lactobacillus fermentum CQPC07 attenuates obesity, inflammation and dyslipidemia by modulating the antioxidant capacity and lipid metabolism in high-fat diet induced obese mice,” J. Inflamm. (United Kingdom), vol. 18, no. 1, 2021, doi: 10.1186/s12950-021-00272-w.

[6] M. Černe et al., “Effect of sewage sludge derived compost or biochar amendment on the phytoaccumulation of potentially toxic elements and radionuclides by Chinese cabbage,” J. Environ. Manage., vol. 293, 2021, doi: 10.1016/j.jenvman.2021.112955.

[7] S. Rout, S. Yadav, and V. Pulhani, “Transfer of radionuclides from soil to selected tropical plants of Indian Subcontinent: A review,” J. Environ. Radioact., vol. 235–236, 2021, doi: 10.1016/j.jenrad.2021.106652.

[8] Z. Sheikh et al., “Potential application of Allium Cepa seeds as a novel biosorbent for efficient biosorption of heavy metals ions from aqueous solution,” Chemosphere, vol. 279, 2021, doi: 10.1016/j.chemosphere.2021.130545.

[9] S. Agarwal and I. I. I. Fulgoni V.L., “Intake of potatoes is associated with higher diet quality, and improved nutrient intake and adequacy among us adolescents: Nhanes 2001–2018 analysis,” Nutrients, vol. 13, no. 8, 2021, doi: 10.3390/nu13082614.

[10] S. Ranjbar, M. Kamarei, M. Khoshneviszadeh, H. Hosseinpoor, N. Eddie, and M. Khoshneviszadeh, “Benzylidene-6-hydroxy-3,4-dihydropthalonone chalconoids as potent tyrosinase inhibitors,” Res. Pharm. Sci., vol. 16, no. 4, pp. 425–435, 2021, doi: 10.4103/1735-5362.319580.

[11] Y. Wu, Z. Wang, L. Zhu, K. Xiao, Y. Yin, and W. Wang, “Preparation of Cu3(BTC)2/PVC mixed matrix membrane for pomegranate seed storage,” J. Food Process Eng., vol. 44, no. 8, 2021, doi: 10.1111/jfpe.13754.

[12] E. Lee, P. R. Rout, and J. Bae, “The applicability of anaerobically treated domestic wastewater as a nutrient medium in hydroponic lettuce cultivation: Nitrogen toxicity and health risk assessment,” Sci. Total Environ., vol. 780, 2021, doi: 10.1016/j.scitotenv.2021.146482.

[13] X. Liu, S. Gu, S. Yang, J. Deng, and J. Xu, “Heavy metals in soil-vegetable system around E-
waste site and the health risk assessment,” Sci. Total Environ., vol. 779, 2021, doi: 10.1016/j.scitotenv.2021.146438.

[14] F. Zhang, Z. Wei, and J. J. Wang, “Integrated application effects of biochar and plant residue on ammonia loss, heavy metal immobilization, and estrogen dissipation during the composting of poultry manure,” Waste Manag., vol. 131, pp. 117–125, 2021, doi: 10.1016/j.wasman.2021.05.037.

[15] C. Cao et al., “Coupling sprinkler freshwater irrigation with vegetable species selection as a sustainable approach for agricultural production in farmlands with a history of 50-year wastewater irrigation,” J. Hazard. Mater., vol. 414, 2021, doi: 10.1016/j.jhazmat.2021.125576.

[16] S. S. Dey, S. Rohith, N. Baruah, and S. K. Nayak, “Study of Heat Transfer Property of the Transformer Oils on Addition of CuO Nanoparticles,” in Proceedings of the IEEE International Conference on Properties and Applications of Dielectric Materials, 2021, vol. 2021-July, pp. 218–221, doi: 10.1109/ICPADM49635.2021.9493919.

[17] U. Singh and M. Rattan, “Design of linear and circular antenna arrays using cuckoo optimization algorithm,” Prog. Electromagn. Res. C, vol. 46, pp. 1–11, 2014, doi: 10.2528/PIERC13110902.

[18] A. T. Abbas et al., “Sustainability assessment associated with surface roughness and power consumption characteristics in nanofluid MQL-assisted turning of AISI 1045 steel,” Int. J. Adv. Manuf. Technol., vol. 105, no. 1–4, pp. 1311–1327, 2019, doi: 10.1007/s00170-019-04325-6.

[19] S. Aggarwal, A. Jindal, R. Chaudhary, A. Dua, G. S. Aujla, and N. Kumar, “EnergyChain: Enabling energy trading for smart homes using blockchains in smart grid ecosystem,” 2018, doi: 10.1145/3214701.3214704.

[20] D. D. Ramteke, A. Balakrishna, V. Kumar, and H. C. Swart, “Luminescence dynamics and investigation of Judd-Ofelt intensity parameters of Sm3+ ion containing glasses,” Opt. Mater. (Amst.), vol. 64, pp. 171–178, 2017, doi: 10.1016/j.optmat.2016.12.009.