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HEALTH RISKS FROM LETTUCE *(LACTUCA SATIVA)* FROM CONTAMINATED URBAN SOILS: A CRITICAL REVIEW OF METAL UPTAKE AND HUMAN EXPOSURE

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ABSTRACT

Urban agriculture is emerging as an effective approach toward food security, social equity and green space utilization. Urban soils are, however, often polluted with old and current pollutants, including heavy metals (lead, cadmium, arsenic, mercury) and organic pollutants (polycyclic aromatic hydrocarbons [PAHs]). Lettuce, (Lactuca sativa), is a particular health issue among the commonly grown vegetables due to its high transpiration rate, strong tendency to uptake the contaminants in its edible parts and being eaten raw. This review summarizes the most recent science available on the human health risks from eating lettuce that is cultivated in contaminated urban soils. The various components of the human health risk assessment (HHRA) framework for applying it to this pathway are examined systematically: contaminant sources in urban soils, bioavailability and soil-to-plant transfer mechanisms (quantified by

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bioconcentration factors and translocation factors), exposure assessment (including ingestion rates, body weight parameters), risk characterization (Hazard Quotient (HQ), Hazard Index (HI) and cancer risk (CR) models). Results from a synthesis of lead, cadmium and arsenic values in global HQ/CR case-study cities across North America, Europe, Asia and Africa suggest a high prevalence of exposures above safe limits (HI > 1; CR > 10-4), especially for children who have lower body weights and consume more per kg of body weight. Most importantly, risk outcomes are influenced by soil conditions (pH, organic matter), cultivar of lettuce, and post-harvest conditions (washing and cooking). The review reveals that there are important gaps in knowledge, such as the lack of standardized protocols that consider contaminant bio accessibility and mixture toxicity. We believe that there is an urgent need to develop urban specific soil guideline values and evidence-based mitigation strategies to protect public health based on current evidence.

Keywords: Urban soil contamination, lettuce (Lactuca sativa), heavy metals, health risk assessment, hazard index, bioconcentration

1.INTRODUCTION

1.1 Urbanization and Soil Pollution Sources

Urbanization has been a worldwide phenomenon, leading to environmental paradox: cities provide economic and social opportunities, but also to the accumulation of anthropogenic pollutants in soils previously used to grow food or used as natural ecosystems. The sources of contaminants to urban soils are numerous and are occurring continuously on long time scales[1]. Traffic emissions are one of the most common and persistent sources, which emit lead, cadmium, zinc and polycyclic aromatic hydrocarbons (PAHS) from gasoline and diesel combustion and zinc and organic additives from tyres and copper, antimony and barium from brake linings. Soil contamination in post-industrial cities around the world is a legacy of the past industrial activities. Lead, arsenic and cadmium have been spread over large areas around former non-ferrous metal processing facilities through smelting processes[2]. Heavy metals and organic solvents have been released over decades of operation from manufacturing plants, especially those dealing with batteries, electroplating, textiles dyeing and chemical synthesis, without proper environmental controls. In contrast to agricultural soils, which can be periodically tested and regulated by either the European Union's Good Agricultural Practice rules or the USEPA's soil screening levels, urban soils are largely not monitored. Furthermore, although evidence has been emerging that levels of soil contaminants in community gardens are increasingly above national screening limits for lead, cadmium and PAHs by two to ten times in many cases, this regulatory failure remains[3].

1.2 Popularity of Urban Gardening and Lettuce as a Model Crop

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Urban agriculture has seen a tremendous re-emergence around the world in contrast to the soil contamination issue in the 20th century. Empty lots, rooftops, and underused green spaces have been turned into productive food-growing spaces through community gardens, rooftop farms, school gardens, and backyard vegetable gardens. Such a shift is motivated by a convergence of desires, most of which are related to food security, access to fresh and nutritious foods, minimising food miles, fostering a sense of community, improving mental and physical well-being and environmental justice in neglected areas[4]. Leafy green vegetables have some special characteristics that make them particularly appealing as part of these urban crop systems: they grow quickly (4 to 8 weeks), yield a lot per acre, can be harvested continually, and are rich in vitamins A, C, K, folate and dietary fiber[5]. Lettuce *(Lactuca sativa)* has become the most popular world salad vegetable and a sentinel model plant for examining contaminant transfer in urban areas within the category of leafy greens. Consumption of lettuce is between 5 and 15 kg per person per year, and is higher in North America and Europe. It is popular for urban gardeners because it's easy to grow, works well in containers and raised beds, tolerates some shade and produces multiple crops from one plant[6]. Lettuce is a good model crop for research because of its short generation time, which allows for quick experiments; a well-studied genome and physiology; and protocols for quantifying levels of contamination in edible parts.

1.3 Why Lettuce is High-Risk for Contaminant Accumulation

Lettuce possesses several intrinsic biological characteristics that render it uniquely vulnerable to soil contamination compared to other common garden vegetables, thereby elevating its importance in human health risk assessment[4]. First, lettuce exhibits an exceptionally high transpiration rate, typically two to three times greater than that of fruiting vegetables such as tomatoes or peppers and substantially higher than that of root vegetables like carrots or potatoes. This high transpiration rate, driven by the large, thin leaf blades with abundant stomata, creates strong mass flow of soil water from roots to shoots. Because dissolved contaminants move passively with this transpirational stream, high transpiration directly enhances the uptake and accumulation of water-soluble metals including cadmium, nickel, and zinc. Second, the large leaf surface area of mature lettuce plants, often exceeding 200 square centimeters per leaf and up to 1,000 square centimeters total per plant, provides an extensive interface for atmospheric deposition and soil splash adherence[5]. Contaminants present in urban soils, particularly lead, chromium, and PAHs, become physically attached to leaf surfaces through irrigation-induced soil splash, wind-driven dust, and direct contact with contaminated soil during growth. This surface contamination can contribute 30 to 70 percent of total lead concentration in harvested lettuce,

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even when root uptake is minimal. Third, and most critically for risk assessment, lettuce is almost exclusively consumed raw.

1.4 Scope of the Review

Given the convergence of expanding urban agriculture, widespread soil contamination, and the inherent vulnerability of lettuce as a raw-consumed leafy green, a comprehensive synthesis of health risk assessment knowledge is urgently needed[7]. The present review systematically examines six interconnected domains essential for quantifying and mitigating human health risk from lettuce grown in contaminated urban soils[8]. First, we characterize the major contaminant classes found in urban garden soils, including heavy metals, organic pollutants, and emerging contaminants. Second, we describe the physicochemical mechanisms governing contaminant transfer from soil to lettuce, including bioavailability, root uptake pathways, translocation to leaves, and quantitative metrics such as bioconcentration and translocation factors. Third, we present the formal steps of human health risk assessment (HHRA) as applied to this pathway, including exposure quantification, hazard quotient and hazard index calculations for non-carcinogenic effects, and cancer risk estimation for carcinogenic contaminants. Fourth, we synthesize findings from global case studies documenting actual risk outcomes in cities across North America, Europe, Asia, and Africa, identifying patterns and thresholds of concern. Fifth, we evaluate evidence-based mitigation strategies ranging from soil remediation and agricultural practices to behavioral interventions that consumers can implement immediately. Finally, we identify critical knowledge gaps that limit current risk assessments and propose priorities for future research. Through this comprehensive synthesis, we aim to provide a scientifically solid foundation for risk assessors, urban planners, public health officials, and community gardeners facing decisions about urban food production on contaminated soils.

2. Contaminants of Concern in Urban Soils

Urban soils are complex environmental matrices that contain a wide range of contaminants in soil aggregates of decades of human use and activities. Urban soils are impacted by many and varied pollution sources, some of which may overlap, which may result in highly non-uniform pollution levels both horizontally and vertically, as compared to agricultural soils or natural soils which are subject to regulation and relative isolation from industrial sources[8]. Heavy metals, organic pollutants and emerging contaminants, such as microplastics, are the three main categories of contaminants of concern in urban garden systems[9]. The challenges of assessing risk vary somewhat for the different categories because of the different persistence of the contaminants in the environment, the different

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uptake mechanisms by plants, the different mechanisms for bioavailability in the environment, and the different toxicological endpoints[10].

2.1 Heavy Metals

Heavy metals are the most thoroughly investigated and always challenging contaminant group in urban garden soils globally. They are important for human health risk assessment due to their basic properties of environmental resistance, non-microbial and chemical degradation, bioaccumulation in food chains and well characterized human toxicity profiles. Lead (Pb), cadmium (Cd), arsenic (As), mercury (Hg), chromium (Cr), nickel (Ni), zinc (Zn) and copper (Cu) are the most studied metals because they are the most common and most toxic in urban areas[11].

Lead is probably one of the most ubiquitous and problematic urban soil contaminants. Lead accumulation on road-sides and surrounding soils in North America has been estimated to have reached 4 to 5 million tons of lead due to the consumption of leaded gasoline from 1920 to 1980, when tetraethyl lead was replaced[12]. Soils directly below older buildings with lead-based paint, especially around eaves and gutters, remain contaminated with lead from paint, and levels of lead may be high (e.g. > 5,000mg/kg) at the drip zone. Emissions from smelters, battery recycling plants and incinerators have established regional contamination plumes which can be kilometers from the source. Although the use of lead water pipes and plumbing is a drinking water problem, leaks and discharges from the past have caused lead to leach into the soils around them[13]. Lead is toxic to many organ systems and the neurodevelopmental effect in children is the critical endpoint of concern for toxicological risk assessment[14].

Cadmium is a unique hazard due to its high plant uptake ability in soils which often contain lower concentrations of Cd than lead[15]. Phosphate fertilizers that are mined from sedimentary rock deposits, which have naturally occurred cadmium impurities; industrial emissions from zinc smelting, nickel-cadmium battery production; and sewage sludge applications to gardens; and tire wear particles containing cadmium as a vulcanization activator are all major urban sources[13]. Cadmium has uptake pathways common with micronutrients, such as iron and zinc, thus entering plant roots via transport proteins that were designed for nutrient acquisition. Chronic cadmium exposure results in kidney tubular damage, bone demineralization and is known to be a human carcinogen[16].

Arsenic is found naturally in certain parent soils, but is found in higher concentrations in urban soils as a result of human activity. A significant historical legacy source is the use of pesticides, especially lead arsenate in apple orchards and other orchard and fruit production sites that were later repurposed for residential uses[17]. Arsenate (As V), the least mobile form, is the predominant form of

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arsenic in aerobic urban soils, and is still bioavailable via phosphate uptake pathways. Prolonged exposure to arsenic leads to skin lesions, cardiovascular disease and skin, bladder and lung cancer[18].

Sourced from coal combustion, municipal and medical waste incineration, historical chlor-alkali plants and broken thermometers or fluorescent bulbs, mercury in urban garden soils can come from a variety of sources[17]. Chromium poses a hazard that is dependent on its valence form, with trivalent chromium (Cr III) being relatively immobile, not particularly toxic, and even beneficial to glucose metabolism, while hexavalent chromium (Cr VI) is very mobile, highly toxic, and linked to industrial waste of tanning, electroplating, and pigment production[19]. The urban sources are the wear of tires (zinc), the wear of brake pads (copper), the use of galvanized roofing and fences (zinc), corrosion of plumbing (copper) and industrial emissions (nickel) [1].

2.2 Organic Pollutants

Beyond heavy metals, organic pollutants represent a significant but historically underappreciated contaminant class in urban soils, posing unique challenges for risk assessment due to their varied chemical properties, degradation pathways, and toxicological mechanisms. Polycyclic aromatic hydrocarbons (PAHs) are among the most prevalent organic contaminants in urban environments. These compounds, consisting of two or more fused aromatic rings, are formed exclusively through incomplete combustion of organic matter under oxygen-limited conditions[20]. Major urban sources include vehicle exhaust, with diesel engines producing higher PAH yields than gasoline engines; residential heating with wood, coal, or oil; industrial emissions from coke production, aluminum smelting, and tire manufacturing; and historical gasworks sites where coal was gasified for municipal lighting[21].

Polychlorinated biphenyls (PCBs) were widely used as dielectric fluids in electrical transformers and capacitors, hydraulic fluids, heat transfer fluids, and plasticizers until their production was banned in the United States in 1979 and in Europe in the 1980s under the Stockholm Convention on Persistent Organic Pollutants[22]. Sources in urban gardens include historical spills from electrical equipment, atmospheric deposition from municipal and medical waste incineration, weathering of building sealants and caulking compounds used between 1950 and 1980, and demolition debris from older industrial or commercial buildings. PCBs are classified as probable human carcinogens and also cause neurodevelopmental deficits and endocrine disruption[23].

Pesticides, both legacy organochlorines and contemporary compounds, are frequently detected in urban garden soils. Legacy organochlorines including DDT (dichlorodiphenyltrichloroethane), dieldrin, aldrin, chlordane, and heptachlor were widely used for agricultural and structural pest control

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from the 1940s through the 1970s before being banned or severely restricted. These compounds persist in soils for decades due to their chlorinated aromatic structures, with DDT degradation proceeding slowly to DDE, which is equally persistent and also estrogenic[23].

2.3 Emerging Contaminants

Among emerging contaminants, microplastics have garnered rapidly increasing research attention over the past decade as both direct toxicants and as vectors for other pollutants in urban soil systems. Microplastics are defined as plastic particles smaller than 5 millimeters in diameter, though particles in the micrometer and nanometer range are of greatest toxicological concern due to their potential for cellular uptake. Sources of microplastics in urban garden soils are diverse and widespread [24]. Industrial plastic pellets, known as nurdles, are lost during transportation and manufacturing. Tire wear particles, which are composed of synthetic rubber (styrene-butadiene rubber) and various plastic additives, are generated continuously during vehicle operation and are transported from roadways to adjacent soils via stormwater runoff and atmospheric deposition. Synthetic textile fibers are released from laundry wastewater when that water, treated or untreated, is used for garden irrigation through municipal reclaimed water systems or direct greywater use[25]. Municipal biosolids applied as soil amendments to gardens consistently contain microplastics that were captured during wastewater treatment, including fibers, fragments, and films. Once present in soil, microplastics can adsorb heavy metals and hydrophobic organic contaminants onto their surfaces, effectively concentrating these pollutants and potentially altering their bioavailability by creating localized hot spots [26]. Additives present in plastics, including phthalates, bisphenol A, and brominated flame retardants, can leach from microplastics in the soil environment and be taken up by plants, adding additional contaminant classes to the exposure assessment burden[27]. Table 1 is showing that Urban soils are commonly contaminated with the following pollutants, at the following concentrations (mg/kg dw) and with the following maximum limits for agricultural soils.

Table 1. Urban soils are commonly contaminated with the following pollutants, at the following concentrations (mg/kg dw) and with the following maximum limits for agricultural soils.

Contaminant	Source (e.g., traffic, paint)	Reported Range in Urban Soils (mg/kg dw)	Regulatory Limit (mg/kg dw)	Reference
Lead (Pb)	Traffic emissions, old paint, industrial activities	50 – 1000+	100 (EU), 400 (USEPA residential)	Alloway (2013); USEPA (2022)

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Contaminant	Source (e.g., traffic, paint)	Reported Range in Urban Soils (mg/kg dw)	Regulatory Limit (mg/kg dw)	Reference
Cadmium (Cd)	Fertilizers, industrial waste, batteries	0.5 – 10	1 – 3 (EU)	Kabata-Pendias (2011)
Zinc (Zn)	Tire wear, galvanized materials, traffic	100 – 2000	200 – 300 (EU)	Alloway (2013)
Copper (Cu)	Brake wear, pesticides, industrial sources	20 – 500	100 (EU)	Tóth et al. (2016)
Nickel (Ni)	Industrial emissions, fossil fuel combustion	10 – 200	30 – 75 (EU)	Kabata-Pendias (2011)
Chromium (Cr)	Industrial processes, waste disposal	20 – 300	100 (EU)	Tóth et al. (2016)
Arsenic (As)	Pesticides, treated wood, industrial pollution	5 – 100	20 (EU), 0.39 (USEPA screening)	USEPA (2022)
Mercury (Hg)	Coal combustion, industrial discharge	0.1 – 5	1 – 1.5 (EU)	Alloway (2013)

3. Transfer of contaminants from soil to lettuce

The mechanism by which urban soil contaminants enter the lettuce tissue is essential to the prediction of human exposure and estimation of health risk[28]. This transfer process is not a simple function of the total contaminant concentration in the soil, but a multi-stage process controlled by the physiochemistry of the soil, the plant physiological properties and the chemical behavior of the contaminant[7]. The movement of contaminants from soil particles into lettuce leaves is a three-step process: contaminant movement from soil solid phases to solution, absorption of dissolved contaminants from soil solution to lettuce roots, and translocations of contaminant from roots to aerial parts[12].

3.1 Bioavailability versus Total Concentration

The most critical concept in making accurate risk assessments is the difference between the total concentration of contaminant in soil and its bioavailable concentration[29]. Strong acid digestion which breaks up soil mineral structure and releases the contaminant mass from the soil always

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overestimates risk as only a fraction of soil-bound contaminants is available for root uptake[11]. This overestimation may vary from a factor of 2 to more than a hundred, depending on the contaminant and soil characteristics. The three major soil properties: pH, organic matter and cation exchange capacity, are interdependent and control the bioavailable fraction[30].

The pH of the soil has the most significant effect on heavy metal bioavailability. At pH levels below neutrality, hydrogen ions also bind to soils' organic matter and clay minerals, and simultaneously increase the solubility of metal hydroxide and carbonate minerals. The outcome is a logarithmic increase in levels of dissolved metals for each drop in pH[12]. The relationship is especially high for cadmium and zinc; pH decreases by 10 to 100-fold for every pH drop from 7.0 to 5.0. The pH relationship is the opposite for anionic contaminants like arsenate, where the bioavailability is higher at alkaline pH because the iron and aluminum oxides are desorbed[31].

Cation exchange capacity (CEC) is the total exchangeable cation (both nutrient and contaminant metals) held by the soil[32]. Those soils containing high amounts of clay and/or organic matter have a high CEC, which will bind more metal cations in exchangeable form that may contribute to increases in bioavailable metals[33]. However, high CEC also means that it is easier to retain it in the solid, and therefore less desorbable into the solution. The net effect will vary with concentrations of the various metals and competing cations. The CEC of soils from glacial till or loess deposits is usually moderate to high, compared to the very low CEC of sands from urban fill soils which have a much higher leaching potential and are likely to have lower metal retention[34].

3.2 Uptake Pathways: From Root Absorption to Leaf Accumulation

Contaminants that are in the soil solution in bioavailable forms must enter the plant vascular system by passing through the root epidermis and cortex. The apoplastic pathway is an unpressurised pathway that water and solutes move through the continuum of cell wall, comprising highly permeable cellulose, hemicellulose and pectin matrices[35]. In the apoplast, contaminants travel without entering into cells and so do not undergo metabolic regulation and selective transport. Pathway is especially significant for cadmium, nickel, and zinc, which are to a large extent present as hydrated cations with free movement in cell walls[36]. The apoplastic pathway is, however, blocked at the endodermis by the Casparian strip, a band of suberized cells with a lignin-like structure that closes the apoplast between endodermal cells. The Casparian strip requires the change of the pathway for contaminants to cross.

Membrane transport proteins (such as ion channels, carriers and ATP-powered pumps) are required for symplastic entry. Cadmium is transported via the iron and zinc transporters, arsenate via the phosphate transporters, and chromate via the sulfate transporters, which the contaminants

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exploit[37].The major water conducting tissue of the plant is the xylem composed of dead hollow tubes (vessel elements) that connect roots to shoots[38]. When water is lost from the leaf surfaces by transpiration, due to the solar energy, there is a negative pressure which forces the water and dissolved substances to rise through the xylem at speeds of 1 to 10 m/h[39]. Contaminants in lettuce leaves are stored mainly in vacuoles which are large membrane-bound compartments in the cells that take up most of the cell volume[35]. Some contaminants, especially lead and chromium, precipitate within the cell walls and/or interact with negatively charged pectin polymers, which restricts further movement.

3.3 Bioconcentration Factor and Translocation Factor

Two widely used metrics are used for quantitative assessment of contaminant transfer from soil to plants and these capture complex physiological processes as single numerical indices[40]. The Bioconcentration Factor (BCF) is the concentration of contaminant in harvested lettuce leaves (usually per dry weight of lettuce) divided by the concentration in soil (also per dry weight of soil). The BCF may be reported as total soil concentration or as a bioavailable concentration and the latter gives more mechanistic insight.[41] BCF values for cadmium in lettuce are normally between 0.5 and 5, which suggests moderate to high bioaccumulation. BCF values ranging from 1-3 are typical for zinc and nickel. BCF values tend to be < 0.1 for lead, meaning that a lot of the lead stays in the roots or is not deposited in leaves. This low BCF for lead is misleading, however, because lead can also be taken up from surface contamination of the plants with soil splash during harvest which is not included in a BCF calculation that only considers the uptake of lead from the root system[42].

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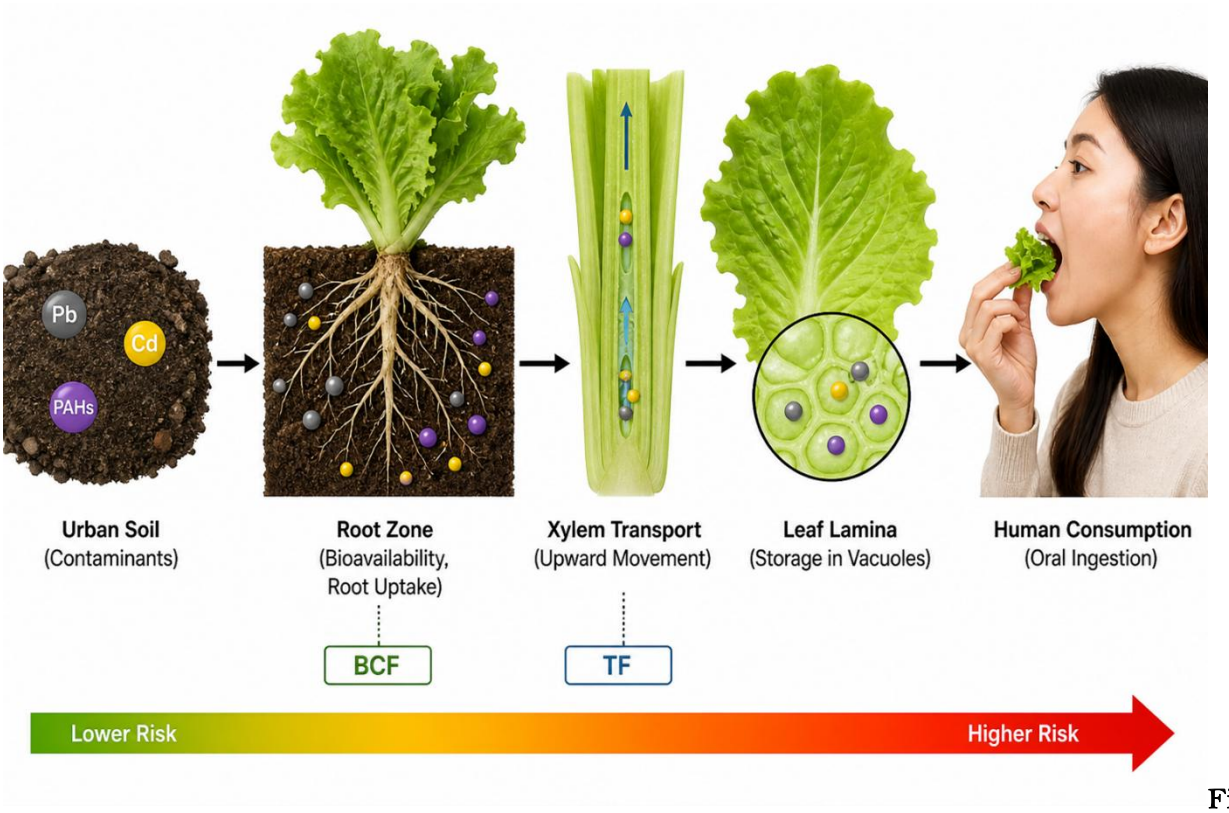


Figure.1 Contaminant transfer pathway from urban soil to lettuce and humans, including movement of contaminants from soil to root uptake, xylem transport, storage in leaf vacuoles, and human exposure via oral ingestion pathways, with BCF and TF indicators, and a gradient of increasing risk.

4. Human Exposure Assessment

The quantitative connection between the concentration of contaminant measured in lettuce and the estimation of health risk is the human exposure assessment. The reliability of all the subsequent risk characterization depends on the accuracy with which the exposure is measured[43]. For lettuce grown on contaminated urban soils, multiple potential pathways of contact need to be assessed, realistic consumption patterns (based on regional and demographic differences) need to be taken into account, and validated mathematical models need to be used to quantify daily exposure[44]. This assessment is based on the conceptual and mathematical basis of the United States Environmental Protection Agency (USEPA) framework, which is widely used throughout the world.

4.1 Exposure Pathways

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There are four different ways that individuals can be exposed to soil contaminants in urban soils, although the relative importance of these pathways varies widely. For most contaminants, the primary, and in most cases the only, route of concern for direct oral ingestion is via ingestion of lettuce leaves[45]. If the contaminated lettuce is eaten raw in salad, sandwiches, or as garnish, all the contaminants in leaf tissues and/or on the leaf surfaces are fed directly to the gastrointestinal tract where they can be absorbed into the systemic circulation[46]. Another pathway of exposure, which may be a significant pathway, is soil adherence to lettuce surface, especially in the case of poorly translocated contaminants. If these leaves are not properly washed, particles of soil are eaten in addition to the plants. Soil adhesion may account for 30 to 70 percent of the lead intake from unwashed lettuce from moderately contaminated soils, circumventing the exclusion mechanisms of the plant[47]. Soil adhesion is related to lettuce morphology; soil is more readily caught by open-headed lettuces than by compact-headed lettuces[48].

Dermal exposure is associated with the gardening-related activities when hands come into contact with contaminated soil and subsequently come in contact with the oral mucosa of lettuce that is eaten, or contaminated soil particles on the surface of lettuce come into contact with the oral mucosa[49]. But with most contaminants, dermal absorption efficiency is much less than gastrointestinal absorption, and the surface area of contact is restricted[50]. Dermal exposure is usually a minor route of exposure for metals and organic contaminants (less than 1% of total systemic dose), and is not routinely considered in risk assessments unless the dermal exposure is extended or the contaminant is highly permeable in the skin (e.g., organic solvents). While inhaling lead-contaminated dust may be a major route for exposed persons in contaminated indoor environments or in the vicinity of smelters, the amount of lead emitted from garden soil during typical activities is minimal and breathing is much less of a route of exposure in contaminated garden lettuce than swallowing[51]. Thus, the inhalation route is generally not included in the risk assessments of urban lettuce.

4.2 Lettuce Consumption Rates

Ingestion rates for lettuce are quite variable, depending on region, culture and demographics, and should be carefully selected when determining ingestion rates for risk assessment [52]. Ingestion rates may be as high as 80 to 150 grams per day, which represents one to two full lettuce servings, for those who grow their own lettuce and eat it regularly during the growing season[52].Lettuce consumption differs significantly among European countries, as reflected in per capita consumption. In

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Mediterranean countries, such as Italy, Greece and Spain, people eat salad regularly, with an average intake of 20-30 grams per day. Countries such as the Netherlands, Northern European countries (Germany) and Scandinavian countries have intermediate consumption rates of 10-20g/day. Average consumption is around 15 grams/day in the United Kingdom[44]. Lettuce is eaten raw in Asian salads and lightly cooked in Asian stir-fry and hot pot dishes, and may need to be cooked when exposure assessment is performed, further complicating exposure assessment. The average intake of lettuce in China is between 5-15g per day, with urban residents consuming more because they are more likely to have access to Western style salads and are more likely to be young consumers[53]. The consumption of lettuce in India is low with an average of 2 to 5 g per day outside the big cities of the country.

Children have a very unique exposure profile. Relative to their body weight, the consumption of lettuce among children is generally lower than that of adults[54]. In general, the daily consumption of lettuce among children aged 3-10 years is 5-10g per day. When dose is given on a per kilogram basis, however, the dose per kg is much higher in children due to their lower body weight. An 18 kg (5 years old) child eating 8 g of lettuce/day has an ingestion rate of 0.44 g/kg/day, while a 70 kg adult eating 15 g/day has an ingestion rate of 0.21 g/kg/day[55]. The ingestion rate for children is two times higher when calculated per unit body weight, plus children are more susceptible to many contaminants, especially the effects on the developing nervous system caused by lead, which could result in an underestimate of risk if the same ingestion rates are used for children as for adults[56].

Table 2. Parameters used in human health risk assessments with regard to lettuce consumption.

Parameter	Symbol	Typical Values (Adult / Child)	Units	Reference
Ingestion Rate	IR	0.2 / 0.1	kg/day	USEPA (2011); EFSA (2012)
Exposure Frequency	EF	350 / 350	days/year	USEPA (2011)

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Parameter	Symbol	Typical Values (Adult / Child)	Units	Reference
Body Weight	BW	70 / 15	kg	USEPA (2011); EFSA (2012)
Averaging Time	AT	25,550 / 5,475	days	USEPA (2011)

5. Health Risk Characterization

The final stage of the human health risk assessment process is health risk characterization, which combines estimates of human exposure with toxicity data on the contaminant to make quantitative statements about the likelihood and magnitude of adverse human health effects[56]. This step translates analytical chemistry information and exposure modelling results to public health information. Risk characterization should be done against two different toxicological endpoints, namely non-carcinogenic effects that are likely to result from high dose exposure for shorter periods, where the effect is likely to be threshold and carcinogenic effects that are likely to result from low dose exposure for longer periods, and are generally modelled without a threshold[57].

5.1 Non-Carcinogenic Risk

Non-carcinogenic risk assessment is based on the assumption that there is a threshold dose, which is a dose below which adverse health effects are unlikely to occur[58]. Toxicological studies in animals or epidemiological studies in humans provide a No Observed Adverse Effect Level (NOAEL) or a Lowest Observed Adverse Effect Level (LOAEL) for each contaminant and these are divided by uncertainty factors to obtain an oral Reference Dose (RfD)[59]. The RfD is the amount of contaminant that is likely to cause no significant harm over a lifetime of exposure, and is expressed in milligrams of contaminant per kg body weight per day. The USEPA has an integrated risk information system (IRIS) that contains RfD values for priority contaminants and the European Food Safety Authority (EFSA) has similar tolerable daily intake (TDI) values[60].

Multiple contaminants are commonly found in contaminated urban soils and in the plants that are cultivated in them, and each Hazard Quotient should be added together to create a summary metric to reflect the cumulative risk of mixtures[61]. The Hazard Index (HI) is the total of the individual Hazard Quotients for each contaminant that shares the same target organ or if it is the same adverse effect, then the same target organ, for example: $HI = \Sigma HQ$[62]. The target organ for most heavy

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metals for lettuce consumptions are the kidney (cadmium, lead, mercury) or developing nervous system (cadmium, lead, mercury). The HI method makes the assumption that dose additivity, which assumes that contaminants act independently in a way that their effects combine. This assumption is conservative and may overestimate risk for contaminants with other modes of action but may underestimate risk for contaminants with synergistic modes of action[63].

5.2 Carcinogenic Risk

Carcinogenic risk assessment is a different approach than non-carcinogenic risk assessment because it is based on the premise that cancer does not have a threshold dose[64]. The rationale behind this assumption is that a single molecule of a genotoxic form of cancer-causing agent has some chance of causing a mutation that starts the process of carcinogenesis, although this chance is very low[65]. The Cancer Risk (CR) is found by multiplying the Average Daily Dose (ADD) by the Cancer Slope Factor (CSF): CR = ADD × CSF. This results in a dimensionless (and usually scientific notation) probability number that is an estimate of the incremental lifetime cancer risk due to the exposure. So if a CR is 1×10^{-6}, it means that, on average, one in a million people will develop cancer as a result of that exposure over their lifetime[13]. The USEPA and most foreign regulatory agencies consider an acceptable risk range of 1×10^{-6} (one in one million) to 1×10^{-4} (one in ten thousand). The risks when less than 1×10^{-6} are usually negligible and not subject to regulation. Carcinogenic risks for lettuce grown in urban soils usually target the presence of arsenic, a known human carcinogen that causes skin, bladder and lung cancers; lead, a probable human carcinogen; some PAHs, especially benzo[a]pyrene; and PCBs[66]. If the mixture contains more than one carcinogen, the total cancer risk is added together assuming additive effects. There is a lot of uncertainty, however, in these calculations, since the CSF values are based on high dose occupational or animal studies and are being linearly extrapolated to the low doses typical of diet[67].

5.3 Target Hazard Quotient for Metals

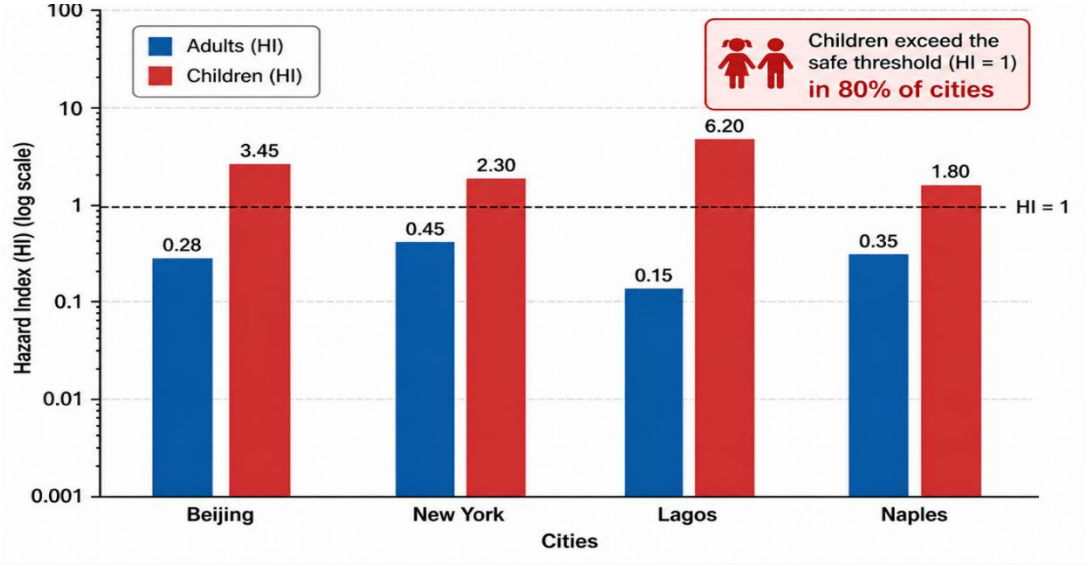
A variant of the Hazard Quotient, called the Target Hazard Quotient (THQ), has been extensively used in the food safety and environmental health literature, especially to estimate heavy metal exposure through food[68]. The THQ is exactly the same as the HQ, except that it is calculated by dividing the ADD by the oral reference dose The THQ can be used to facilitate comparative assessments at the metal level and the food level since both the exposure and toxicity parameters have been standardized[69]. The sum of the THQ for several metals is the same as the Hazard Index. The terminology used by THQ has continued to be used in the peer-reviewed literature on urban agriculture and vegetable

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contamination and it is important to point out that THQ and HQ are synonymous and mean the same underlying calculation and interpretation[42].

Lettuce consumption in contaminated urban soil (Hazard Index, HI)

Lettuce consumption in contaminated urban soil (Hazard Index, HI)



5.4 Summary of Global Studies

Extensive and expanding peer-reviewed research has been conducted in urban gardens throughout the world in a wide range of geographic, climatic, and socioeconomic environments using the HHRA framework[70]. Studies in community gardens in New York City, Baltimore and Minneapolis in the United States have found opposing risk profiles[71]. Current levels of lead in garden soil are from 100 to 1,200 mg/kg, and Hazard Quotients for children who eat unwashed lettuce are often greater than 1. Hazard Index values for other metals found in garden soil range from 1.2 to 2.8. Hazard Index values in the range 1.1–1.9 have been reported for children in Baltimore, where soil lead levels tend to be lower and cadmium more common than in other areas[72]. Studies conducted in Minneapolis, with younger soils and less contamination because of a different industrial past, have found consistently low Hazard Index values for adults and somewhat higher values (just above 1), under worst case assumptions, for children[7].

Lettuce cultivated in garden soils in Naples near main roadways had lead Hazard Quotients of 1.8 for adults and 4.2 for children, along with other hazards from cadmium and zinc. Hazard quotients

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(HQs) are calculated for children in Veles, North Macedonia in the vicinity of a former zinc smelter, and reached 6.5, a six-fold over the daily allowable intake[73].

Lettuce planted in gardens around e-waste recycling facilities in Lagos had lead concentrations up to 8.2 mg/kg fresh weight and lead Hazard Quotients that were above 10 for children, and total Hazard Index values that were more than 15[74]. The increase in cancer risk at the same gardens due to exposure to arsenic and PAHs was more than 5×10^{-4} which is five times the upper bound of the acceptable range[75]. Cadmium and lead levels in urban lettuce were higher in Nairobi, ranging from 3 to 8 Hazard Index values, with higher values being correlated with gardens irrigated using untreated wastewater[76].

6. Factors that affect the variation of risk

Health risk estimates based on the HHRA framework are not fixed or absolute, but rather, vary significantly from one urban garden to another, across growing practices and even between individual plants in the same garden[77]. It is important to know the sources of this variability in order to be able to move beyond general risk assessments to recommendations that are specific to the site and can be acted upon[78]. Soil physicochemical properties, cultivar choice by lettuce, and combined effects of multiple contaminants, and post-harvest management practices are factors that have a pronounced effect on the final risk outcome. There are risk mitigation opportunities in each of these categories, but there are also uncertainties to be recognised in any risk characterization for each of these categories[79].

6.1 Soil Properties

The soil physicochemical properties are the most important variables to determine the bioavailability of the contaminants and are therefore the greatest influence on the magnitude of human health risk due to lettuce consumption[73]. Of these properties, soil pH is the most significant factor affecting uptake of heavy metals. With decreasing soil pH below neutral, the number of sites on soil organic matter and clay minerals available for binding of metal cations is reduced, in addition to the dissolution of metal hydroxide and carbonate minerals which are insoluble at higher pH[80]. The uptake of metals is an exponential relationship with the pH. The reducing of soil pH from 7.0 to 6.0 will approximately double soluble cadmium and zinc concentrations, and reducing pH from 7.0 to 5.0 will increase soluble concentrations by 10 to 30 times[81]. This effect is less dramatic, but still significant, for lead; the decrease in pH causes the solubility of lead to increase by about 5 times. Thus, total concentration of lead in the soil may be the same in two gardens (400 mg/kg) but the lead concentration in the lettuce may be orders of magnitude different due to soil pH: at pH 7.5, the lead concentration in the lettuce can

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be as low as 0.5 mg/kg, while at pH 6.0, the same soil can contain more than 2.0 mg/kg of lead in the lettuce, which is well over the food safety standard[82].

The total capacity of a soil to hold exchangeable cations is known as cation exchange capacity (CEC) and is affected mainly by the amount of clay and organic matter present. Soils with high CEC values (glacial till or loess deposits) have greater amounts of metal cations in an exchangeable state but have lower desorption rates[83]. The net uptake by plants is dependent on the concentration of other competing cations in soil solution and the type of metal. High CEC soils generally have lower plant uptake for cadmium, because it is not very well bound by the exchange sites. Lead uptake is significantly lower with high CEC. The effect of CEC is less pronounced in the case of essential nutrients (Zn and Cu) where the uptake systems are active[84].

6.2 Lettuce Cultivar

The differences in the levels of contaminants found in lettuce cultivars are significant and have been largely ignored, which could provide an effective risk management technique when dealing with soil that does not need to be remediated. Growth of several lettuce varieties in the same contaminated soil has been compared and have shown up to three-fold or more variation in the amounts of lead and cadmium that can be found in the plants; patterns have been consistent across studies[85]. There are varieties of red-leaf lettuce, such as Lollo rosso and Red Salad Bowl, that tend to have more cadmium and lead than green-leaf lettuces that are grown in similar environments. This difference seems to be related to anthocyanin pigments that are formed due to oxidative stress and can chelate metals in leaf tissues or regulate transpiration[86]. A causal link, however, is far from clear and not all red-leaf varieties are superior accumulators for all contaminants.

Butterhead lettuce has a loose, soft head with closed rosette leaves, and has been found to have lower levels of lead in it compared to open-leaf varieties like Loose-leaf and Oak-leaf types[87]. This differential is mainly due to less soil splash on the interior leaves, which are protected from the soil by outer leaves. The head structure is less effective in insulating against cadmium, which is absorbed mainly via the roots and moves within the plant, and butterhead varieties are likely to take up cadmium as much as open-leaf varieties are. The relatively high cadmium accumulation in romaine lettuce (high transpiration rate) is intermediate lead accumulation, which is moderately high[88]. Iceberg lettuce is the least contaminated of common lettuces due to its small, dense head but at the same time it is the least nutritious. A low cost and readily available method of hazard reduction for the urban gardener is cultivar selection, which can lower the Hazard Quotient by two to three, and without changing anything with soil management or post-harvest methods[89].

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6.3 Post-Harvest Handling

Post harvest handling practices represent the most immediate and accessible opportunity for consumers to minimise their exposure to contaminants in urban-grown lettuce as the intervention is after the lettuce has left the garden, and before it is placed in the mouth[90]. Simple and widely practised intervention is washing. The use of tap water for washing for 30-60 seconds, coupled with gently rubbing the surface of the leaves, removes 20-40% of total lead contamination from lettuce leaves. This is primarily through the removal of soil particles, especially those attached to leaf surfaces, leading to greater effectiveness in the case of lead (which is mostly surface-bound) compared to cadmium (which is mostly internalized). Washing with warm water is as effective as washing with cold water, but washing with a dilute acid solution (such as 0.5% vinegar, acetic acid or 1% citric acid) can remove 50 to 65% of the lead by dissolving metal-containing soil particles and desorbing metals from leaf surfaces. Acid washing, however, doesn't work as well for cadmium and can lead to some wilting and/or quality loss[91].

Lettuce is not a typical food for cooking, but in some cuisines where lettuce is lightly cooked in stir-fry, soups, or braised dishes, the amounts of contaminants are changed in complex manners. Lettuce was found to leach 20 to 35 percent of the cadmium into the cooking water during a 5 to 10 minute boil, after which the cooking water is discarded[92]. But boiling virtually does nothing for lead as it is mostly surface bound and very tenaciously held on to leaf surfaces even when boiled. Cooking could also have no effect on the concentration of hydrophobic organic contaminants, or even cause them to become higher, since loss of water would increase concentrations on a fresh weight basis. Steaming (non contact with a large volume of water) only achieves a reduction of 10-15% of cadmium. However, not all contaminants are reduced by cooking, so cooking isn't a safe and effective risk-reduction measure for lettuce, and preference for raw consumption is the primary risk factor[93].

6.4 Co-Contamination Effects

In practice, urban soils are not contaminated with just one contaminant, but are also composed of numerous contaminants, including heavy metals, organic contaminants, and emerging contaminants and each of these contaminants interact both with each other and with the soil matrix. Co-contamination effects can result in synergistic toxicity (combined effect is greater than the sum of individual effects) or antagonistic toxicity (interference between contaminants in toxicity or bioavailability)[94]. Laboratory and field studies have provided evidence of synergistic toxicity of heavy metals and PAHs. The simultaneous presence of Cd and benzo[a]pyrene (BaP) in urban soil near traffic corridors results in more than additive genotoxic interactions in animal models and human cell lines[95]. The proposed

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mechanism is that the cadmium blocks the DNA repair enzymes which results in the inability of the cell to repair the DNA damage from benzo[a]pyrene metabolites.. If lettuce consumers eat a garden with soil that has 200 mg kg-1 of lead in it and the same garden has 5 mg kg-1 of benzo[a]pyrene in the soil, then the amount of risk that the individual components of the two represent may not add up to the same level of total risk[96]

Table 3. Bioconcentration factors (BCF) for some selected contaminants in various lettuce cultivars cultivated in urban soils.

Contaminant	Butterhead (BCF)	Romaine (BCF)	Leaf Lettuce (BCF)	Reference
Lead (Pb)	0.01 – 0.10	0.01 – 0.08	0.02 – 0.12	Cui et al. (2004); Intawongse & Dean (2006)
Cadmium (Cd)	0.20 – 1.50	0.15 – 1.20	0.30 – 1.80	Peris et al. (2007); Alexander et al. (2006)
Zinc (Zn)	0.50 – 3.00	0.40 – 2.50	0.60 – 3.50	Broadley et al. (2007)
Benzo[a]pyrene (PAH)	0.001 – 0.01	0.001 – 0.008	0.002 – 0.015	Wild et al. (2005); Tao et al. (2009)

7. Risk Mitigation Strategies

This was a consistent result for lettuce crops grown in contaminated urban soils that showed higher Hazard Index and Cancer Risk levels, which highlights the need for the development and implementation of effective risk mitigation measures. These strategies are available on a continuum, from permanent high cost interventions that are directed to the source of the contamination, to low cost, easily implemented behavioral interventions that decrease direct exposure to the soil but do not change the soil contamination[7]. There is no one best approach; rather, the best choice will vary by the type of contaminants, the concentration of contaminants, the scale of the garden, resources available, and risk-tolerance of the gardeners. Generally a multifaceted risk management strategy is a mix of various strategies at different levels, ranging from soil remediation to individual consumer behavior[97].

7.1 Soil Remediation

Strategies for soil remediation focus on the source of the contamination and attempt to lower the concentration or bioavailability of the contaminants in the soil matrix. These strategies can take a long

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time, money, or labor to implement, but provide lasting or long-term risk reduction[98]. Phytoremediation is most suitable for gardens containing low to moderate levels of contamination (50 to 200 mg/kg lead, 1 to 3 mg/kg cadmium) and where gardeners do not want vegetables to be produced for several years.Soil replacement involves excavating and removing contaminated soil and importing clean topsoil from certified sources. It means that the entire replaced volume is instantly and permanently risk-free, but can be difficult and costly to implement. For small individual home gardens, however, the possibility of replacement of the soil in a raised bed or in a separate planting site may be economically viable[99].

Raised beds made from clean soil and a physical separation from the contaminated soil below have become the most practical and cost effective remediation solution for gardeners in the city[100]. A raised bed made of untreated wood, concrete blocks or recycled plastic materials, at least 30 centimeters high, is filled with imported clean soil, and separated from contaminated soil below by a permeable geotextile fabric or a impermeable liner. The physical barrier will stop roots from entering the contaminated soil and stop soil splash getting on the contaminated surface[101]. The comparison of contaminant levels in lettuce that have been grown in raised beds with those that have been grown in the adjacent in-ground field has documented reductions of 85-95 percent for lead and 70-90 percent for cadmium. The clean soil offers the added benefit of providing a clean rooting medium and a clean surface that will not lead to leaf contamination from splash[102].

7.2 Agricultural Practices

Soil management techniques change the soil environment to limit the bioavailability of contaminants without removing or replacing the contaminated soil matrix. The application of liming (calcium carbonate or other alkaline materials to increase soil pH levels) is one of the best agricultural practices to reduce the uptake of heavy metals. Field studies have shown that a rise of soil pH from 6.0 to 7.0 will lead to a 40 to 60 percent decrease in cadmium uptake by lettuce leaves, and a 50 percent decrease in cadmium solubility[103]. Only cadmium, zinc and nickel will be affected by liming most effectively; the effects of liming on lead are also not consistent due to the presence of other factors which affect the solubility of lead. The amount of lime needed depends on the soil's initial pH and buffering capacity, and is typically 1-5 tons/ha or 0.1-0.5 kg/m2 for garden-size applications[104].

Clean mulching with organic material is performed by using clean mulch (straw, wood chips, shredded leaves, etc.) which helps minimize soil splash on lettuce leaves by providing a physical barrier between soil surface and lower leaf of the plant[105]. Apply a mulch layer 5-10cm thick, which will reduce lead contamination from soil adhesion by 30-50%, but will not affect the uptake of cadmium or

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other internalized contaminants. Other advantages of mulching are that it helps retain moisture and suppresses weeds, as well as adding organic matter to the soil as the mulch breaks down[106]. The main drawback is the need to replace mulch each year, and, in some cases, having to take the mulch out between years and replace it to reduce the amount of decomposing material that may contain pests.

7.3 Behavioral Interventions

Behavioral interventions involve the consumer in the risk-reduction process, do not require new soil management practices, and do not involve new gardening practices. These strategies are low cost, readily available and effective, but are individual responsibility rather than problem solving. Commercial produce washes are not more effective than dilute vinegar solutions, and are far more costly. Washing should be done carefully to avoid bruising the leaves and thus affecting storage quality.It is important to note that the root-shoot junction is the location of the highest tissue concentrations of lead and removing this area by pruning removes lead from the lettuce[107]. Lead is poorly translocated from roots to shoots, and accumulates at the base of the stem (2 to 5 times more than leaf blade concentrations). The bottom 1 to 2 cm of the stem will contain 5 to 15 percent less lead, depending on how much lead is in the soil and how much of the surface soil is attached to the stem. Being easy and inexpensive, this practice is neglected by consumers who remove only visibly damaged or discolored tissue.

7.4 Regulatory Benchmarks

One of the existing gaps in the risk assessment and mitigation strategy is the lack of regulation benchmarks specifically developed for urban agricultural soils.

Residential soil screening levels were established for children's hand-to-mouth exposure to soil, but are not applicable to the consumption of vegetables that may be exposed to soil[108]. The 400 mg/kg concentration may be acceptable for a residential yard with a grass cover and infrequent soil ingestion, but it is not acceptable for a residential yard where lettuce is grown and eaten daily. On the other hand, industrial soil limits, such as 1000 – 2000 mg/kg for lead in non-residential situation, are totally unsuitable for any food production situation. Lacking urban-specific soil guideline values, decisions for risk management vary from community to community, with some communities adopting a conservative approach to banning gardening and others allowing gardening on soils that result in Hazard Index values in excess of 10 under strict risk assessment for children[109].Consensus must be achieved on the following key exposure parameters: soil ingestion rates for frequent soil consumers, suitable body weights for vulnerable groups, acceptable risk levels (HI = 1 versus HI = 0.5 or 0.2 for children) and the amount of soil adhesion to be assumed if there is no mitigation measures. A number of jurisdictions

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have started to work on the establishment of such guidelines. There is, however, no generally agreed upon urban garden soil standards and standards yet need to be developed for evidence-based risk management[110].

8. Knowledge Gaps and Future Research Directions

8.1 Lack of Longitudinal Risk Studies

The most recent risk assessments concerning lettuce consumption are virtually all cross sectional studies, that is, they measure contaminant concentrations in soil and in lettuce at one time, and apply simple exposure equations to make inferences about lifetime exposure. This does not reflect the temporal variation of soil contamination and human consumption[111]. Lettuce contaminant concentrations fluctuate seasonally as a result of changes in soil moisture, soil temperature and transpiration rates. People's eating habits also vary from year to year, and some people garden more intensively in some years than others. No study has followed a similar group of people consuming lettuce in urban areas for several years or decades, used actual consumption data obtained through duplicate diet studies, and correlated consumption with measures of exposure, such as blood lead, urinary cadmium or PAH metabolites[112]. Future studies should focus on prospective cohort studies of gardeners from low-income urban areas recruited at the time of starting a new garden plot, and measure soil contamination, lettuce contamination, actual consumption (using food diaries) and biological monitoring for at least 5 to 10 years. These studies would also represent chronic low dose exposure effects that could not be effectively predicted from acute and subchronic toxicology studies.

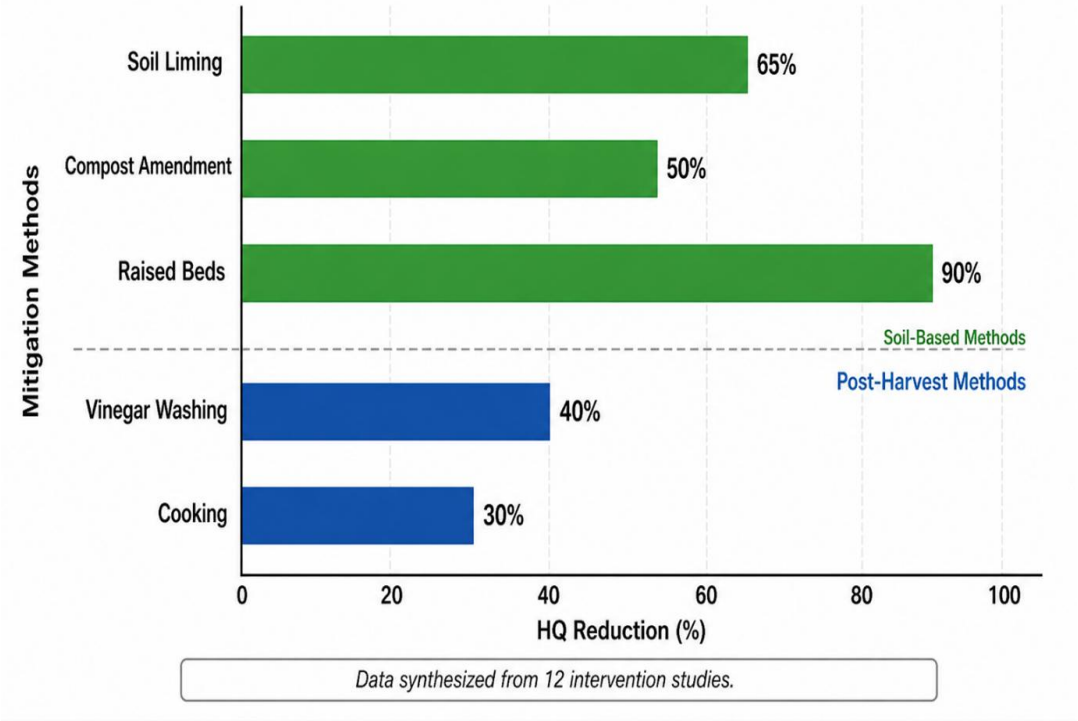
The effectiveness of various mitigations for human health risk reduction (HQ Reduction Percentage)

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8.2Mixture Toxicity

The most scientific question that remains is whether there are validated risk assessment models for mixtures of contaminants. The heavy metal, the PAH and the PCBs and the emerging contaminants in urban soils are generally present in dozens together and yet, almost all of the regulatory guideline values and nearly all published risk assessments consider each contaminant separately and add individual Hazard Quotients to account for dose additivity[113]. Few models exist to evaluate mixture toxicity, and those that exist are developed for mixtures of contaminants with different modes of action that are found at levels different from those found in urban garden soils, where evidence of synergistic neurodevelopmental toxicity between lead and PAH, nephrotoxicity between cadmium and lead, and genotoxicity between cadmium and benzo[a]pyrene has been established in vitro and in animal studies[114]. In addition, the Hazard Index approach also makes the assumption that all contaminants have the same target organ or have the same type of effect. Also, the assumption used in the Hazard Index approach is that all contaminants cause the same type of effect or affect the same target organ, which may not be true[96]. Development of mixture toxicity models should be a priority using

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experimental designs with realistic urban soil contaminant profiles and testing for deviations from additivity over a range of total mixture concentrations.

8.3 Bioaccessibility versus Bioavailability

All current risk assessments make the simplifying assumption that 100 percent of the contaminant ingested by lettuce is absorbed from the gut into the systemic circulation. Bioaccessibility is the proportion of a contaminant that leach from the food matrix into digestive fluids during simulated intestinal passage in an in vitro digestion model like the Unified BARGE Method (UBM) or the Physiologically Based Extraction Test (PBET)[55]. Bioaccessibility levels (in vitro) for lettuce are generally between 30 and 70 percent, depending on soil particle size and composition of the digestive fluid. The bioaccessibility for cadmium varies between 50 and 90 per cent. Bio accessibility of PAHs is very variable and influenced by the fat content of the meal eaten at the same time[115]. The correlation between in vitro bioaccessibility and in vivo bioavailability is, however, inadequate, and there are no standardized bioaccessibility procedures that have been used for food regulatory risk assessment of vegetables in urban gardens for the range of contaminants present in these food matrices[116]. Further research is needed to further validate in vitro digestion models with animal feeding trials, with the ultimate goal of testing these models in human volunteer trials with stable isotope tracers. The development of simple and cost-effective bioaccessibility screening procedures that can be routinely used in risk assessment laboratories is also a priority.

8.4 Socio-Economic Dimensions

The risk of lettuce from urban agriculture is not evenly distributed among populations, but is systematically disproportionated toward low-income and communities of color. There are several mechanisms to this environmental injustice[117]. Historical industrial sites, waste disposal sites and major roadways are more likely to be found in proximity to low income urban areas than in other areas and the background contamination of soils is higher. These communities also have fewer supermarkets and less access to fresh produce, with home-grown lettuce becoming a more vital source of nutrition and food security[118]. Low-income residents might not have the money to do raised beds or soil replacement, and might not be able to get information on soil risk reduction practices like discarding outer leaves or vinegar washing. Although these socio-economic aspects are important, few published risk assessments have explicitly included these in their analysis[119]. Future studies should utilize community engaged approaches for measuring the risk in vulnerable communities, create culturally and linguistically responsive risk communication tools, and examine the effectiveness of low-cost mitigation strategies in community garden environments. Cost-effectiveness of subsidy for raised bed construction

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or replacement of soil in low-income neighbourhoods versus health care costs of uncontrolled exposure should be explored[120]. Risk assessment and risk management can be ineffective or unintentionally work in favour of the privileged population while failing to offer protection to the most vulnerable groups.

Table 4. Summary of existing human health risk assessment models for lettuce consumption and their limitations.

Model	Target Contaminants	Output (HQ, CR)	Limitations	Reference
USEPA Human Health Risk Assessment Model	Heavy metals (Pb, Cd, As), organic pollutants (PAHs)	HQ (Hazard Quotient), CR (Cancer Risk)	Assumes 100% oral bioavailability; limited consideration of contaminant mixtures; default exposure factors may not reflect local diets	USEPA (2011, 2022)
EFSA Dietary Risk Assessment Model	Heavy metals, pesticides, food contaminants	HQ (or Margin of Exposure), CR (for carcinogens)	Relies on standardized consumption data; limited site-specific soil–plant transfer; mixture toxicity often not addressed	EFSA (2012, 2019)
Chinese HJ 25.3 (Technical Guidelines for Risk Assessment of Contaminated Sites)	Heavy metals (Pb, Cd, Hg, As), some organics	HQ, CR	Assumes fixed exposure parameters; limited crop-specific uptake variability; bioavailability corrections often simplified	Ministry of Ecology and Environment of China (2014)

9. Conclusion

The findings presented in this review are clear: lettuce grown in polluted urban soils is a clear threat to human health in a variety of geographies and socio-economic situations. Most individual published studies report non-carcinogenic risk levels (Hazard Quotients and Hazard Indices) that are consistently above the safe threshold of 1, especially for children, who have a lower body weight, higher relative exposure to food and a greater susceptibility to exposure to neurotoxicants like lead. Although the concentrations of arsenic, lead, and PAHs in urban-grown lettuce often exceed the lower bound of the

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acceptable range of $(1 \times 10\text{-}6)$ to $(1 \times 10\text{-}4)$, these levels are not necessarily incompatible with chronic exposure over decades and a cancer risk is possible. The results of this study are not limited to one city or region but have been reported in cities all over North America, Europe, Asia, and Africa, indicating that urban soil contamination is a worldwide problem that needs international attention.

Most importantly, but, risk is not inevitability. The same evidence base that indicates higher risks also shows that risk is significantly modifiable via interventions at a number of levels. Raised beds using clean soil will lower contaminant levels in lettuce by $85 - 95$ percent and eliminate risk for most urban gardens. Practice such as liming to increase soil pH and adding composts to bind metals to the soil can lower the risk by 40-60% at little to no cost. Cultivar selection alone, as romaine and butterhead varieties have lower levels of lead than red and loose-leaf varieties, can reduce risk by 2-3-fold, for no change in soil management practices. Immediate exposure is cut 30-50% due to post harvest treatments such as washing in dilute vinegar solution and discarding outer leaves. None of one intervention is ideal in all situations, but a combination of multiple interventions at different levels can decrease overall risk by over 95 percent and change a hazardous garden into a safe garden.

This review has also highlighted key current shortfalls in the practice of risk assessment that need to be overcome to ensure that meaningful and fair advice is given. Standardized HHRA procedures for urban lettuce should go beyond the total concentration of soil, and consider the bioavailable concentration, which should account for soil properties and digestion effects on soil contaminant release. The presence of co-contaminants in mixtures (which is more common in urban soils than not) requires models to account for possible synergy effects other than simple dose-additivity. Bioaccessibility factors validated using in vitro digestion models that have been correlated to in vivo bioavailability studies should be taken into account to prevent systematic overestimation of risk. Urban-specific guideline values should be established in a consensus process that incorporates exposure parameters that are representative of urban gardeners, such as realistic ingestion rates for lettuce by frequent consumers, healthy body weight for children, and explicit recognition of the pathway via which soil is ingested for contaminants that are poorly translocated like lead.

There are clear and actionable policy implications from this review. Community gardens, especially new ones and the addition of space to existing gardens, should be required to be planted on vacant land within the city that has been subject to soil testing. At a minimum, tests should be analysed for lead, cadmium, arsenic and PAHs and then compared to urban-specific screening levels, not to generic agricultural or industrial levels. Gardens with contaminant levels above these screening limits may benefit from a three-tiered approach: low exceedances can be addressed by ag practices and

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behaviors; moderate exceedances can be addressed through raised beds or replacing soil in vegetable gardens; severe exceedances, especially those that exceed 1,000 mg/kg lead or 10 mg/kg cadmium, should warrant that no vegetable production will occur in that garden or that only fruit crops (such as tomatoes and peppers) will be grown, as these crops accumulate lower concentrations of contaminants. The public budget should be used to provide financial support to soil test and remediation in low-income communities where it is most needed and has the greatest scarcity of resources. In the end, urban agriculture is a concept that provides many benefits for communities, and the trends in urban agriculture must be realized without compromising public health. However, this can be reversed by proper risk assessment, risk mitigation and risk regulation; contaminated urban soils and healthy urban food production can go hand in hand.

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