Chapter 10
Urban Soil and Human Health

Andrew W. Rate

Abstract In cities, human health and well-being, socioeconomic status, food security, education, gender equity, employment, climate change, and biodiversity are interlinked, and one perhaps surprising common factor is urban soils. In this chapter we explore how a unifying framework for these interrelationships is presented by the United Nations' Sustainable Development Goals (SGDs). The analysis in this chapter suggests that soils have a role to play in the first fifteen of the seventeen Sustainable Development Goals. We suggest ways in which the knowledge and use of soils by urban inhabitants can help to address poverty, maintain a stable food supply, sustain physical, emotional, and social health, provide opportunities for education, promote gender equality and empowerment of women and girls, generate employment, maintain water quality, moderate climate change, and slow biodiversity and habitat loss. The chapter also addresses other soil-related effects on human health such as soil remediation and acid sulfate soils and has a particular focus on environmental justice issues related to urban soil contamination.

Keywords Human health · Urban soils · Sustainable Development Goals · Environmental justice

A. W. Rate (✉)
School of Agriculture and Environment, University of Western Australia, Crawley, WA, Australia
e-mail: andrew.rate@uwa.edu.au

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What you could learn from this chapter:

- How the relationship between urban soils and human health can be understood in the context of the United Nations' Sustainable Development Goals, especially the goals related to poverty, food security, human health and well-being, education, gender equality, water quality, employment and economic growth, climate change, and non-human ecosystems.
- How soil contamination and degradation, and soil remediation, can affect human health.
- What environmental justice means in the context of urban soils, and the types of environmental benefits and services that are inequitably distributed in cities.

10.1 Urban Soils and Sustainable Development

A highly relevant framework for considering the relationships between urban soils and human health are the seventeen Sustainable Development Goals (United Nations (2015) and Table 10.1). The United Nations Environment Program acknowledges that environmental issues underpin all seventeen Sustainable Development Goals (UNEP n.d.). An analysis of the role of urban soils in the context of the Sustainable Development Goals allows us to develop a holistic view of the multiple, interlinked components of human health and well-being (Table 10.1).

The remainder of this chapter will discuss the relationships between urban soils and human health by addressing some of the UN Sustainable Development Goals (SDGs): 1 No Poverty; 2 Zero Hunger; 3 Good Health and Well-Being; 4 Quality Education; 5 Gender Equality; 6 Clean Water and Sanitation; 8 Decent Work and Economic Growth; 13 Climate Action; and 15 Life on Land. This discussion is not intended to be a social or political agenda, but only to present what might be possible roles of urban soils in achieving international goals for sustainable

Table 10.1 How urban soils are related to the UN Sustainable Development Goals

Sustainable Development Goal		Opportunities related to urban soils	Threats related to urban soils
1	End poverty in all its forms everywhere	Soil as an income source, e.g. growing food, pottery	Soils tend to be more contaminated in less advantaged urban areas, so potential for perpetuation of poverty
2	End hunger, achieve food security and improved nutrition, and promote sustainable agriculture	Contributions of urban agriculture to food security (Siegner et al. 2018)	Soil continues to be lost to urbanization processes: Waste disposal, surface sealing
3	Ensure healthy lives and promote Well-being for all at all ages	Community and individual emotional/psychological/relational Well-being	Soil contamination and associated risks to human health (Chaps. 6, 7, 8 and 9)
4	Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all	Focus on urban soils for environmental, health, and related education (Wortman and Lovell 2013; Kim et al. 2014; Gregory et al. 2016)	Without appropriate education, risks from soil contamination, etc. may be greater (Fett et al. 1992; Dietz et al. 2004; Lioy 2010), or adoption of sustainable practices may be less (Dhakal and Chevalier 2017)
5	Achieve gender equality and empower all women and girls	Women are commonly leaders of urban soil-related enterprises (Hovorka et al. 2009; Orsini et al. 2013; Wozniacka 2019)	Poverty related to urban soil loss may have more impact on women and girls; they may bear burden of soil-related work (Hovorka et al. 2009)
6	Ensure availability and sustainable management of water and sanitation for all	Permeable urban soils can act as physical/chemical/biological filters for groundwater	Transfers of contaminants can occur between urban soil and potable surface- or ground-water sources
7	Ensure access to affordable, reliable, sustainable, and modern energy for all	Urban soils used for insulation or heat exchange. Urban soils used to grow sustainable energy crops. Landfill gas extraction	–
8	Promote sustained, inclusive, and sustainable economic growth, full and productive employment, and decent work for all	Employment opportunities in urban agriculture, extension, environmental consultancy, urban soil remediation	Soil continues to be lost to urbanization
9	Build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation	Disseminate soil knowledge to developers and engineers. Landfill mining	–

(continued)

Table 10.1 (continued)

Sustainable Development Goal		Opportunities related to urban soils	Threats related to urban soils
10	Reduce inequality within and among countries	Also through urban agriculture (Orsini et al. 2013) and restoration of degraded soil in low-socioeconomic areas	–
11	Make cities and human settlements inclusive, safe, resilient, and sustainable	Exposed urban soil can reduce urban heat island, especially when vegetated. Urban agriculture	–
12	Ensure sustainable consumption and production patterns	Urban agriculture and WSUD often emphasize practices such as recycling (Gathuru et al. 2009; Wortman and Lovell 2013)	Contamination or poor availability of urban soils may limit urban agriculture
13	Take urgent action to combat climate change and its impacts	Urban soils can provide a sink for carbon (with intentional management), and growth medium for urban forests to reduce urban heat islands	Urban soils (e.g. landfills, but also others) can be net GHG emitters
14	Conserve and sustainably use the oceans, seas, and marine resources for sustainable development	Urban soils can minimize downstream losses (with intentional management), e.g. rain gardens, constructed wetlands	Transfers of contaminants can occur between urban soil and potable surface- or ground-water sources
15	Protect, restore, and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss	Urban soil rehabilitation, use of urban land for urban forests (Keesstra et al. 2018)	Soil continues to be lost to urbanization (sealing, compaction, contamination, etc.) causing loss of fertility, biodiversity, and soil itself. Poorly applied, UA may degrade soil
16	Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable, and inclusive institutions at all levels	–	–
17	Strengthen the means of implementation and revitalize the global Partnership for Sustainable Development	–	–

development, and acknowledges that some authors have considered different combinations of the Goals (e.g., Keesstra et al. 2018).

As we progress, it will become clear that practices that address one Sustainable Development Goal also address others (e.g. urban agriculture can address poverty, food security, climate change adaptation, and so on).

10.1.1 Poverty and its Relationships with Urban Soil

Ending poverty in all its forms everywhere (Sustainable Development Goal 1) is perhaps the most noble of the SDGs, and the Earth's urban soil resource, although significant, is just a part of any solution. The role of urban soils perhaps fits most neatly into two components of SDG Target 1.4, which addresses equal rights to economic and natural resources, and SDG Target 1.5 which aims to build resilience of poor people to extreme environmental, economic, and social risks (including those derived from climate extremes).

Soil management and use has the potential to provide an ongoing income source. For example, urban agriculture is a soil-based enterprise in which the primary objective is growing food, creating an economic advantage by savings in food expenditure, or by selling surplus produce (Hovorka et al. 2009). Other soil-based economic activities are possible; for example, Oladimeji et al. (2015) describe the use of clay collected from soil to make and sell pottery in a peri-urban area of Ilorin city in Nigeria.

In contrast, many studies in the discipline of *environmental justice* have shown that soils tend to be more contaminated in less economically or socially advantaged urban areas, such as those predominantly occupied by people who are poor or belong to a minority group (e.g. Mielke et al. 1999; Aelion et al. 2012; Zhuo et al. 2012; McClintock 2015). This uneven distribution of soil contamination limits the ability of poor people to use soil for food production or other enterprises (or may cause adverse health issues if the soil is used), and so polluted (or otherwise degraded) urban soils have the potential for perpetuation of poverty.

10.1.2 Food Security and Its Relationships with Urban Soil

Sustainable Development Goal 2 is to "End hunger, achieve food security and improved nutrition and promote sustainable agriculture," and so has clear links to soil use and management in urban environments. These links are most well-defined in SDG Target 2.3, which deals with increasing agricultural productivity of small-scale food producers. Just as it does for poverty (SDG 1), urban agriculture can make significant contributions to food security. For example, Siegner et al. (2018) concluded that urban agriculture could provide a number of benefits to communities in the USA, including food security, when allied with intentional policies to improve social justice and equity.

The rapid pace of urbanization in many parts of the world does create some threats to urban food security, in the form of limits to food access and safety, and effective distribution of food (Lal 2017). Urbanization will continue to remove soils from potential for food production. Inevitably, the pressures to develop more land for residential and commercial use will decrease the area of productive land by surface sealing. It is also likely that productive land will be compromised by ongoing soil degradation and contamination related to urban development, such as compaction and the need to dispose of ever-increasing amounts of wastes.

10.1.3 Physical Health and Well-being and Urban Soils

Sustainable Development Goal 3, which aims to "Ensure healthy lives and promote well-being…," has numerous connections to urban soils, most notably in SDG Target 3.9 which addresses health issues relating to pollution and contamination of soil and other environmental compartments. Some of the direct and indirect risks to human health were associated with soil contamination and have been addressed in Chaps. 6, 7, 8 and 9, and we present more details in this chapter. It is also important, however, to be aware of the positive effects on human health which relate to a connection to urban soils.

Nutrients Elements which are essential macronutrients are not generally considered to have direct human health effects when present as soil contaminants, although there may be deficiency symptoms in cases of insufficient supply by soils. However, in soils with high concentrations of nitrogen and phosphorus, for example, due to over-fertilization (Taylor and Lovell 2015) or organic waste disposal, leaching of nitrate and phosphate to groundwater and surface water can occur (Carpenter et al. 1998). Nitrate, in particular, can have adverse health effects if ingested at high concentrations, the most concerning of which is the potentially fatal blood disorder methemoglobinemia or "blue baby syndrome" in human infants (Croll and Hayes 1988).

Metals Contamination of soils with metals and metalloids may cause human health issues if a plausible pathway exists. Some metals or metalloids (e.g., As, Cd, Cr, Ni) can be carcinogens (Morgan 2012). Most metals or metalloids can also cause a wide range of chronic health effects if humans are exposed to contaminated soil (Morgan 2012; Pepper 2013). Historically, considerable concern has been raised about lead contamination in soils, since lead exposure in children can cause a range of neurological disorders, and children have a greater risk of direct or indirect soil ingestion than do adults (e.g., Aelion et al. 2009; Oliver and Gregory 2015; Li et al. 2018). Soil in public open space, including children's playgrounds, may be contaminated, and children deliberately or accidentally ingest more soil than adults (De Miguel et al. 2007). More recently, however, arsenic and cadmium have emerged as contaminants of concern, including issues of soil contamination with As and Cd in urban environments (De Miguel et al. 2007; Rodríguez-Eugenio et al. 2018).

Organic Contaminants There is a very wide range of organic contaminants to which humans may be exposed if they are present in soils. Several organic substances (PAH, PCB, PCDD, etc.) generate considerable concern due to their known potential as human carcinogens (Oliver and Gregory 2015; Rodríguez-Eugenio et al. 2018). Similarly to metals, exposure of humans to organic contaminants in soils is also believed to have several other adverse health effects; for example, exposure to organic pesticide compounds can cause hormone disruption, asthma, allergies, hypersensitivity, and even cancers. The wide range of persistent organic pollutants (POPs) have long residence times in soils; combined with their known carcinogenic and toxic properties, and widespread occurrence in urban soils worldwide, they pose significant risk to human health (Rodríguez-Eugenio et al. 2018).

Asbestos and Other Mineral Contaminants The fibrous minerals in the asbestos group are serious threats to human health, because of their ability to be ingested by inhalation, the very long lifetimes of asbestos minerals in soils, and the severity of their adverse effects. The severe effects of asbestos exposure include forms of cancer such as lung cancer and mesothelioma (and other cancers), and other potentially fatal respiratory ailments such as asbestosis (Frank and Joshi 2014). The only direct exposure route for asbestos is by inhalation, so contact with asbestos-contaminated soil and consumption of plants grown on such soil are not necessarily indirect pathways. Asbestos adhering to skin or clothing can, however, generate airborne asbestos fibers, as can soil exposed to wind erosion or soil disturbance (USEPA 2008).

Chronic (long-term) exposure to non-asbestos silicate minerals can also lead to human health effects. Inhalation of quartz particles less than about 4 μm in size can lead eventually to silicosis, a non-cancer lung disease similar to asbestosis (Derbyshire 2007; Pepper 2013).

Radionuclides The radionuclides that may be present in soil can be transferred to humans via inhalation (as radon gas, or atmospheric particles), or by ingestion, since radioactive elements may leach into groundwater; this has been documented in some urban environments (Lee 2011). The most likely human exposure route is through the seepage of radon gas from underlying soil material into confined living spaces such as buildings (U.S. EPA 2008). Human exposure to radionuclides can result in serious adverse health effects; radon and uranium can both cause cancers, and uranium can also cause kidney damage. Some of the toxic effects of uranium are chemical rather than derived from the radiation it emits (Bjørklund et al. 2017).

Establishing a causative relationship between urban soil contamination and human health is difficult, because indirect exposure and the common time lags between exposure and symptoms serve to decouple soil and humans in space and time.

Pathogens A range of potentially pathogenic organisms can be found in urban soils, especially if organic wastes containing fecal material such as biosolids, animal manures, or incompletely treated wastewater have been applied to soil (Alloway 2004; Amoah et al. 2005). There has been a resurgence in interest in using biosolids as a “zero-waste” recycling strategy; one of the strategies to minimize the incidence of pathogens is with more rigorous pre-treatment of waste materials (Alvarez-Campos and Evanylo 2019; Chakravorty 2019). This is of particular relevance for many poor people in developing countries, where residential structures often lack constructed floors (Pickering et al. 2012); the soil floors can be contaminated with bacteria and viruses. Pathogens can also be transmitted to humans who consume vegetables grown on contaminated urban soil (Amoah et al. 2005).

Health Benefits Community and individual well-being is considered to derive benefits from soil-related activities such as gardening and urban agriculture. These benefits are manifested as improvements in physical health, related to improvements in nutrition and increases in physical exercise. In addition, emotional, and/or psychological, and/or relational health improvements occurred for a range of reasons including the calming, meditative nature of gardening; increased connection to nature; increased mental activity; and connections with like-minded others (Wakefield et al. 2007; Kim et al. 2014).

10.1.4 Education and Urban Soils

Soil science is a highly integrative subject, requiring skills across the *STEM* spectrum including literacy and numeracy, and specialized skills and knowledge relevant to geography, geology, hydrology, biology, chemistry, and physics. The access to urban soils afforded by the concentration of population in urban centers therefore means that Sustainable Development Goal 4 focus on “…inclusive and equitable quality education…” and “…lifelong learning…” can be facilitated by learning experiences based around soils. In particular, urban soils can be used as a focal point for environmental, health, and related education (Wortman and Lovell 2013; Kim et al. 2014; Gregory et al. 2016).

In the absence of appropriate soil-focused education, the risks from urban soil contamination may be exacerbated (Fett et al. 1992; Dietz et al. 2004; Lioy 2010), or adoption of sustainable practices may be less (Dhakal and Chevalier 2017). Some of the types of information required by individuals and communities who use urban soil to grow food are summarized in Table 10.2.

Table 10.2 The main types of information, related to contamination risks in urban soil, needed by people conducting urban agriculture (from Kim et al. 2014, used under terms of CC-BY-4.0 license)

Category	Specific information
Site history	How to find information about past uses of a plot of land
	Which contaminants to test for, given specific past land uses
	Geographic areas of the city where there are likely to be high levels of contamination
Soil testing	Importance of obtaining a soil test prior to gardening
	Which contaminants to test for
	Why to test for certain contaminants and not others
	Where to get soil testing done
	How much soil testing costs
	How to correctly take a soil sample for a soil test
Remediation	Best practices for remediating contaminated urban soils
Minimizing exposure	How to reduce exposure risks when gardening
	Contamination risks associated with imported materials such as compost or mulch

10.1.5 Gender Equality and Empowerment and Urban Soils

Sustainable Development Goal 5 contains Target 5.5, to "Ensure women's full and effective participation and equal opportunities for leadership…," and Target 5.a to "Undertake reforms to give women equal rights to economic resources, as well as access to ownership and control over land…." In this context, it is important to recognize that women are commonly leaders of urban soil-related enterprises (e.g., Hovorka et al. 2009; Orsini et al. 2013; Wozniacka 2019). Conversely, poverty related to urban soil loss may have more impact on women and girls, who may bear a disproportionate burden of soil-related work while still expected to perform domestic duties, or who provide mainly the labor for urban agriculture while men retain financial control (Hovorka et al. 2009).

10.1.6 Healthy Water and Urban Soils

Sustainable Development Goal 6 is to "Ensure availability and sustainable management of water and sanitation for all." In an urban soil context, Target 6.3 which addresses water quality and pollution reduction is clearly relevant, as is Target 6.6 to protect water-related ecosystems.

Permeable urban soils can act as physical/chemical/biological filters for groundwater (Pepper 2013). The filtration ability of soils is partly physical; the transport of particulates and microorganisms (including pathogens) can be suppressed by soil pores which are too fine to allow passage of solid particles or microbial cells (Voisin et al. 2018). Chemical immobilization, such as ion exchange, adsorption, or precipitation of contaminants, can also occur (Abiye et al. 2009), along with biological processes to remove contaminants, such as denitrification (Bettez and Groffman 2012). *Managed Aquifer Recharge* (Fig. 10.1), from surface infiltration basins (not injection wells), deliberately relies on the filtration ability of urban soils and the underlying regolith to safely recharge groundwater (Misra 2014). The input water for Managed Aquifer Recharge can either be stormwater (Voisin et al. 2018) or treated wastewater (Abiye et al. 2009).

It is usually thought that the amount of impervious surface cover in urban areas decreases recharge to groundwater, but this is not always the case. In an urban catchment with shallow groundwater and very permeable soils, recharge increased following urban development, since the impervious surface cover served to substantially decrease evaporation losses of water (Barron et al. 2013). In other urban environments, excess runoff caused by impervious surface cover can be decreased by rainfall interception by the canopies of large street trees (Livesley et al. 2014). Other factors related to urbanization can alter hydrological processes; for example, the loss of wetlands due to urbanization decreases hydrological buffering and can lead to flooding and soil erosion (Rashid and Aneaus 2019).

Urban soils, if contaminated, can also represent a threat to supplies of safe drinking water. Transfers of contaminants such as nutrients, metals, and organic pollutants can occur between urban soil and potable surface- or ground-water sources by leaching (Carpenter et al. 1998; Zhang et al. 2001; Imperato et al. 2003; Rodríguez-Eugenio et al. 2018). Leaching of contaminants is more pronounced if they are present in forms which are minimally retained by soils. For example, nitrate is very weakly retained by under most soil conditions and is a commonly encountered groundwater contaminant with potentially serious health consequences as described

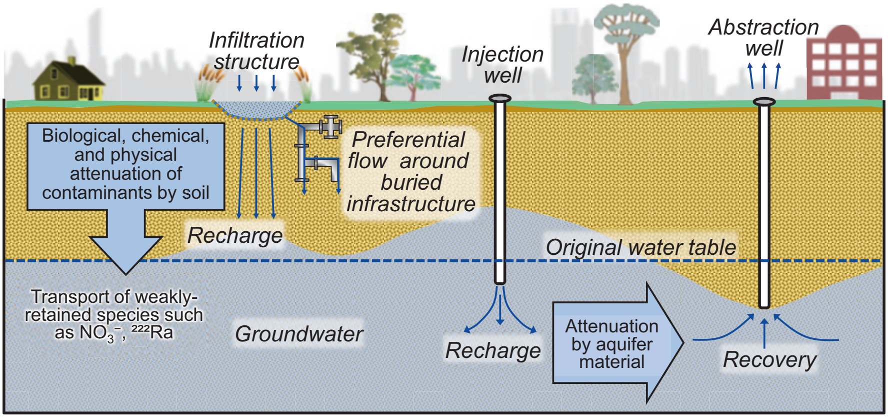

Fig. 10.1 Idealized schematic of Managed Aquifer Recharge. Structures such as infiltration basins or trenches (but not wells) utilize urban soil properties for passive treatment of wastewater and stormwater, causing concentration decreases (i.e., attenuation) for contaminants such as nutrients, metals, organics, and pathogens. (Based on Department of Water and Environmental Regulation n.d.)

above ("Physical health and well-being and urban soils" section). Similarly the radionuclide ^{222}Ra (radon) can leach into groundwater (Lee 2011). The physical properties of urban soils can also influence leaching of contaminants to groundwater. Preferential flow around the smooth surfaces of underground infrastructure such as pipework can increase leaching in urban soils, a phenomenon known as the "urban karst" effect (Bonneau et al. 2017), named after the preferential water flow observed in soils in dissected limestone, or "karst" landscapes (see Chap. 5).

Climate change is also predicted to increase flooding, which may severely affect some urbanized areas and have detrimental effects on water quality and access to safe water (Whitehead et al. 2015). Since urban flooding can be managed to some extent by modification of urban soils and landscapes, soils have a role to play in responses to climate change. We will discuss the future of urban soils, specifically in relation to climate change and other environmental threats, in the final chapter (Chap. 12).

10.1.7 Urban Soils and Employment

Sustainable Development Goal 8 is to promote sustained, inclusive, and sustainable economic growth, full and productive employment, and decent work for all. In particular, soil-related employment can help to achieve Target 8.5, to "…achieve full and productive employment and decent work for all women and men, including for young people and persons with disabilities."

Employment opportunities which relate to urban soils exist in field such as urban agriculture and forestry, extension, environmental consultancy, and urban soil remediation. As with other SGDs, one of the main barriers to employment related to use and management of urban soil is that soil continues to be lost to urbanization.

10.1.8 Climate Change and Urban Soils

Sustainable Development Goal 13 exhorts humanity to take urgent action to combat climate change and its impacts; the urgency reflects the status of anthropogenic climate change as possibly the most serious hazard to affect life on Earth. The adverse effects of climate change are more likely to be experienced in faster-growing cities, mainly present in the developing world (Verisk Maplecroft 2018). Urban areas are major contributors of greenhouse gases, with soils playing a part in emissions (Bellucci et al. 2012). Climate change is predicted to cause severe adverse health effects (WHO 2018), for example, increases in deaths from cardiovascular and respiratory disease, and longer transmission seasons for diseases transmitted via other organisms such as mosquitoes.

It is often assumed (Lal 2011) that soils, including those in urban environments, can provide a sink for carbon (with intentional management). The success or otherwise of soil management to address the primary cause of anthropogenic climate change, the emission of greenhouse gases into Earth's atmosphere, depends on the answers to these questions:

1. **Can we add carbon to [urban] soils that otherwise would have entered the atmosphere as CO_2 or CH_4?**

For example, diverting organic waste streams from landfill to compost (or even biochar) destined for urban soils; could a strategy as seemingly mundane as composting be a viable *carbon sequestration* technique? It is certainly true that urban environments are significant sources of organic waste materials which could be re-used beneficially (Lehmann 2011). Other ways to add carbon are to modify urban land uses, such as developing urban agriculture or urban forestry (FAO 2019). A special report of the Intergovernmental Panel on Climate Change relating to land-based processes (IPCC 2019) concluded that urban and peri-urban agriculture, along with other forms of "green infrastructure," can contribute to mitigation of climate change. Urban forests, another important form of urban green infrastructure, can store up to three times more carbon in the underlying soil than in the trees themselves (Lorenz and Lal 2012). In addition, lawns and other urban turf grass environments can store considerable quantities of carbon as soil organic matter (Brown et al. 2012).

It also has been suggested that inorganic carbon sequestration could represent a carbon capture mechanism in urban soils, since urban soils commonly contain finely particulate silicate minerals in the form of construction and demolition dusts which can consume atmospheric CO_2 during chemical weathering reactions (Jorat et al. 2015; Kolosz et al. 2019).

2. **Will the added carbon remain in urban soils for long enough to represent its removal from the short-term carbon cycle, and/or promote other mechanisms for removal of CO_2 or CH_4 from the atmosphere (such as increased carbon fixation by plants)?**

A common process used to stabilize organic waste material produced in urban environments is *composting*. Composting of urban organic wastes, followed by application to soils, has considerable advantages over disposal of organic wastes in landfill (Biala 2011). Composting is ideally an aerobic process for decomposition and stabilization of organic materials; this is in contrast to the predominantly anaerobic decomposition of putrescible wastes in landfills. Composting should emit only CO_2 and not result in significant emissions of methane and nitrous oxide to the atmosphere, as landfills do (Lou and Nair 2009). This is an advantage since the global warming potentials of both CH_4 and N_2O are substantially greater than for CO_2. Another stabilized carbon product applied to soils, *biochar*, is also believed to be able to sequester carbon (Singh et al. 2014). The use of biochar in some urban soils may provide additional benefits, for example, in maintaining soil fertility and an adequate soil water content range in the soil-limited "*green roof*" substrate studied by Chen et al. (2018). In the cases of both composts and biochar, rigorous quality control of the initial organic substrate is important, given the contamination of some urban organic waste sources with potentially toxic inorganic and organic contaminants (Rodríguez-Eugenio et al. 2018).

Urban soils can also represent suitable environments to grow trees which, apart from being able to sequester carbon, also offer several other benefits to urban residents (Fig. 10.2). Globally, it is possible that sufficient tree planting could sequester enough carbon, in combination with other strategies such as reduction in fossil fuel consumption, to capture more than two-thirds of all historical anthropogenic carbon emissions (Bastin et al. 2019). The other benefits of increased urban tree cover include shading, food production, wildlife habitat, filtration of particulates and pollutants, and even improved mental health, so urban and peri-urban forestry (FAO 2019) is an excellent use of urban soil resources. Of course, people living in urban environments also enjoy open spaces, and lawns and other turf grass environments such as sports facilities are also known to be able to sequester soil carbon, with the soil organic carbon persisting since turf grass environments are subject to minimal disturbance (Zirkle et al. 2012). In some urban environments, the carbon storage in soils exceeds that in vegetation (Fig. 10.3).

The sequestration of atmospheric carbon by abiotic mineral weathering has not been widely considered in the context of soils. This is despite the finding that silicate-based waste materials in soils containing calcium and magnesium, such as demolition and construction wastes, can remove considerably more carbon from the atmosphere than is possible by biotic processes alone (Washbourne et al. 2012). Enhancement of CO_2 concentration in the air-filled pore space of soils by microbial and root respiration suggest that shallow burial of construction and demolition wastes would promote more rapid chemical weathering of the silicate minerals by carbonic acid. Interestingly some researchers suggest that cement-based wastes, which also consume CO_2 as they chemically weather, are less important since the cement manufacturing process produces CO_2 emissions equivalent to consumption by weathering (Jorat et al. 2015). While this is true, the opportunity to improve the carbon footprint of cement manufacture should not be ignored.

The amount of atmospheric carbon realistically able to be sequestered by soils is controversial, and some scientists argue it be minimal, partly due to socioeconomic and political barriers (e.g., Amundson and Biardeau 2018). However, there are numerous additional benefits when urban enterprises, communities, and individuals are involved in soil carbon sequestration. For example, Christie and Waller (2019) outline how composting projects in residential apartment buildings generated a desire to create positive global change toward sustainability in participants, who also felt more connected to each other and nature. These environmental education outcomes can also provide strong momentum toward more widespread activism and adoption of sustainable practices by regulators and the wider community (Waller et al. 2018). In addition, the biodiversity and productivity of urban soils are also improved by deliberately increasing soil organic matter content (e.g., Basta et al. 2016; Huang et al. 2019).

Soils can also be involved in modifying urban microclimates, moderating the effect of urban heat islands (Alcoforado and Andrade 2008). Coutts et al. (2013) describe how increased soil water contents, in the context of *Water Sensitive Urban*

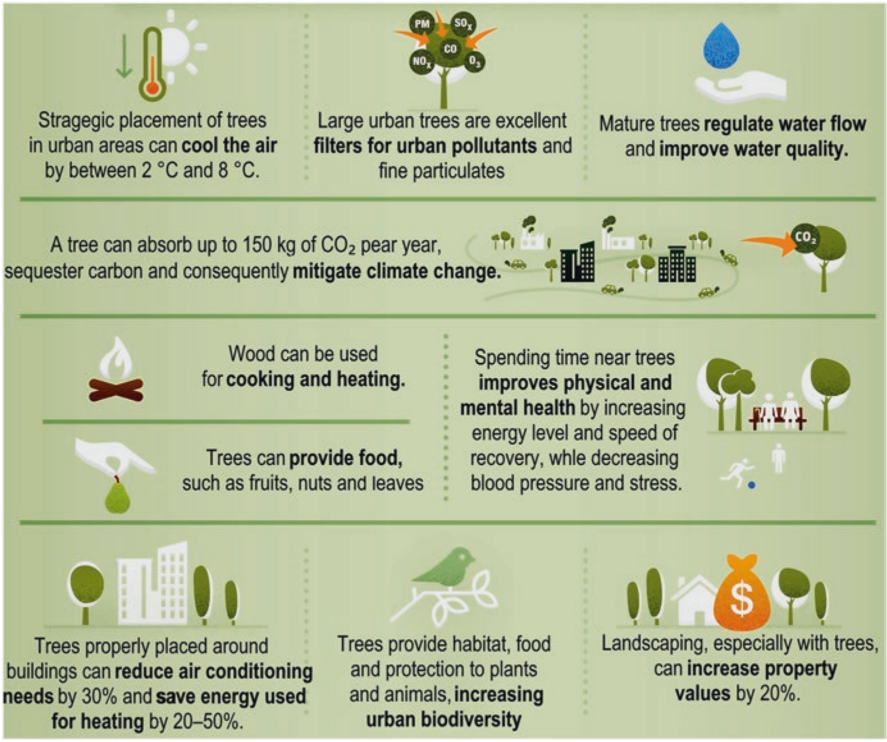

Fig. 10.2 Benefits of urban trees (modified detail of an infographic by FAO 2016)

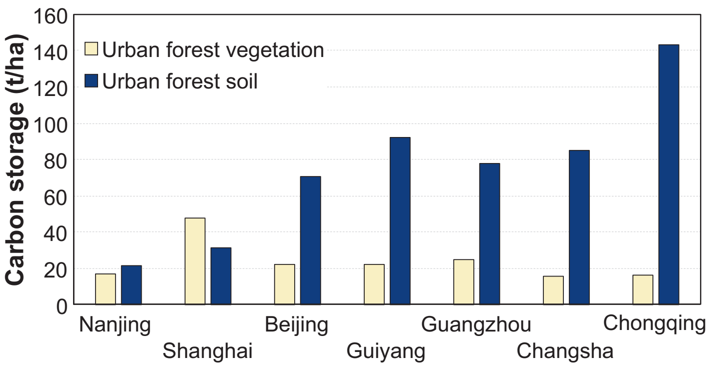

Fig. 10.3 Carbon storage in vegetation and soils in urban forests in Chinese cities (re-drawn from data tabulated in Wang et al. 2013)

Design, provide a cooling effect. Wetter soils, where the additional water may come from sustainable re-use of urban stormwater or appropriately treated wastewater, increase the capacity of the soil to absorb heat and allow for greater evaporative cooling (Coutts et al. 2013).

Urban soils overlying landfills are well known to emit greenhouse gases, mainly carbon dioxide and methane (Blume 1989). Greenhouse gas (GHG) emissions in urban soils are not limited to those on or near landfills, however; soils under urban turf can be net greenhouse gas emitters, especially of N_2O and CH_4 (Livesley et al. 2010; Townsend-Small and Czimczik 2010). In particular, urban soil respiration causes CO_2 emissions much greater than surrounding non-urbanized soils, and emissions depend on land use. In urban soils of Boston, USA, urban forest soils had the lowest carbon losses by soil respiration, with more CO_2 loss from lawns and the greatest losses from garden and landscaped soils (Decina et al. 2016). The losses of greenhouse gases from urban soils are also dependent on management; for example, where agricultural soils are very intensively managed, as in eastern China, urbanization may actually result in an increase in soil carbon storage (Xu et al. 2011).

10.1.9 Terrestrial Life and Urban Soils

The overall aim of Sustainable Development Goal 15 is to "Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss." There are many ways that urban soils are related to the targets within SDG 15, such as (among others) Target 15.1 "…conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems…"; Target 15.5 "…reduce the degradation of natural habitats, halt the loss of biodiversity…"; and so on. SDG 15 is not specifically related to human health, but we will take the holistic view that human health is closely linked to ecosystem health, especially for the terrestrial and inland freshwater ecosystems specifically referred to in Target 15.1. If this is a valid viewpoint, then any function or management outcome related to urban soil that promotes healthier terrestrial ecosystems, therefore, promotes human health. There is certainly evidence that a connection to nature, of which a large proportion would be soil-dependent ecosystems, is beneficial for people's mental health and also physical health by providing places for exercise (Wakefield et al. 2007; Soga et al. 2017; Laidlaw et al. 2018).

The functioning of terrestrial ecosystems is vital to their resilience to external pressures such as climate change and soil pollution (Pavao-Zuckerman 2008; Nero and Anning 2018). Healthier urban ecosystems can promote better human health by diversifying dietary intake through urban agricultural ecosystems (Werner et al. 2019), or by allowing foraging for "wild" food in urban environments (McLain et al. 2014). The landscape diversity of cities is also important for human health;

Arnold and Gibbons (1996) assert that one indicator of urban quality of life and environmental health is the proportion of impervious surface cover. A low proportion of impervious surface cover means greater proportions of a city's land with unsealed soil, and therefore the existence of urban ecosystems such as gardens, grassland, and urban forests. Urban quality of life is therefore greater in areas of cities having less impervious surfaces.

Keesstra et al. (2018) explicitly address Target 15.3, which has the general aim of land restoration, in the context of soils. They discuss a number of ways in which soils (considered in this chapter to mean urban soils) can be part of Nature-Based Solutions to land degradation, including promoting infiltration of water and increasing soil organic matter which are expected to have multiple benefits including increases in biodiversity.

Biodiversity in urban environments depends to some extent on the soil, and commonly the extent to which soil is degraded or restored. Urban soils are often considered to support a less diverse plant community, which is related to the differences in ability of plant species to adapt to urban conditions (Vallet et al. 2010). In contrast, some anthropogenically modified urban soils may also provide specific habitats, not present in undisturbed sites, in which threatened plant species can survive (Albrecht and Haider 2013). An important issue for urban biodiversity is that urban environments can be hotbeds of invasive non-native species such as weeds, with urban soils containing large weed seed banks from their prior existence as degraded areas (Lake and Leishman 2004; Pavao-Zuckerman 2008). Even soil restoration in the form of urban agriculture can, in some instances, increase urban biodiversity (Orsini et al. 2013). Similarly, urban forests may also contain highly diverse plant communities, as shown in a study by Stewart et al. (2009) in the city of Christchurch, New Zealand.

Fewer studies have investigated the biodiversity of soil fauna in urban soils. Fountain and Hopkin (2004) found that for Collembola (springtails) in a range of contaminated and uncontaminated urban soils, the contaminated sites typically had a few dominant species with many rare species. Soils on contaminated sites sometimes contained more species than at uncontaminated sites. Pavao-Zuckerman and Coleman (2007) found that, while the functions performed by soil nematodes differed with varying degrees of urbanization, the taxonomic diversity of nematodes was similar for urbanized and non-urbanized soils. In contrast, Uno et al. (2010) found that the diversity of ant species was greater in forested areas than in urban environments; the lower urban ant diversity may have been related to the colonization of urban soils by an introduced ant species. We have discussed soil biodiversity and related issues in more detail in Chap. 8.

Soil continues to be lost to urbanization (compaction, sealing, contamination, etc.) causing loss of fertility, biodiversity, and soil itself. Poorly implemented, even urban agriculture may degrade soil (Taylor and Lovell 2015).

10.2 Other Human Health Issues Related to Urban Soils

10.2.1 Urban Soil Remediation

Remediation of urban soils, a topic we will address in detail in Chap. 11, offers multiple direct and indirect benefits to human health. The direct benefits are lower exposure to contaminants such as potentially toxic elements ("metals") and persistent organic pollutants (Thornton et al. 2008), and consequent lower risk of ingestion, especially for children (Ottesen et al. 2008). Urban soil remediation has benefits from several perspectives. Remediated soil should result in cleaner ground water and surface water (Van Wezel et al. 2008); there may also be improved infiltration and reduced runoff of precipitation (Olson et al. 2013). Cleaner soil, or soil with improved physical properties, facilitates urban agriculture (Wortman and Lovell 2013) – community gardening itself is a practice that can be used to remediate soil (Al-Delaimy and Webb 2017). Soil biological properties are also affected by remediation, which improves soil ecosystem functioning (Kumar and Hundal 2016). Further indirect benefits may be educational (Kim et al. 2014), for example, the opportunity to promote phytoremediation and other "nature-based" solutions (Song et al. 2019) which also lack the adverse effects of more conventional soil remediation, such as dust generation from excavation.

Urban forests. We have discussed the benefits of urban trees earlier in this chapter; remediated urban soils improve the growth of trees (Layman et al. 2016). Urban forests can be an outcome of soil remediation and rehabilitation, or may represent remnant vegetation. The soils supporting remnant forests sequester more carbon than soil under other urban land uses (Pouyat et al. 2002), which is also an indirect benefit for human health. Livesley et al. (2016) summarized multiple ecosystem services provided by urban forests: at the scale of individual trees, the street scale, and for whole cities. The benefits to human health included cooling, carbon sequestration, energy savings, increased biodiversity, lower water losses by runoff, and reductions in particulate air pollution.

10.2.2 Acid Sulfate Soils and Human Health

There are a number of human health issues associated with acid sulfate soils, with public concern about living in areas known to contain acid sulfate soils (Thomas et al. 2016). The low pH in acid sulfate soils can cause declines in quality, or contamination, of groundwater (Appleyard et al. 2004; Salmon et al. 2014; see also Chap. 6). Acid sulfate soils cannot support a dense plant community, and the resulting susceptibility to wind erosion and generation of atmospheric dust can have health effects (Ljung et al. 2009). The acidic water associated with acid sulfate soils may be toxic to aquatic life such as fish (Powell and Martens 2005), but mosquitoes are often tolerant of acidic conditions and may thrive in acid sulfate soil landscapes (Soukup and Portnoy 1986; Alsemgeest et al. 2005), and so the risk of mosquito-borne diseases can increase.

Contact with water acidified by acid soil processes can result in skin irritation (DER 2015). One study has shown some evidence for increased uptake of metals (arsenic, cadmium, lead, copper, and zinc) by individuals who consume groundwater from acid sulfate soil areas (Hinwood et al. 2008). The higher concentrations of bioavailable aluminum and other metals may have the potential to cause human health problems (Fältmarsch et al. 2008). Food production, such as the growth and survival of agricultural crops (Khuong et al. 2018) and fish or crustaceans grown in aquaculture (Widyatmanti and Sammut 2017), can also be adversely affected.

10.2.3 Environmental Justice Issues

Environmental Justice emerged in the 1980s as a grassroots social activist movement, in response to concerns about the tendency for waste facilities to be located in areas populated with ethnic minorities. Such issues are compounded in low socio-economic neighborhoods, since the residents' overriding concerns are often economic, and the regulation or closure of polluters may result in loss of employment opportunities (Checker 2002). Inequitable access to a healthy environment, however, consists of more than just exposure to water, air, or soil pollution, however. In many cases, people of low socio-economic status, or those outside the dominant ethnic group, have less access to environmental benefits such as good-quality urban infrastructure, "green" infrastructure, urban green space, or opportunity to grow food locally (Rowan and Fridgen 2003; Baker et al. 2019; Siegner et al. 2019). The United States Environmental Protection Agency (USEPA 2008) defines environmental justice broadly to allow application of the concept to all aspects of healthy environments, stating that environmental justice is:

> … the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income, with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies.

A number of international studies have shown that environmental inequity occurs in urban areas. For example, Zhuo et al. (2012) and Aelion et al. (2013) found that concentrations of potentially toxic elements (Pb, As) in soils were spatially correlated with socioeconomic status and/or predominant ethnic background in urban areas in the USA. Similar relationships between soil pollution and socioeconomic measures have been identified in several other countries, including cities in Australia (Cooper et al. 2018), Canada (Lambert et al. 2006), and the UK (Morrison et al. 2014). The risk of environmental injustice was also recognized as a possible consequence of introducing more stringent environmental regulations for soils in China (Hou and Li 2017) and in an analysis of the aftermath of the Fukushima nuclear accident in Japan (Otsuki 2016). These and other studies reinforce the need for the principles of environmental justice to be incorporated into environmental legal frameworks.

The United Nations' Sustainable Development Goals address issues of social and environmental justice on a global scale, with clear implications for local instances of inequity. Despite the SDGs including aims to achieve both "…sustained, inclusive and sustainable economic growth" (SDG 8) and "Build resilient infrastructure, promote inclusive and sustainable industrialization…" (SDG 9), the SDGs also mandate conservation and sustainable use of water and marine and terrestrial resources (SDGs 6, 14, and 15) and promote "…urgent action to combat climate change and its impacts" (SDG 13). The Sustainable Development Goals also clearly aim to achieve just societies, including equitable access to education (SDG 4), gender equality (SDG 5), reduction of inequality within and among countries (SDG 10), and "…access to justice for all…" (SDG 16). The common ground occupied by environmental justice and the SDGs was analyzed by the Center for International Environmental Law (2002), who identified the most important common issues to be the right to life, including the right to a healthy environment; property rights of indigenous communities; and the rights of communities to make decisions related to their livelihoods and survival (Newton 2009).

10.2.4 Case Studies of Environmental (in)Justice in Urban Soils

Warren County Landfill, North Carolina, USA. In 1982, actions which precipitated the birth of the environmental justice movement as a significant social force (at least in the USA) began in Warren County, North Carolina, USA (Fig. 10.4). The triggering event was the proposal to develop former farmland as a landfill for ca. 180,000 m^3 of soil material contaminated with polychlorinated biphenyls (PCBs), at concentrations up to 500 mg/kg (Hirschhorn 1998; Burnwell 2007). It is significant for this book that this incident involved soil, both as the source and disposal site of contaminated material, even though the environment was predominantly rural. The local residents, mostly African-Americans with low incomes, conducted a series of protests which greatly raised the profile of environmental justice issues in the USA, with a Presidential Executive Order establishing a national office of Environmental Justice in 1994 (Checker 2002). Although the protests were not successful in preventing the landfill, they did prompt a commitment from the state Governor to assess remediation options once technology became available. The site was fully remediated in 2003 using base-catalyzed decomposition (Burnwell 2007; Lyons 2007).

New Orleans: lead-contaminated soils and children's health. The relationships between lead (Pb) concentrations in soils and population variables, in New Orleans, Louisiana, USA, were studied by Campanella and Mielke (2008). The relevance of this study is that lead pollution is widespread in soils, potentially being derived from

Fig. 10.4 Scenes from the construction of the Warren County landfill, NC, USA: (**a**) dumping of PCB-contaminated soil (from Burnwell 2007); (**b**) protesters attempting to block access to the landfill site (from Lyons 2007)

a number of sources, including lead-based paints, lead additives in vehicle fuel, and other industrial uses such as roofing or batteries. The most significant sources in soils for human health are leaded gasoline due to the presence of added Pb in very fine particles, although fine paint fragments can also be important (Mielke and Reagan 1998). Humans can be exposed to lead by ingestion of soil, via soil adhering to plant produce, or inhalation of soil-derived house dusts; children are at greater risk since some younger children ingest soil directly (Clark et al. 2008). Lead poisoning causes neurological effects in humans, and in children has adverse effects on their cognitive and learning abilities.

Campanella and Mielke (2008) found that, in areas of New Orleans having soil lead concentrations greater than 100–200 mg/kg, people of African-American ("black") ethnicity represented the greatest proportion of the population (Figure 10.5a). The median income for residents was negatively correlated with soil lead concentration. Significantly, there were significant proportions of children exposed to soil Pb concentrations greater than the EPA guideline of 400 mg/kg applicable at the time (Figure 10.5b). The risk may have been compounded by significant resuspension of soil during flooding caused by the catastrophic Hurricane Katrina in 2005.

Soil metal pollution and deprivation in Glasgow, Scotland. Glasgow, a major city in Scotland (UK), has been urbanized and industrialized for several centuries, and was studied by Morrison et al. (2014) since its history has resulted in widespread soil contamination. They measured selected soil metal and metalloid concentrations (As, Cr, Cu, Ni, Pb, Se, Zn) which were combined into an average index value for each map polygon (see Fig. 10.6a). A "deprivation index" was also calculated from population demographic data in each map polygon, based on health, education, employment, housing, income, access to services, and crime (Fig. 10.6b). Each map polygon contained approximately equal numbers of households having similar socioeconomic attributes.

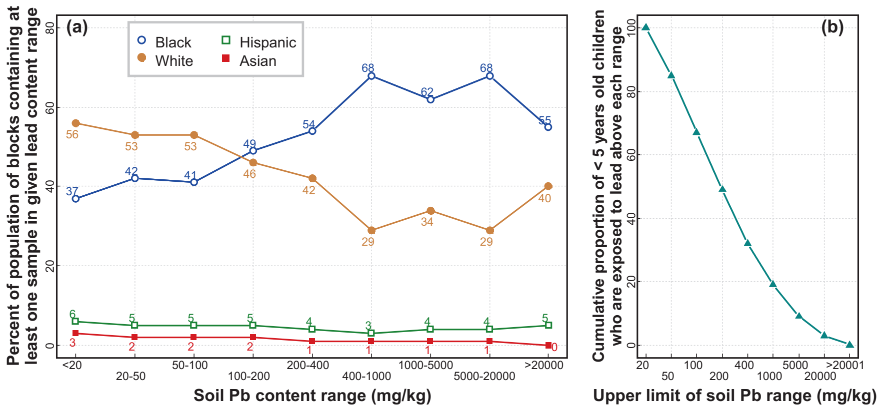

Fig. 10.5 (**a**) Racial composition of New Orleans population as a function of soil lead (Pb) content; (**b**) proportions of young children (< 5 years old) in New Orleans exposed to different concentrations of lead (redrawn from Campanella and Mielke 2008; used with permission from Springer)

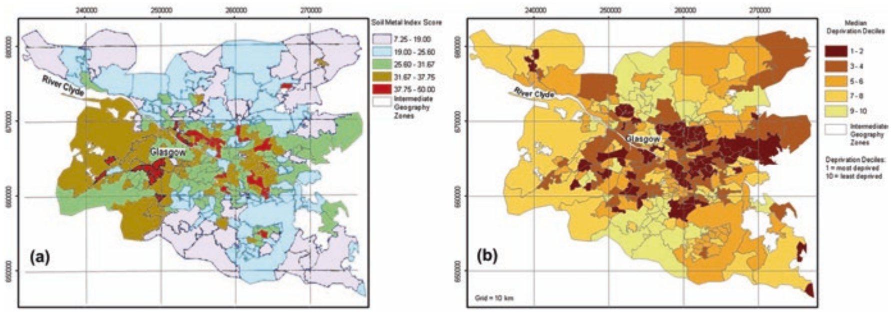

Fig. 10.6 Comparison of (**a**) soil metal contamination index (red/darker colors are most contaminated) and (**b**) socioeconomic deprivation index (darker colors are most deprived) in Glasgow, Scotland, UK (redrawn from Morrison et al. 2014 and used with permission from Springer)

Morrison et al.'s (2014) data showed a statistically significant correlation between soil metal index and deprivation index, which is illustrated in map format in Fig. 10.6. The correlation was explained in terms of the lower cost of rehabilitated former industrial land, which supported lower cost housing, but on which the soil also contained a legacy of trace element contamination from historical metal-processing industries. The authors recommended that assessments of communities in the context of deprivation and environmental justice should include information on soil chemical quality.

10.3 Further Reading

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Li G, Sun G-X, Ren Y, Luo X-S, Zhu Y-G (2018) Urban soil and human health: a review. European Journal of Soil Science 69:196–215. https://doi.org/10.1111/ejss.12518

10.4 Summary

- With appropriate use and management, urban soils have crucial roles to play in complete achievement of the United Nations' Sustainable Development Goals. The links between the Sustainable Development Goals and urban soils represent a link between urban soils and human health in multiple contexts.
- The main Sustainable Development Goals requiring an understanding of urban soil processes are as follows: 1 No Poverty; 2 Zero Hunger; 3 Good Health and Well-Being; 4 Quality Education; 5 Gender Equality; 6 Clean Water and Sanitation; 8 Decent Work and Economic Growth; 13 Climate Action; and 15 Life on Land.
- Urban soils are increasingly used for food production by urban communities, with an opportunity to address poverty and food security.
- Many of the adverse human health effects of urban soils are related to soil contamination with nutrients, potentially toxic trace elements, organic contaminants, mineral contaminants such as asbestos, radionuclides, and pathogens. Soil has a role in maintaining water quality as well, where contaminants are also an issue.
- An urgent human health issue in a holistic sense is that of the effects of climate change. Urban soils have the capacity to directly (through sequestration of carbon) and indirectly (by supporting urban vegetation especially trees) affect processes relevant to climate change.
- Environmental (in)justice issues are highly relevant in cities; for example, many studies show that communities having lower socioeconomic status also live in environments where soil contamination is more severe.

10.5 Questions

10.5.1 Checking Your Understanding

1. What are the risks and benefits, in term of the Sustainable Development Goals, of growing food for human consumption in urban soils?

2. How can soils in cities affect water quality?
3. Recall the various adverse human health effects that might occur if urban soils are contaminated with potentially toxic trace elements, organic contaminants, asbestos, radionuclides, and pathogens.
4. What are the ways in which urban communities can be involved with urban soils?
5. List some benefits to urban communities of being involved with urban soils. Which of the Sustainable Development Goals could be addressed from community involvement with soils?

10.5.2 Thinking About the Topics more Deeply

6. Discuss the benefits and risks of managed aquifer recharge in the context of human and ecosystem health.
7. Identify the mechanisms by which urban soils can be either a source of, or a sink for, atmospheric carbon.
8. What do you think the factors are, which result in environmental injustice involving soil or land in urban environments?
9. What are the barriers to urban communities having access to the information that they need about urban soils? How might these barriers be overcome?

10.5.3 Thinking Creatively About Urban Soils

10. Design a soil-based activity for an urban community, and show how the proposed activity addresses three or more of the Sustainable Development Goals.

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