Chapter 12
The Future of Urban Soils

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Abstract Urban soils are a global resource which presents many challenges and opportunities for human populations in cities. This chapter addresses several of these opportunities and threats, and highlights where scientific knowledge is uncertain or incomplete with implications for the direction of further research. Climate change and global warming is discussed in terms of soil resilience, carbon cycling and storage, pollutant fluxes, and changes in water inputs. We review studies finding that biodiversity change in the context of urban soils may be negative or positive and suggest that some urban environments can promote conservation of flora and fauna. Urban agriculture is a significant opportunity for beneficial use of urban soils, and the benefits and constraints of growing food and trees in cities are examined. Water Sensitive Urban Design is unevenly implemented globally and offers multiple benefits for sustainable development which are not fully realised. Urban soil contamination is presented as an ongoing issue, with discussions of both legacy contamination and emerging contaminants. We highlight the potential for urban soil remediation to be performed more sustainably by widespread adoption of life cycle assessment and emphasise the need to promote environmental justice in the context of urban soils worldwide. Finally, we draw attention to the opportunities to include indigenous, traditional, and local soil knowledge in parallel with scientific and technical understanding of urban soils.

Keywords Climate change · Urban soils · Biodiversity · Urban agriculture · Water Sensitive Urban Design · Soil contamination · Life cycle assessment · Environmental justice · Soil knowledge · Ethnopedology

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What you can learn from this chapter:

- How climate change, arguably the most pressing issue for humanity, could affect urban soils and the processes and ecosystem services occurring in them.
- How soil-based land use may change in cities as a result of increasing urbanisation and environmental change.
- What the ongoing and emerging concerns for urban soils are now, and are likely to be in the future.
- Some of the issues relating to urban agriculture, gardening, and forestry.
- Why urban soil remediation is likely to require a thorough assessment of the complete life cycle of remediation activities.
- Why issues related to urban soils will remain an important component of environmental justice.
- That there are different ways of knowing about urban soils, not restricted to the purely scientific.

12.1 Introduction to the Future of Urban Soils

There is slow, but increasing recognition of the importance of soil in urban environments. Soil allows the existence of worthwhile public open spaces; supports the practice of urban agriculture, horticulture, and private and public gardens; modifies urban hydrology; and is crucial in urban carbon cycling. In many cases, official recognition of urban soils has not considered soil in the context of ecological functions or sustainability (Teixeira da Silva et al. 2018; Calzolari et al. 2020). The gradually emerging awareness of soil's essential functions, however, is demonstrated by the increased consideration of soil resources in official urban planning documents. A good analysis of the awareness of soils in urban planning was conducted by Blanchart et al. (2019), who found that reference to a "soil resource" in urban planning documents for 15 cities in France increased significantly in the period from 2000 to 2015. Of course, soils have been considered for a long time in formal urban planning schemes, mainly from the perspective of their suitability for infrastructure development (Morris 1966). We also know from preceding chapters that soil contamination limits urban development in many jurisdictions.

The need to conserve urban soils for their ability to provide essential ecosystem services is an even more pressing issue given the continuing and projected global trend for human populations to increase in cities relative to non-urban areas (United Nations 2018). As cities grow in geographical extent, soil and associated green spaces are replaced in many instances by impermeable surfaces, and extraction of water increases (Alcoforado and Andrade 2008). Larger areas of soil become dumping grounds for urban wastes (Asabere et al. 2018), and fertile land used for food production is commonly lost (Schneider et al. 2012; Du et al. 2014). There is increasing evidence that urban green space, underpinned by functioning urban soil, has many beneficial effects on human health and well-being (Li et al. 2018), so a clear argument exists for ethical stewardship of urban soil. There are many ways of preserving ecosystem functioning, in its most holistic sense, in urban soils; Fig. 12.1 and the following sections address some of these.

In many cases the awareness of soils by urban authorities is biased towards the engineering properties of soils, and their potential risks such as those from contaminated sites and acid sulphate soils. The future of urban soil lies in our ability to move beyond seeing soil as an inert substrate or a threat, and building a general awareness of the ecosystem services provided by soils and the opportunities that soils create for more healthy and harmonious urban communities. In Chap. 1 we discussed the idea that soil knowledge was not widespread, nor was it widely used, in urban communities. It seems, then, that the story of living, functioning soils in cities will need to be told by soil enthusiasts and educators. This narrative will come in many forms; formalised in academic literature and textbooks like this one; passed down from the original, indigenous inhabitants of the lands our cities are built on; and in the years of practical experience of home gardeners and (peri-) urban farmers.

Fig. 12.1 A selection of entities and activities sustaining the future of soils in urban environments

12.2 Climate Change Effects

Anthropogenic climate change is arguably the most pressing environmental challenge currently facing humanity (Steffen et al. 2015). The potential for global climate change to affect humans is likely to be exacerbated in cities, which present environmental challenges of their own in the form of increasing urbanisation and urban population growth (Grimm et al. 2008).

Urbanisation is known to have caused historical declines in soil fertility and organic matter content (based on a study of Mayan cities by Douglas et al. 2018). Although these declines were not caused by climate change, they represent processes which decrease the resilience of urbanised ecosystems to climate change effects. The effects of urbanisation on soils persist and continue to occur into contemporary times, and climate change is likely to cause soil fertility and organic carbon decline as warmer temperatures promote microbial decomposition of soil organic matter (Lal 2017). There is evidence from several studies, though, that soil organic carbon can increase with urbanisation. For example, Asabere et al. (2018) measured greater soil carbon contents in Kumasi, Ghana, in long-term urbanised environments than in recently urbanised or even rural soils, related to waste disposal practices (Fig. 12.2). While Asabere et al. (2018) focused on urban horticulture, similar effects were found by Pouyat et al. (2002) for forest soils, with urban oak forests having greater organic carbon contents than their suburban and rural counterparts. The greater soil carbon storage in urban forests was attributed to lower leaf litter quality in urban forests, leading to less decomposition by soil fauna and microorganisms. In addition, we have already mentioned (in Chap. 10) how urban soils can accumulate large amounts of inorganic carbon, in the form of carbonate

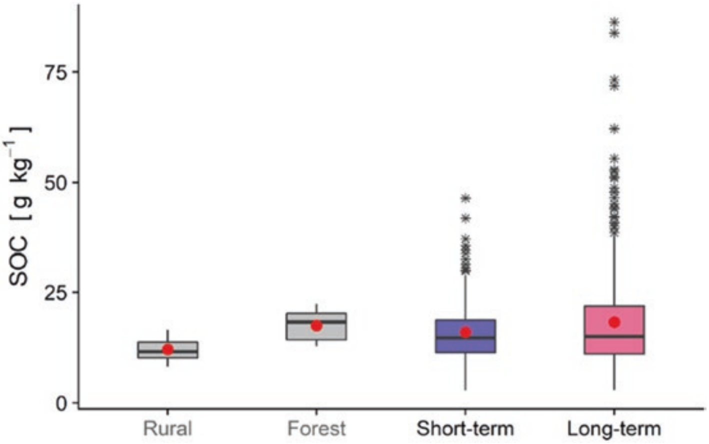

Fig. 12.2 Comparison of soil organic carbon content in the ≤ 2 mm fraction of soils from rural, forest, short-term urban, and long-term urban locations in Kumasi, Ghana (from Asabere et al. 2018, used under terms of CC-BY license). Solid red circles on box plots are arithmetic means (standard errors of mean are smaller than symbols)

minerals from construction and demolition wastes (Rawlins et al. 2015; Kolosz et al. 2019). In some city environments, however, urban forest soils may be more sensitive to the effects of climate change, and may lose carbon and nitrogen more rapidly than forests in rural areas (Hosseini Bai et al. 2015). Overall, urban soils collectively can contain large amounts of carbon, which should be accounted for and which are important in terms of the direction of their carbon fluxes to or from the atmosphere (Pouyat et al. 2006; Dorendorf et al. 2015; Calzolari et al. 2020). In particular, urban parklands can accumulate soil carbon (Wang et al. 2013).

The effects of a warming climate may be exacerbated in urban environments, due to the urban heat island effect which we discussed in Chap. 5 (Coutts et al. 2013). Warmer temperatures are also predicted to promote increased transfer of lower-volatility pollutants such as many POPs and Hg from soil to atmosphere. This increased volatilisation may in turn promote increased pollutant deposition into soils at higher latitudes. Higher temperatures may also, however, result in increased degradation rates of organic pollutants in soils (Nadal et al. 2015). Climate change is also expected to affect the behaviour of inorganic contaminants such as metals, such as increased fluxes of metal-bearing dust, or increases in metal bioavailability in drying soils (Paltseva and Neaman 2020).

Climate change is not restricted to increased temperatures, and changes in precipitation patterns are expected to alter hydrology and soil water contents. Most future climate scenarios are characterised by more frequent storm events which may be of greater intensity. Intense storm events have been known to increase the risk of pollutant transfer, for example, by flooding contaminated sites or increasing soil erosion (Maco et al. 2018). Combined with the observed and expected rises in sea level, flooding in coastal cities may also salinise soils, or result in longer seasonal or even permanent inundation of soils in low-lying areas.

The likely effects of climate change in some regions are decreased precipitation, and the effects of a drying climate on the water balance in soils are also important. Drying of soils and sediments and lowering of groundwater levels will obviously decrease plant productivity. Soil drying also allows greater aeration of soils, and may lead to increased acidification of potential acid sulphate soils (Devito and Hill 1999). The situation of many cities in coastal zones underlain by recent marine or estuarine sediments, the frequent disturbance of urban soils, and the extraction of groundwater may make acid sulphate soil formation an even more likely outcome in urban environments (for an example see Appleyard et al. 2004). Drying of soils and sediments may also have favourable outcomes, in that greater rates of aerobic decomposition of organic pollutants are possible (Noyes et al. 2009).

It is clear that more needs to be known about climate change and its effects before we can predict its effects on urban soil environments with any certainty. Nevertheless, it is very likely that climate change presents risks to urban environments, and that proper management of urban soils can have various roles in limiting those risks.

12.3 Urban Soils and Biodiversity

The loss of biodiversity on Earth is sufficiently critical that it exceeds the "safe operating space for humanity" defined by the planetary boundary concept (Steffen et al. 2015). Urban environments, including soils, are commonly thought to have less biodiversity than comparable natural environments (Foley et al. 2005; Albrecht and Haider 2013). These losses in biodiversity are related to habitat loss from urban land use change, altered hydrology, food consumption with its concomitant land requirements for production, and waste generation (McDonald et al. 2019). The conclusion of lower biodiversity of soil organisms in urban or contaminated environments is supported by some studies (e.g. Kozdrój and Van Elsas 2001; Uno et al. 2010), but not by others (e.g. Pavao-Zuckerman and Coleman 2007); the large number of potential controls on soil biodiversity means that it is hard to generalise results. Some studies have found that while the total numbers or biomass of organisms was lower in urban soils, the taxonomic diversity was not significantly different from non-urban soils (Pavao-Zuckerman and Coleman 2007; Santorufo et al. 2012). It may also be true, however, that urban environments present opportunities for conservation of biodiversity (Knapp et al. 2009). In some urban areas, biodiversity can increase in situations such as residential gardens or urban agriculture which include non-native plant species (Low 2003; Orsini et al. 2013), although whether or not this extends to soil organisms is uncertain.

Vegetated, unsealed urban soil is clearly more common in sports grounds, parks, gardens and reserves (Calzolari et al. 2020), and even wastelands (Bonthoux et al. 2014), and so these land use categories represent sanctuaries or *refugia* for soil biodiversity. For example, as mentioned in Chap. 8, Ramirez et al. (2014) found a rich diversity of soil microorganisms and invertebrates in the soil of Central Park, New York City. The distribution of soil organisms in Central Park was also significantly related to soil properties such as soil pH. In Paris, France, the diversity of soil environments in urban public gardens was found to contribute to the diversity of above-ground plants and animals (Shwartz et al. 2013). It should be noted, however, that soil preparation prior to creation of parklands has significant effects on soil biodiversity; for example, imported topsoil can result in greater diversity (Vergnes et al. 2017).

Urban soil biodiversity can even be linked to human health outcomes, in terms of its effect on the diversity of human microbiomes and the consequent immune system functioning (Li et al. 2018). In contrast, undesirable biodiversity exists in urban soils in the form of increased populations of potentially pathogenic organisms in areas where inadequate sanitation exists or where wastewaters are used for irrigation (Pickering et al. 2012; see Chap. 8).

While plant and animal biodiversity in urban environments has received considerable attention, with much being known about how these organisms are affected by urbanisation, much less is known about soil organisms. Nevertheless, soils are unquestionably an essential part of any urban ecosystem, and their biodiversity affects their functioning. Since humans are also intimately linked to the urban ecosystem, there will be an ongoing need to learn about and understand both the effects of urbanisation on soil organism diversity, and the consequences of soil biodiversity and its dynamics for other organisms and compartments in urban ecosystems.

12.4 Urban Agriculture and Gardening

12.4.1 Urban Gardening for Food Production and Wellbeing

Urban agriculture – used in a general sense here to mean the growing of plants in cities to produce food crops – has significant potential to contribute to food production, particularly for urban inhabitants (Edmondson et al. 2020). The land area available in cities worldwide is sufficient to meet plant-based food requirements for the global urban population (Martellozzo et al. 2014), but there may be limitations in terms of the availability of a suitable water supply (Mawois et al. 2012), and balancing sustainable energy and water usage (Eriksen-Hamel and Danso 2010; O'Sullivan et al. 2019). Urban agriculture has the potential to increase urban biodiversity in the form of agro-biodiversity (Orsini et al. 2013; Taylor and Lovell 2015).

Apart from water availability, the main constraints on the expansion of urban agriculture may be the possibility of urban soils already being contaminated with potentially harmful chemicals or pathogens, and a need for soil information in urban communities. Since urban soils are commonly contaminated or degraded in some way (Kessler 2013; Wortman and Lovell 2013), the concern about contamination is a real one, for example, with metals such as Pb (Brown et al. 2016; Jacobs et al. 2017) or organic pollutants such as pesticides (Margenat et al. 2018). Importing soil materials and amendments can address this problem if the imported materials have low or negligible concentrations of contaminants (Jones and Healey 2010; Chakravorty 2019), but this is not always the case (Gómez-Sagasti et al. 2018). Amendment of soil used for urban agriculture with solid wastes can also improve soil properties, particularly organic wastes (Chap. 11, and Anikwe and Nwobodo 2002), but solid waste re-use can also result in risks of contamination (Clarke and Smith 2011). Similarly, although beneficial re-use of wastewater to irrigate crops is a strategy to improve sustainability, Amoah et al. (2005) found that, in urban agriculture in Ghana, wastewater re-use resulted in contamination of vegetables with bacteria and parasites. Wastewater irrigation to support urban agriculture can also cause leaching of nutrients to groundwater (Werner et al. 2019). Another option for increasing the sustainability of water supply to soils used for urban agriculture is to capture precipitation from the roofs of buildings. For a large sample of urban gardens in Roma, Italy, Lupia et al. (2017) showed that rainwater harvesting from rooftops could supply between 19 and 44% of urban food garden water requirements, depending on garden type and water use efficiency.

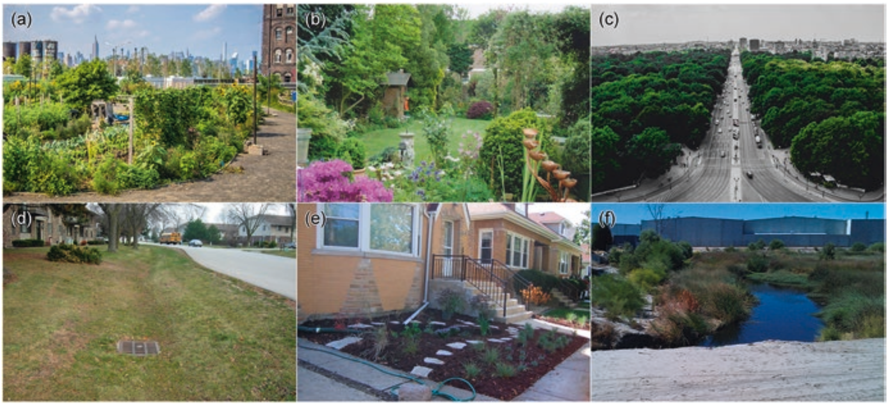

Fig. 12.3 Examples of urban green spaces and green infrastructure: (**a**) **urban agriculture**, New York, USA; (**b**) **suburban garden**, Blackheath, UK; **urban forest**, Berlin, Germany; (**d**) **roadside stormwater swale**, Greenfield, WI, USA; (**e**) **suburban rain garden**, Chicago, USA; (**f**) **meandered and revegetated stormwater drain**, Perth, Australia. (Photo credits (all flickr images are CC-BY-2.0): (**a**) Preston Keres, USDA, public domain; (**b**) monoclepix on flickr; (**c**) Tomasz Baranowski on flickr; (**d**) Aaron Volkening on flickr; (**e**) Linda on flickr; (**f**) Andrew W. Rate on flickr)

In Chap. 10 we discussed the benefits of urban agriculture and gardening for human health and the wellbeing of individuals and urban communities. Although the most critical need globally is food production, other common factors also appear to inspire urban gardening worldwide, and some examples of beneficial urban green spaces are presented in Fig. 12.3. For example, Home and Vieli (2020) who studied a selection of cities in Switzerland and Chile found that, in order of importance, the common factors which motivate urban residents to tend gardens were ecological restoration, social connection, and food production. In other words, as well as growing food, urban citizens are inspired by desires to (re)create natural environments, and connect with one another around a soil-plant-nature-based activity.

Soil-less urban agriculture is possible (e.g. variations on hydroponic systems) but is unlikely to offer the same community cohesion and mental health benefits as soil-based gardening. The soil-less gardening systems which are proposed, or even highly water-efficient partially soil-based systems such as vertical gardens, seem to be more suited to commercial urban food production (Bradley and Marulanda 2001). As such they fulfil a need to provide food, but are not likely to foster ecological restoration or community-building.

12.4.2 Urban Forestry

In addition to urban food production, one of the most beneficial uses of vegetated urban soils is for different forms of urban forestry, ranging from isolated street trees to larger nature reserves. The “urban forest” refers to the collective tree cover in a city environment. Trees in urban environments fulfil multiple functions, many of which are addressed in Chap. 10. The constraints common to many urban soils may, however, restrict tree growth and survival, and particular attention needs to be paid to making urban soils suitable for trees (Jim 1998). Urban forests favour conservation of biodiversity by providing habitat, food sources, and travel corridors for urban wildlife, from insects to birds and mammals. Humans benefit from the urban forest as well, since trees provide cooling by evapotranspiration and shading. The interception and infiltration of stormwater is also improved by trees in urban environments, reducing runoff and decreasing the likelihood of flooding. The future of urban forests seems to be hopeful in more economically prosperous nations, with widespread and increasing adoption of urban forest strategies by city-wide and local governments. There is less information about urban forestry or urban greening in developing nations, and the economic constraints in less prosperous countries often lead to an emphasis of development over protection of ecosystems (Jim 2013). Despite this, urban trees of many so-called developing nations are important assets.

One of the ways in which the urban forest provides services is by direct provision of food in the form of fruit and nuts. Street and garden trees form an important food source, especially for poorer residents in developing countries and also in the developed world (Kaoma and Shackleton 2014). Some studies have shown that as well as producing large yields, trees may take up less contaminants into their fruit than do vegetables from soil in urban areas (Colinas et al. 2019).

Since soils in cities are most commonly left unsealed in areas such as parks, gardens, sports grounds, and so on, a wide range of tree and other plant species are cultivated, including those native to an area but also introduced species. There is some concern about the disadvantages of non-native tree species, for example, their invasiveness or the changes in soil properties that they can cause (Barker 2008; Useni Sikuzani et al. 2019). In contrast, tree species which are not native to an area can also represent significant food sources, and have more rapid growth and consequently earlier achievement of urban cooling and rain interception effects. It should be noted that the needs of urban forestry and urban agriculture are not always compatible, since trees compete with food crops for solar radiation and water (Johnson et al. 2015). Urban trees themselves, however, can provide food for urban residents, through deliberate harvesting or informal foraging (McLain et al. 2014; Colinas et al. 2019).

12.4.3 Manufactured Soils

As cities grow and physical space becomes increasingly limited, green infrastructure features such as green roofs, vertical gardens, rain gardens, and constructed plant beds are likely to become more common features of urban environments. In many cases these green infrastructure features will contain manufactured soils – materials which may behave like, or be derived from, natural soils but which have different composition or layering from in situ soils. Such soils are classified as

Isolatic Technosols (IUSS Working Group WRB 2014), meaning that they are emplaced by humans, contain anthropogenic materials, and are located in some sort of container (i.e. the infrastructure).

Urban soil science will need to expand to more fully understand how such materials behave and change, in the situations in which they are placed. Some research has already addressed green infrastructure materials (e.g. Komlos and Traver 2012; Bouzouidja et al. 2018), and both commercial suppliers of manufactured soil materials and designers of green infrastructure also maintain a body of knowledge on this topic. Many issues will need clarifying; for example, whether or not organic soil amendments, which are commonly used in green infrastructure, will need screening for contamination (Gómez-Sagasti et al. 2018; Rodríguez-Eugenio et al. 2018). Green infrastructure projects will probably need to be subject to the same level of scrutiny (including life cycle assessment) as currently is required for brownfield redevelopment.

12.5 Water-Sensitive Urban Design

Water-Sensitive Urban Design (WSUD) aims to allow, as far as possible, all the components of natural water cycles to occur in urban environments (Wong 2006). One of the most important components of WSUD is that of maintaining a more natural balance between runoff and infiltration, given that impermeable surfaces are an unavoidable feature of urban systems (Jacobson 2011). This hydrological balance, and other components of urban water cycles such as evapotranspiration and groundwater recharge, will be dependent to a large extent on the exposed area of urban soils and their properties and management.

The principles of Water-Sensitive Urban Design are being incorporated into planning guidelines by government entities, particularly in Perth, Western Australia, where Water-Sensitive Urban Design originated in the 1990s (Whelans et al. 1994). Perth is a seasonally dry city (*Köppen-Geiger* Csa) having a mean annual excess of potential evapotranspiration over precipitation of 716 mm, and the city is reliant on groundwater for a large proportion of its water supply. In addition, Perth's location on a sandy coastal plain is reflected in its mainly highly permeable soils, with only about 12% of urban stormwater generating excess runoff (Cargeeg et al. 1987). Since Perth has such permeable soils, it is an urban environment that facilitates WSUD, but the low retention capacity of its soils mean that contaminant transport is likely. The drivers of WSUD in Perth include the need to decrease export of nutrients to sensitive environments such as rivers and estuaries, and the benefits of increasing infiltration to recharge groundwater (which is a valuable resource for metropolitan water supply). Favouring infiltration of stormwater into soil rather than exporting stormwater as runoff also increases evapotranspiration, cooling urban environments (Coutts et al. 2013) – a desirable outcome for seasonally hot cities such as Perth and many others worldwide.

In cities with less permeable soils, WSUD strategies are potentially even more essential, since the excess runoff generated by impermeable surfaces can cause soil and stream-bank erosion, affecting receptors such as waterways (Paul and Meyer 2001). Large proportions of impermeable surfaces also lead to increased risks of flooding, with subsequent public health and contaminant mobilisation issues (Jacobson 2011).

There is considerable awareness of the beneficial effects of WSUD (or "Sustainable Drainage Systems" (SuDS), or Low Impact Development (LID)) in many cities worldwide (Zhou 2014). This awareness has not yet led to full implementation of WSUD and related strategies, even though it can be more cost-effective than conventional stormwater infrastructure (Eckart et al. 2017). In the developing world, even more barriers to the adoption of green infrastructure such as WSUD exist (Jiusto and Kenney 2016), even though adoption of WSUD offers substantial improvements to many aspects of urban populations and environments (Mguni et al. 2016).

In terms of urban soils, green stormwater management strategies such as WSUD are about retaining (or re-introducing) soil processes into urban water cycles. Through benefits such as flood control, groundwater recharge, increased green space, and increased evapotranspiration, such strategies offer options to improve public health and liveability in cities worldwide. As discussed in Chap. 10, WSUD and related green urban water management systems address several of the Sustainable Development Goals, such as Goal 3 to ensure health, Goal 6 relating explicitly to sustainable water management, and Goal 9 which includes building of resilient infrastructure (United Nations 2015). Implementation of green stormwater management, which depends to a large extent on urban soils, will not necessarily fix global issues such as climate change and biodiversity loss, but it presents numerous opportunities to improve the quality of life for the world's increasing urban population.

12.6 Soil Contamination

Contamination of urban soils is, of course an ongoing problem by itself, independent of the imperatives of environmental justice. Many pollutants, as we have seen in previous chapters, persist in soils for very long times or even indefinitely, and soil remediation is costly and may not be performed at all. As a result, historical soil contamination continues to be a concern in urban environments, especially as land uses change to accommodate burgeoning urban populations. Humanity is also very accomplished at unearthing or releasing existing hazardous materials, creating new contaminants, or simply recognising that substances we previously thought were harmless are almost certainly not. The topic of "emerging contaminants" has effectively become a research field in its own right.

12.6.1 Ongoing and Legacy Contamination and Brownfields

Legacy contamination is contamination that continues to be an issue after long time periods have elapsed. Of course, some legacy contamination has been used to generate archaeological information, as discussed in Chap. 2. The phenomenon of longevity means that legacy contaminants are persistent, such as trace elements or persistent organic pollutants (POPs), and the term particularly applies to substances where regulation has substantially restricted their use, but where they still present a potential risk. The legacy contaminant of most ongoing concern is probably lead (Pb), but legacy issues also exist for persistent organic compounds such as polycyclic aromatic hydrocarbons (PAHs), and asbestos.

Brownfields are sites, commonly in urban areas, where an industrial source of contamination such as a smelter or factory previously operated but is currently derelict or has been demolished, leaving vacant but contaminated land. As described by Albanese and Cicchella (2012), increases in urban populations also increase the demand for land for residential purposes. Effective remediation then needs to be conducted to avoid putting residents at risk of exposure to brownfield pollutants. Even before development, brownfields have been used for activities such as gardening, in which cases risks still existed. For example, concentrations of As and Pb in allotment gardens at a former industrial site in Newcastle, UK, exceeded environmental guidelines (Pless-Mulloli et al. 2004).

As we discussed above, in the context of environmental justice, lead pollution in soils still persists. This is despite complete bans on the use of leaded paint beginning in 1909 in France and in most other countries by the early twenty-first century, and similar bans on the leaded fuel additives such as tetraethyl lead by the late 1990s in the USA (with later complete bans in Europe and other countries). Soils in many cities worldwide have been found to have legacy lead contamination, and several examples are shown in Table 12.1. (Note that Table 12.1 has notable omissions from developing countries, such as on the African continent, partly since use of leaded fuels is still widespread (Maas et al. 2010; Sellami et al. 2020)).

Although we have focused on lead, legacy contamination with other pollutants is also, unfortunately, relatively common (Nadal et al. 2015). For example, Qu et al. (2019) found substantial contamination of urban soils of Napoli, Italy, with organochlorine pesticides, polychlorinated biphenyls (PCBs), and polycyclic aromatic hydrocarbons (PAHs). From Table 12.1 it is also apparent that, while the expected sources of legacy contaminants may be common (traffic and pigments for Pb), there are other sources which need to be considered, some of which (like shooting ranges or archaeological artefacts) may be unexpected. The same caveat would apply to contamination of urban soil with any persistent substance, and that is one good reason that a Preliminary Site Investigation (Chap. 11), which would include a site history, is essential for management of any projects involving use of disturbance of urban soil or sediment.

Table 12.1 Examples of contamination of urban soils with lead with sources identified as "legacy" or "historical"

Urban area	Country	Assumed legacy Pb source	References
Melbourne	Australia	Lead-based paints in older buildings; traffic sources of leaded fuel emissions	Laidlaw et al. (2018)
Sydney	Australia	Lead-based paints in older buildings; traffic sources of leaded fuel emissions	Rouillon et al. (2017)
Copiapó	Chile	Mining (e.g. tailings) and smelting; industries	Carkovic et al. (2016)
Beijing	China	Pigments; traffic sources of leaded fuel emissions	Xia et al. (2011)
Nanjing	China	Industries, pigments (cultural layer); industry, traffic (contemporary surface)	Zhang et al. (2005)
Lefkosia	Cyprus	Older developed areas in the city	Zissimos et al. (2018)
Athens	Greece	Former shooting range	Urrutia-Goyes et al. (2017)
Napoli, Roma	Italy	Road traffic	Cicchella et al. (2015)
Mexico City	Mexico	Traffic sources of leaded fuel emissions	Morton-Bermea et al. (2011)
Dunedin	New Zealand	Lead-based paints in older buildings; traffic sources of leaded fuel emissions	Turnbull et al. (2019)
London	UK	Lead-based paints in older buildings; traffic sources of leaded fuel emissions	Kelly et al. (1996)
Newcastle	UK	Ash from power-from-waste generation	Pless-Mulloli et al. (2004)
Multiple urban areas in California	USA	Lead-based paints in older buildings; highway sources of leaded fuel emissions	Mielke et al. (2010)
New York	USA	Lead-based paints in older buildings; automobile emissions	Mitchell et al. (2014)

12.6.2 *Emerging Contaminants*

A wide range of synthetic chemicals are manufactured in contemporary human societies to meet the demand for health and medical products, personal care, packaging, industrial uses, and so on. As a result, many of these compounds are entering receiving environments such as soil, water, and air. In many cases involving recently developed compounds or materials, though, there is currently insufficient knowledge of their human health or ecological effects. Advances in technology have introduced many new materials into widespread use, and a proportion of these are potential contaminants. In parallel, advances in chemical analysis techniques have made it possible to detect and measure a wide range of new and existing compounds at trace concentrations. The term *emerging contaminants* (or "contaminants of emerging concern") was used as early as the 1980s (and somewhat later for soils) to describe substances that were not usually considered when assessing contamination of environmental compartments. Of course, many of the early emerging contaminants are now well-known and, in some jurisdictions, regulated as pollutants (e.g. PBDE flame retardants, or neonicotinoid pesticides). The types of materials considered include plasticisers, pharmaceuticals including endocrine-disrupting chemicals, chemicals used in cosmetics, nanoparticles, preservatives, plastics and microplastics, flame retardants, antibiotic-resistant bacteria, by-products of water treatment, and numerous others (Sauvé and Desrosiers 2014).

Given the large concentrations of human population in urban centres, it is not surprising that many emerging contaminants have been found in urban soils. In some cases, an anthroposequence of contamination has been observed, with concentrations of PBDEs in soils decreasing from intense urban to rural areas (Mahmood et al. 2015). In other examples, there is no clear effect of land use on the distribution of emerging contaminants (Karpuzcu et al. 2014). Similarly, microplastics in urban soils have not, so far, shown a consistent effect of urban land use. Rafique et al. (2020) found similar concentrations of microplastic particles across a range of urban and peri-urban land uses in Lahore, Pakistan. In contrast, Choi et al. (2020) found that land use did have an effect on microplastic concentrations in urban and adjacent soils (Fig. 12.4). Similarly, Lutz et al. (2021) showed an effect of land use on the concentrations of microplastics in urban stormwater drains. The findings of

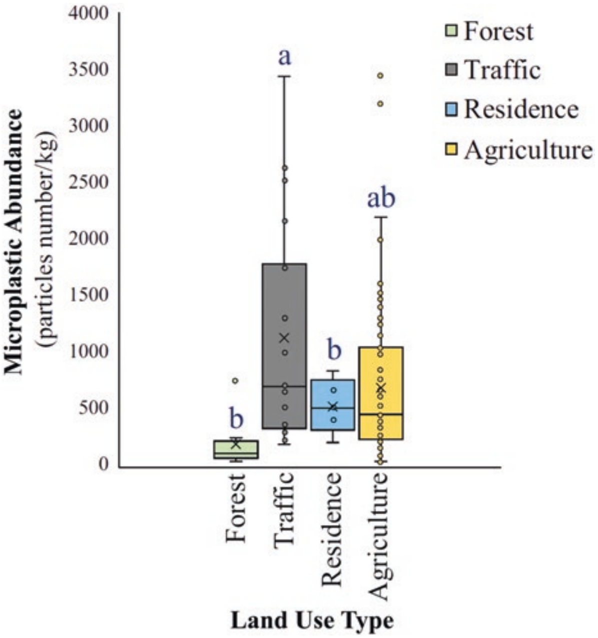

Fig. 12.4 Microplastic concentrations in soils for different land use types in Yeoju City, Republic of Korea. Different letters above each box mean a significant difference ($p \leq 0.05$) between mean values in each land use category (redrawn from Choi et al. (2020); used with permission from Springer)

Choi et al. (2020) and Lutz et al. (2021) suggest that more attention should be paid to examining the interaction of urban soils and land use as controls on terrestrial inputs of microplastics into oceans.

Considerable worldwide attention has been given recently to the issue of soil and groundwater contamination with poly- and perfluorinated alkyl sulfonates (PFAS). The concern with PFAS relates to their uncontained usage in large amounts in flame-retardant firefighting foams (especially at aviation facilities), a use for which they are very effective. The PFAS represent a large group of related compounds which resist environmental degradation, and therefore persist for long periods of time in soil and groundwater (EPA 2017). PFAS can also bioaccumulate and transfer up the food chain, and so behave like many other persistent organic pollutants (POPs) which were discussed in Chap. 7 (Conder et al. 2010). An additional concern with PFAS and related compounds is their high water-solubility – and for some PFAS compounds, relatively high volatility – both properties allow PFAS compounds to be mobile between environmental compartments (EPA 2017). PFAS-type compounds are known to affect the health of animals, but human health effects are poorly understood (U.S. EPA 2019).

The phenomena of legacy and ongoing contamination, and of continuing emergence of new contaminants, mean that urban soil science will evolve to meet these challenges. In order to manage urban soil contamination correctly, the risks need to be known. To understand these risks, scientific and regulatory communities will need to collect data on the occurrence, distribution, and controls on the environmental behaviour of the contaminants. Importantly, we will also need to be able to measure the toxicological responses and identify and quantify the exposure pathways, for all receptors. Given that we have an incomplete knowledge of soil biodiversity, we may also need to identify a more complete range of receptors.

12.7 Life Cycle Assessment of Soil Remediation

There is an opportunity for longer-term planning around urban soil remediation if the cost-benefit analysis extends over longer time frames, and includes a life cycle assessment. The relevance of considering the longer-term impacts of remediation options is related to fossil fuel and energy consumption by many commonly used remediation methods such as excavation and disposal. Energy usage obviously has implications for carbon budgets, atmospheric warming, and climate change, but there are other factors which are relevant as well. Urban soil remediation decisions are based on multiple, often opposing, factors such as environmental protection and potential for income from redevelopment. As with any decision having multiple standpoints and stakeholders, there will also be differing and potentially opposing values placed on the various forms of amenity involved, whether these be ecologically, commercially, or socially motivated.

The increasing awareness of the importance of soil remediation which is sustainable is illustrated by the US Sustainable Remediation Forum, which produced a guidance document for remediation practitioners to conduct life cycle analyses and *footprint analyses* for remediation projects (Favara et al. 2011). The guidance is structured into nine steps, of which one of the most relevant here is the establishment of system boundaries. What this means is to identify which components of, or processes in, the life cycle of a project are relevant to include. The life cycle components and processes considered include energy (including transport), materials, processing, and waste treatment factors. Spatial boundaries are also considered, under on-site, local, regional, and global categories. The time frame over which impacts are considered also needs to be defined, as do any restrictions on the choice of remediation technology (e.g. restrictions resulting from availability or regulatory constraints) (Favara et al. 2011). The main innovations of completing a life cycle assessment for soil remediation are that (i) the environmental impact of the remediation itself is considered, and (ii) the environmental effects considered are expanded in scope to account for impacts from a more comprehensive spatial and temporal influence of the remediation project.

Perhaps independently of the trends towards life cycle and footprint assessments, there are indications that more sustainable, less energy-intensive remediation methods have recently been chosen in favour of less advanced methods. For example, the compilation of European data summarised in Fig. 11.1 show that, in several European states, in situ remediation is used for contaminated soils (European Environment Agency 2020). It is a reasonable assumption that a substantial proportion of these sites would be in urban environments. Similarly, an analysis of groundwater remediation choices for the "Superfund" sites in the United States of America (Simon 2020) shows several interesting trends which are apparent in Table 12.2. Energy-intensive remediation methods such as pump-and-treat have declined in use (from approximately 98% of sites in 1982 to 19% in 2017), whereas in situ groundwater remediation techniques became more commonly used (from 0% of sites in 1982 to 53% in 2017). Similarly for soils, in situ remediation such as chemical treatment and amendments increased in use over time, whereas soil vapour extraction, soil flushing, and somewhat surprisingly ex situ bioremediation decreased in usage between 1988–2002 and 2003–2017 (European Environment Agency 2020).

If life-cycle assessment of urban soil remediation or urban development projects becomes the norm, a potential benefit may be to introduce and normalise processes for non-market valuation of urban soil resources. So far, this has not been attempted widely, perhaps due to the difficulties in assigning monetary values to ecosystem services in heterogeneous urban soil environments (Saad et al. 2011; Greenhalgh et al. 2017).

Table 12.2 Soil and groundwater remediation trends at Superfund contaminated sites in the United States of America (modified from Simon 2020 and used with permission from John Wiley and Sons)

	Treatment technologies compared between 1988–2002 and 2003–2017 [a]	
Treatment category	Increased frequency of use	Decreased frequency of use
Ex situ source treatment	Physical separation	Soil flushing
	Recycling	Incineration
	Solidification/stabilisation	Aeration
	–	Thermal desorption
In situ source treatment	Soil amendments	Flushing
	Chemical treatment	Bioremediation
	–	Soil vapour extraction
	–	Solidification/stabilisation
In situ groundwater treatment	Chemical treatment	Vapour extraction
	Thermal treatment	Air sparging
	Bioremediation	–
	Permeable reactive barriers	–

[a] The 4 technologies showing the greatest increases, and the 4 technologies showing the greatest decreases, but limited to technologies used to remediate ≥ 10 U.S Superfund sites between 1998 and 2017

12.8 Urban Soil and Environmental Justice

The issue of environmental justice issues is becoming increasingly important, even developing into a key concern during the United States of America's contentious Federal election campaign in 2020 (Redd et al. 2020). Instances of inequity in environmental quality or access are still emerging, however. For example, lead poisoning in children in the city of Baltimore, USA, was recognised in the 1940s (Schucker et al. 1965). Segregation of Baltimore neighbourhoods by race and income, however, still means that some socioeconomic groups – residents who are poor, and/or have non-European ethnic backgrounds – still suffer the most from lead pollution (Zaleski 2020). In the specific case of lead toxicity, soil pollution is just one component of the problem, with issues such as legacy infrastructure and household dust contaminated with historical lead-based paint also needing to be addressed.

Forms of environmental injustice other than soil contamination are also relevant, and the issues are not restricted to the global north. In the Limpopo Province, South Africa, increasing urbanisation is a factor contributing to soil erosion, which inequitably affects the rural poor (Musakwa et al. 2020). On a more global scale, indigenous people have historically been subjected to colonisation or land appropriation from other ethnic groups, and in many instances this has led to environmental injustice with urbanisation as one of the drivers. Pollution of soil and other media is known for many indigenous peoples, with poverty decreasing indigenous people's capacity to address environmental injustice (Fernández-Llamazares et al. 2020).

Urban biodiversity, which depends to some extent on the area of exposed urban soil and its properties, can be linked to socioeconomic measures such as a deprivation index (Stewart et al. 2009). Urban residents' access to urban green space (which represents vegetated urban soil) is also unevenly distributed among different socioeconomic zones of cities such as Berlin, Germany (as described by Kabisch and Haase 2014). Inequity in access to urban green space could potentially be addressed by provision of green stormwater infrastructure, which would logically be needed in all socioeconomic zones of a city (Wendel et al. 2011).

Environmental justice as a social movement, as discussed in Chap. 10, had its origins in soil contamination issues. Degraded or contaminated soils and their uneven socioeconomic distributions in cities can foster an awareness of environmental justice. Part of the mandate for soil enthusiasts and educators, then, could be to highlight environmental justice inequities at the same time as empowering citizens to address soil degradation and pollution issues.

12.9 Indigenous, Traditional, and Local Soil Knowledge

Practitioners of any scientific discipline can find it difficult to acknowledge that non-scientific knowledge can stand on an equal footing with the understanding gained from the "scientific method". At the same time, people untrained in science commonly believe scientific principles to require an unreachable level of intellect and erudition, or may even become suspicious of science and scientists themselves. The intellectual detachment required to achieve the scientific method's ideal of objectivity may also have contributed, ironically, to self-reflection by some scientists and a questioning of the primacy of scientific knowledge over knowledge obtained in other ways. Fortunately, a recent trend in academia is to value both scientific, technical understanding and local, indigenous, or traditional forms of knowing. The argument over which form of knowledge, or which way of obtaining it, is superior then becomes irrelevant, in a worldview that considers all forms of knowledge to have some validity.

Soil knowledge is an excellent example of a discipline in which information and understanding can have multiple valid origins. The various types of soil knowledge have been considered in academia for a few decades. In one of the earlier studies, Winklerprins (1999) concluded that sustainable land management could be planned more effectively if "local soil knowledge" was considered. She defined local soil knowledge as *"…knowledge of soil … possessed by people living in a particular environment for some period of time"*. The advantages of considering such knowledge reflect the close relationship that local inhabitants have with particular areas of land and the soils underlying them. In contrast, scientific or technical knowledge often has an overview of issues, and detailed process-based understanding, both of which may be generalisable to specific situations. It makes sense, then, to combine both local and scientific soil knowledge, and integrate the generalisable mechanistic understanding with the intimate knowledge of specific soil environments gained from a local perspective.

Local soil knowledge is also called “ethnopedology” (or “indigenous soil knowledge”, “traditional soil knowledge”, or “folk soil knowledge” (Winklerprins 1999)). Barrera-Bassols and Zinck (2003) studied how academia has reacted to diverse forms of soil knowledge, and many of the academic responses seem to try to fit such knowledge into a scientific mould, for example, by looking for soil or landscape classification schemes within a body of local soil knowledge. More recent work acknowledged the detail inherent in local soil knowledge (e.g. a soil or landform classification), and that the knowledge was both practically oriented and did not require technical inputs in the form of laboratory analyses. A technical soil classification scheme is based on soil-forming processes and rigorous identification of certain features, but use of classifications based on local knowledge are more pragmatic and easily implementable, having their origins in the lived experience of land use and soil management (Barrera-Bassols 2015). Indigenous people have, by definition, the longest history of inhabiting a particular land area and interacting with its soils. In particular, many indigenous peoples have a belief system that explicitly considers soils and their origins and role in the cosmos (Pauli et al. 2016). A cosmology which includes soils would presumably also favour soil conservation, but we do not yet know of any evidence for the existence, in urban environments, of a credo which explicitly includes soils.

Much of the published work on local soil knowledge relates, understandably, to rural agriculture. Some studies on the importance of local soil knowledge in urban agriculture and gardening are emerging. In Chap. 10 we discussed the multiple health, social, and ecological benefits of urban agriculture and gardening. These are often community-building activities: as Teuber et al. (2019) point out, gardens are “… social ecological systems …” in which “… humans interact with the ecological environment through soil and plant cultivation”. Local soil knowledge allows urban gardeners to understand soil-plant relationships, conserve their soils, and implement novel soil management practices. A beneficial collaboration between stakeholders in urban soils would place local knowledge on an equal footing with scientific/technical knowledge and knowledge of urban policy (Teuber et al. 2019).

As an increasingly urbanised species, humanity still has an opportunity to develop a more holistic and compassionate attitude towards all of our urban neighbours: human, animate and inert, sentient and reflexive. Those of us who breathe, breathe the same air; we depend, every part of our ecosystems on the same water, the same land, the same soil. Urban soils stand at a multivariate intermingling of the traditional environmental compartments; and of human creativity, endeavours, follies, anxieties, and longings. The soils in cities, then, are one hub around which we can centre our collective efforts to preserve Earth’s fragile yet exquisite ecology, and build a kind and just society.

> *The soil is the great connector of lives, the source and destination of all. It is the healer and restorer and resurrector, by which disease passes into health, age into youth, death into life. Without proper care for it we can have no community, because without proper care for it we can have no life. — Wendell Berry (1996), The Unsettling of America: Culture and Agriculture*

12.10 Further Reading

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12.11 Summary

- The future of urban soils will involve substantial change due to increasing urbanisation, larger urban populations, changes in climate, and changes in societal attitudes towards issues like food production and soil remediation.
- Climate change will change urban soils. There are likely to be some significant risks for the soils in cities, such as contaminant mobilisation and soil erosion, associated with climate change. There may be some positive effects as well, such as increased degradation of organic pollutants. The response of urban soils to climate change is very complex, and not enough is yet understood.
- There is not yet enough knowledge about urbanisation effects on soil biodiversity.
- Use of soils in cities for urban agriculture and urban forestry is likely to increase to meet humanity's requirements for food, sustainable water management, and climate moderation.
- Soil contamination will persist in urban environments, in many cases with new or as-yet undiscovered substances. Remediation of this contamination is likely to require thorough assessment of the complete life cycle of remediation and development projects, requiring a better knowledge of how to value urban soils.

- As humanity continues to address the Sustainable Development Goals, access to soil-based ecosystem services will remain an important component of strategies to achieve urban environmental justice.
- Knowledge about urban soils will need to reflect a functional partnership between all stakeholders including scientists and technologists, regulators and policy-makers, and indigenous and local communities.

12.12 Review and Study Questions

12.12.1 Checking Your Understanding

1. List biological, chemical, and physical changes that might be expected in urban soils as a result of climate change.
2. What are some direct and indirect effects of urban soil management on biodiversity?
3. List the possible constraints on the utilisation of urban soils for growing plants to feed humans.
4. What is meant by Water-Sensitive Urban Design? What are its advantages and disadvantages?
5. What is "legacy contamination" of urban soil? For which contaminants is it relevant, and why?
6. Why do "emerging contaminants" become apparent? List as many examples as you can of emerging contaminants which have (i) become mainstream pollutants, and (ii) are emerging now.

12.12.2 Thinking About the Topics More Deeply

7. Consider a typical urban soil remediation project. If you were asked to prepare a Life Cycle Assessment for the project, what inputs of materials and energy, and broader environmental impacts, would you need to consider?
8. What are some ways in which we could use soil knowledge to work towards achieving environmental justice in urban environments?
9. What points would you include in an argument to support ethical stewardship of urban soils?

12.12.3 *Thinking About Urban Soil Remediation with Your "Left Brain"*

10. In which instances might local or traditional knowledge about soils enhance a purely scientific approach in the context of urban environments?

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