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Soil related ecosystem services in urban areas – a literature review

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Abstract. Urban soils considerably promote in maintaining the quality of life in urban systems, being a key indicator of the risk of urban population's exposure to harmful factors. The attention generally paid to urban soils and their ecosystem services is very small, if any, resulting in a general lack of awareness of the potential contribution that urban soils can provide not only to the wellbeing of residents but also in terms of mitigation and adaptation to the current climate crisis. In this context, the scope of the present paper is to: i) emphasize the importance of soil ecosystem services to urban sustainability; ii) propose, from the most recent knowledge, a contextualized list of ecosystem services provided by urban soils, iii) analyze the linkage between urban soils' ecosystem services and human well-being. Our hypothesis was that taking into account urban soils' services into urban planning strategy would contribute to the mitigation of the major environmental issues and to the development of sustainable and resilient cities. We performed a literature search (in Scopus, Web of Science and Science Direct platforms) to gain an understanding of which urban soil ecosystem services have been recognized. A list of 20 ecosystem services provided by urban soils was established. The existence of about 4 linkages for each urban soil's function, and of about 8 linkages for each of the ecosystem services to the human well-being was found. Three essential directions for future studies of ecosystem services of urban soils was recommended for ensuring urban sustainability.

Key words: urban soil, soil functions, urban sustainability, human well-being.

Introduction

Rapid urbanization, urban regeneration, economic cycles and natural hazards are only a few of the diverse factors that urban areas should address (Lopez De Asiain & Díaz-García, 2020). Resilience and sustainability are considered effective strategies to face any hazards and help the urban planning process (Pirlone et al., 2020). Since sustainable development goals viewed sustainability and resilience are inherently connected (UN, 2015), academic's understanding of these concepts is necessary for use in related fields (Fitzgibbons & Mitchell, 2019).

Sustainability is a broadly defined phrase (Toli & Murtagh, 2020; Zeng et al., 2022). Urban sustainability focuses on the persistence of a desirable outcome of urban environments over time. It is frequently defined by aspects like intergenerational justice, intragenerational equity, natural resource protection, economic viability and diversity, societal self-sufficiency, social well-being, and fulfillment of fundamental human needs (Toli & Murtagh, 2020). Sustainable development represents a long-term progress that meets human needs and improves their quality of life. Simultaneously, natural resources should to be used in a frequency and degree that is compatible with the ecosystem's regenerative potential (Zeng et al., 2022).

Resilience is a considered as a system's ability to 'bounce back' or return to a previous sustainable condition after stressors caused by any hazard (Sarker et al., 2020). Thus, the urban resilience is a city's capacity to adjust, adapt, and, most importantly, changes in response to various internal and external hazards (McGill, 2020). The Sustainable Development Goals specifically mention that cities should be "inclusive, clean, resilient, and sustainable (SDG 11)" (UN, 2015). That why urban management becomes a critical element of global efforts to address disaster risk and adverse effects of climate change. New urban policies should focus on the concept of resilience considering its importance for the future sustainability (da Silva et al., 2019).

A principle goal of urban design is to maintain human well-being, which requires integrated support for the restoration of urban biodiversity. This would help to synergize the link between man and nature and could be of benefit to all stakeholders' efforts to rearrange urban areas and enhance their resilience and regenerative potential. As the prevailing part of humanity lives in cities, the sustainable urban planning and architectural design are needed.

At the same time, urban biodiversity is subjected to many anthropogenic threats as air, water and soil pollution, urban sprawl, soil sealing, acid rain, climate change, deforestation of agricultural areas, introduction of alien or exotic species of plants and animals, etc. It is for this reason that urban areas should recognize the biodiversity importance and address the problem of its conservation and restoration (Zari, 2018).

Urban biodiversity is often underestimated. For example, the city of Mexico covers an area of 1,479 km^2, of which 41% is urbanized and 59% is agricultural (under protected status). As one of the world's most densely inhabited cities (8.8 million in rural areas and another 22 million in the city itself), Mexico has about 2% of all taxonomically described species in the world: 300 different plant species, 350 mammal species and 316 bird species, some of which are endemic (Pérez-Campuzano et al., 2016). Just as people are affecting biodiversity, so the loss of biodiversity, especially in cities, is affecting people in terms of increased climate change and changing ecosystem services in the urban environment. Conversely, increased urban biodiversity has positive effects (Lyubenova & Peteva, 2016; Taylor & Hochuli, 2015). Research shows that biodiversity in urban areas has a notable impact both on human physical (Aerts et al., 2018; Kilpatrick et al., 2017) and psychological health (Frumkin et al., 2017), as well as on social and cultural well-being (Botzat et al., 2016), economic prosperity and stability (Walsh et al., 2016).

Societies are embedded in ecosystems that depend on and influence the ecosystem services they produce. Ecosystem characteristics, such as species composition, green cover or growing conditions, modulate the type and size of ecosystem services. The governance regime, modern technologies and mechanisms for regulating the ecosystem itself affect the very benefits of services to society (Baro, 2016). In other words, ecosystem services are derived from the mutuality between ecosystems and societies, which together form a socio-ecological system.

The Millennium Ecosystem Assessment (MA, 2005) for the first time focuses on assessing the state and trends of changes in the ecosystems and their ecosystem services. The Millennium Assessment undoubtedly proved that the whole Earth's environment has significantly worsened and even degraded in the past 50 years. It also showed that the need for drastic change in people's thinking and environmental politics towards sustainable development at local, regional, national and global levels, is already imminent. An adequate understanding of the role of the urban environment and its repercussions to the human well-being (both economic, social, etc.) is crucial for development and implementation of management decisions towards sustainable use of natural resources maintaining ecosystem stability.

Ecosystem services (ESs) are the benefits (direct and indirect) that we receive free of charge from ecosystems; they are co-produced by interactions between ecosystems and humanity (MA, 2005). Ecosystems provide people with food, water, fuel, raw materials, medicinal plants, etc. Far more invaluable are all the intangible benefits that we consciously or not take advantage of - water purification and filtration, protection from erosion and floods, biodiversity conservation, spiritual prosperity, inspiration and aesthetic enjoyment of nature.

The Millennium Ecosystem Assessment (MA, 2005) emphasizes the concept of ecosystem services and demonstrated the close relation between ecosystem derived benefits and human well-being. This assessment divides ecosystem services into the following categories:

1) Provisioning - food, fiber, water, genetic resources, medicinal plants, herbs, raw materials, art and artistic products.

2) Regulatory - reflect the ability of ecosystems to regulate important natural processes such as: clean air, climate change, water quality and quantity (treatment), waste treatment, disaster management and prevention, erosion prevention, maintenance of soil fertility, control of biological processes, pollination, etc.

3) Supporting – all services that contribute to providing conditions for all natural processes and providing an environment for photosynthesis, soil formation, genetic diversity, etc.

4) Cultural - all intangible benefits of ecosystems - cultural, aesthetic and recreational value of the landscape, places for rest and recreation, spiritual and religious values.

Many of the fundamental ecosystems, processes and their services are often taken for granted and this is more expressed in urban dwellers which live in the most developed parts of cities (Muller et al., 2012). Complex environmental processes, such as relying on water and carbon storage, are out of the human insights (Elmqvist et al., 2013). Therefore, the degradation of ecosystems and their services could be regarded as a consequence to the increasing urbanization and the corresponding lack of understanding to the environment and of environmental benefits. For this purpose, the MEA is increasingly being used to focus public awareness of the crucial role of ecosystem services and functions not only for human well-being but even for human existence (Gomez-Baggethun & Barton, 2013). Awareness of citizens about their dependence on ecosystem services can raise their engagement to the environment and promote the urgently needed sustainable management of the urban ecosystems (Elmqvist et al., 2013; Anderson et al., 2014). Lack of awareness of the importance of the ecosystem services also affects environmental governance. Traditionally focused on ecosystem assessment, this approach now needs to integrate urban ecosystem services into urban policy and management (Primmer & Furman, 2012).

The link between ecosystems and human well-being is insufficiently acknowledged in the wider philosophical, social, and economic literature. Although human well-being is receiving much attention by academics, policy-makers, and practitioners, a little is understood about the well-being benefits derived from the natural environment and its ecosystem services (Summers et al., 2012). The Millennium Ecosystem Assessment (MA, 2005) provides a useful framework for exploring these relationships. From a well-being perspective, the MEA's value is its recognition of how well-being cannot be considered in isolation from the natural environment. The human well-being is composed of four primary components—basic human needs, economic needs, environmental needs, and subjective happiness (Dominati et al., 2010; Summers et al., 2012). In this review we will examine the potential linkages between urban soils' properties, the ecosystem services they provide and the human well-being (with its four components).

Ecosystem assessment represents an integrative approach addressing the above-mentioned issues that can be successfully implemented in urban planning and sustainable management. Ecosystem assessment in cities should be used as a tool for structured and targeted analysis of environmental changes and their impact on the quality of urban environment and quality of life. Such analysis should address all structural and functional units of ecosystems, their interactions with each other and with the abiotic environment, as well as the effect of these interactions on human life and activities. In many cases the ecosystem assessment reveals only the description and evaluation of ecosystem services without reflecting the holistic ecosystem approach. So, it is important to have in mind that these ecosystem services are a function of the complex state of the urban ecosystem as a whole.

Soil plays a key role in ecosystem existence and functioning as well as in global nutrient cycles and many other processes. Soils are a critical and a dynamic three-dimensional regulatory system that supports the delivery of various ecosystem services (Adhikari & Hartemink, 2016). The need for soil ecosystem services assessment and for integrating soil-ecosystem linkage in the land resource policy and management is emphasized by some authors (Adhikari & Hartemink, 2016; Bouma & McBratney, 2013; O'Riordan et al., 2021). The role of urban soils in the planning and design of sustainable cities is still underestimated (Anne et al., 2018). The soil functions' concept (Blum, 2005) includes six benefits a soil provides as follows: production of biomass, health prevention due to the pollutants disposal and retaining, gene reservoir, physical substrate for various human activities (infrastructure, agriculture, etc.), source of raw materials (clay, sand, etc.), reservoir of geogenic and cultural heritage. One year later, the European Commission has enlarged these features by adding the carbon storage ability of soil (CEC, 2006). It is well-known that soil functions strongly depend on soil quality, which was defined by the American Soil Science Society as "the capacity of specific kind of soil to function within natural or managed ecosystem boundaries…" (Doran & Parkin, 1994; Karlen et al., 1997; Karlen et al., 2003; Kibblewhite et al., 2008). The concept of assessing soil functions emphasizes the multifunctionality of soils as Drobnik et al. (2018) propose in recent review.

Soil functions are a result of the integration of its physical, chemical and biological parameters, as well as of the processes they concern (Schindelbeck et al., 2008). Soil quality is the capacity of a given soil to function within a natural or managed ecosystem boundaries, to maintain or to enhance environmental quality, to provide plant and animal productivity, as well as to support plant, animal and human health (Vrščaj et al., 2008). Urban soils considerably promote in maintaining the quality of life in urban systems, which is why they are a key indicator of the risk of exposure of the urban population to the impact of harmful factors. There are no other soils to be exploited with such intensity based on the number of users per square meter of soil surface, such as urban soils. Although their role in providing ecosystem services does not differ from that of soils in non-urban areas, data revealed that many times more people, plants and animals benefit from the functions of soils in the settlements.

Generally, the contribution of urban soils to the cities' resilience can be considered in four main areas:

1) Prevention of hazards - protection against flood by water infiltration; decomposition of hazardous organic pollutants by soil microorganisms; retention and immobilization of pollutants; protection of groundwater from contamination; an environment for alternative rainwater management;

2) Provision of renewable resources of water and food - plant products; groundwater recharge;

3) Basement and medium for engineering - they serve as substrata for infrastructure, commercial and housing projects, rest areas, recreation and sports activities;

4) Quality of the urban environment and quality of life - foundation for urban vegetation (green patches, green corridors, urban gardens, parks) influencing climate and capturing air pollution at local and regional level (Foldal et al., 2022; Petrova et al., 2022).

Recognition of the role of urban soils and their functions is scarce, if ever, considered in the process of urban planning (Blanchart et al., 2019; Teixera da Silva et al., 2018). In most cases, soil is perceived by urban planners as a simple supporting platform or as a waste to be disposed of after being removed from its original location. Therefore, with few relevant exceptions, the attention generally paid to urban soils and their ecosystem services is very small, if any, resulting in a general lack of awareness of the potential contribution that urban soils can provide not only to the wellbeing of residents but also in terms of mitigation and adaptation to the current climate crisis (Rawlins et al., 2015; Calzolari et al., 2020).

Obviously, many of soil related ecosystem services are the same in natural, rural and urban areas and there are many literature reviews on soil related ESs in general (Adhikari & Hartemink, 2016). Nevertheless, the number of studies focused especially on ecosystem services of urban soils significantly increased in the last 2-3 years (O'Riordan et al., 2021) which highlights the gaps in knowledge in this field of research.

In this context, the scope of the present paper is to: *i*) emphasize the importance of soil ecosystem services to urban sustainability; *ii*) propose, from the most recent knowledge, a contextualized list of ecosystem services provided by urban soils, *iii*) analyze the linkage between urban soils' ecosystem services and human well-being. Our hypothesis was that taking into account urban soils' services into urban planning strategy would contribute to the mitigation of the major environmental issues and to the development of sustainable and resilient cities.

Material and methods

Literature search

We performed a literature search to gain an understanding of which urban soil ecosystem services have been recognized, discussed, measured through empirical data or modelling studies. The initial identification of scientific literature in the field was done by searching for articles in Scopus, Web of Science and Science Direct platforms (Fig. 1). The keywords searched were urban soil, ecosystem services, urban sustainability (first stage of the review process). Some additional key words associated with soil functions and soil processes were also used as the definitions of the concepts of soil ecosystem services and soil ecological functions are quite interrelated (Vasenev et al., 2018). This interrelation is mentioned by Baveye et al. (2016) who stressed that it is important to consider both soil functions and ecosystem services, so long as they are articulated in relation to soil properties and processes (Bünemann et al., 2018).

Second stage screening of the outputs included manual removal of duplicates, and after that by checking the title, abstract, and conclusions. Third stage screening revealed 132 papers that were relevant from all 413 found at first stage (O'Riordan et al., 2021).

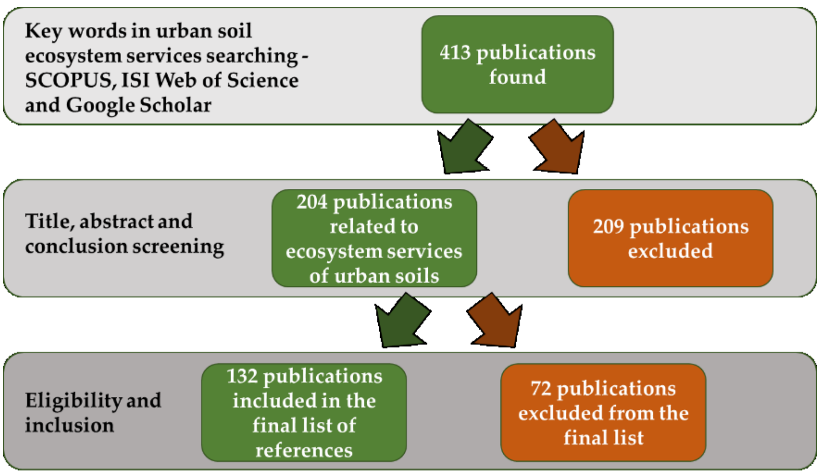

Fig. 1. Literature review process

The exclusion criteria used at the second stage of the screening process are presented in Table 1. From all 413 publications found only publications that addressed any context of soil in urban areas or mentioned soil as a factor of urban sustainability were selected – 204 passed and 209 excluded. At third stage, the thematic relevance was subjected to screening and total of 132 publications that addressed ecosystem services provided by urban soils or urban sustainability were included into review analysis.

Table 1. List of criteria used in the three-step review process

Stage	Inclusion criteria	Exclusion criteria
1. Identification	Key words	no
2. Title, abstract and conclusion screening	Thematic relevance to ecosystem services, urban sustainability, urban soils and synonyms	Unrelated topic to urban soil, abstract out of scope, no access
3. Eligibility and inclusion	Thematic relevance to urban soil-related ecosystem services and urban sustainability/urban resilience	Content out of scope

Data analysis

Urban ecosystems are usually considered as the antithesis of natural (or agricultural) ecosystems. Furthermore, this division of "urban areas" and "natural areas" contribute to the complicated understanding of the interconnected social and environmental processes especially in relation to the urban green systems (Baruch et al., 2021; Elmqvist et al., 2013; James et al., 2009). The urban ecology is needed to overcome this division by integrating ecosystem science within urban planning to understand cities as interconnected socio-ecological systems (Niemela et al., 2011; Pickett et al., 2008; Pickett et al., 2013a,b). Both urban and natural areas have to be regarded as complementary parts of one bigger hierarchical ecosystem. Based on this finding, the boundaries between cities and adjacent peri-urban areas become diffuse, as does the boundary between urban areas and the urban green infrastructure (Andersson et al., 2014). From this conceptual understandding, the ecosystem services provided by urban vegetation are treated as a co-product of complex environmental and social processes (Andersson et al., 2007; Jansson & Polasky, 2010).

The literature review revealed that the assessment of ecosystem services in urban areas is rarely linked with soils. There is still a lack of understanding that urban soils and the ecosystem services that they provide are one of the key factors for addressing many environmental problems in cities (Blanchart et al., 2018). Based on the analysis of scientific literature found, a list of 20 ecosystem services provided by urban soils was established (Table 2). The list follows the 4 categories ecosystem services defined in the MEA (e.g. regulating, provisioning, supporting and cultural services) (MA, 2005). All 20 listed ecosystem services demonstrate that the urban soils have significant potential to address the main environmental issues faced by urban ecosystems.

There is still one basic prerequisite - the concept of an ecosystem approach should be implemented in the assessment of ecosystem services. The ecosystem approach aims at biodiversity conservation combined with the sustainable management of natural resources and the benefits they provide. This can all be achieved by appropriate scientific methodologies according to the structure, processes, functions and interactions between organisms and their environment (Adhikari & Hartemink, 2016). All of this could be used from the local authorities and municipalities as a basis for integrating the urban soils derived benefits in the construction and management of a sustainable urban areas.

Table 2. List of targeted ecosystem services supported by urban soils

Category	Ecosystem service
Provisioning	Food production
	Fiber and raw material
	Ornamental resources
	Biochemical products and medicinal resources
Regulating	Air quality regulation
	Climate regulation
	Carbon storage and GHG regulation
	Water purification
	Waste treatment
	Noise attenuation
	Natural hazard mitigation
	Filtering nutrients and contaminants
	Biological control of pests and diseases
Supporting	Nutrient cycling
	Water cycling
	Soil biological activity
Cultural	Heritage conservation
	Leisure
	Science and education
	Spiritual and religious inspiration

The role of soils in the provision of ecosystem services remained underestimated for a long time. Furthermore, the concepts of ecological functions of soils and ecosystem services were developed independently from one another (Vasenev et al., 2018). Thus, revealing of the relationships between the urban soil properties, ecosystem services and human well-being is crucial for future urban planning and the transition to urban sustainability. This is demonstrated on Fig. 2 which shows the presence of about four linkages for each of the soil properties to the ecosystem services, and of about eight linkages for each of the ecosystem services to the human well-being. Each one of the relationships found was tracked and analyzed in order to fully discover the significance of the ecosystem services supported by urban soils.

Results and discussion

Relationship Urban soil properties - Provisioning ecosystem services – Human well-being

Soils specifically provide a number of products useful for humans and determining their well-being classified in two major groups:

- Provision of food, wood, fibers, medicinal and ornamental resources. By enabling plants to grow, soils provide a service to humans. Soils physically support plants and also supply them with nutrients and water. The natural capital stocks insuring the provision of these services are embodied by many soil properties like structure, water holding capacity, nutrients fertility, storage of seeds and other germs (de Groot et al., 2002). All four components of human well-being are affected by these ESs provided by urban soils, but may be the relationship with economic needs is the strongest, followed by the basic needs (as the urban soils are not the primary producer of food and raw materials).
- Provision of raw materials: soils can be source of raw materials like, for example, peat for fuel and clay for potting (de Groot et al., 2002). These materials stocks are maintained by the soil content, texture, pedogenesis and other properties. They could address some basic human needs (e.g. building materials), some economic needs (e.g. workers in these sections of industry) or even subjective well-being (of artists, craftsman, etc.).

Although there was found a notable lack of studies on provisioning services derived by urban soils, particularly on food production, which is in contrast with most nonurban soil ES literature, we could discuss some of them as we consider meaningful to the both human well-being and the transition to the urban resilience and sustainability.

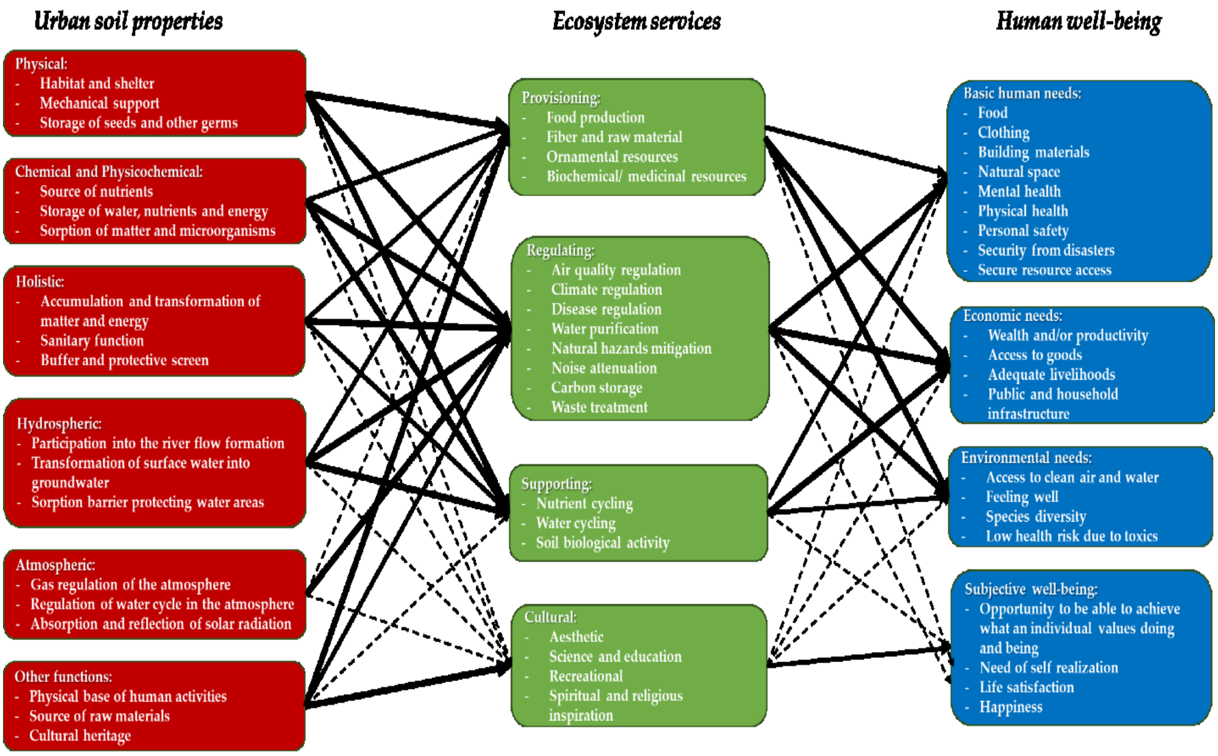

Fig. 2. Relationships between ecological functions of urban soils, ecosystem services and human well-being (according to the literature review process). Solid lines indicate direct relationships, and dotted lines indicate indirect relationships. The arrows width represents the intensity of linkage.

Food production

Soils are the media for plant growth and development, as well as source of nutrients and water, so, by sustaining plants, urban soils provide a service to people (Dominati et al., 2010; Dominati, 2013). Urban farming is not possible at a large scale, so it is attributed mainly to the peri-urban areas, although there are possibilities of food production on rooftops, in backyards, and in community gardens (Andersson et al., 2007). It is obvious that cities can produce a very small part of the total food amount that their inhabitants need (Gómez-Baggethun Barton, 2013). Even though, the increasing demand for food produced by urban agriculture may substantially enhance primary production and associated nutrient cycling in urban soils. Furthermore, the urban allotment garden could strengthen their role in food security and resilience, especially in periods of crises.

As a whole, there are no many studies that examine spatial variations of urban agriculture in cities and megacities. More often are studies concerning the urban agriculture in towns and villages. We found some studies from Portland (McClintock et al., 2016), Chicago (Taylor & Lovell, 2012) and Rome (Pulighe & Lupia, 2016), which reported a significant variation in the extent and spatial patterns of residential urban agriculture. Main factors determining the urban agriculture was found to be firstly the housing density and housing types, followed by some demo-graphic, cultural and economic factors. For example, an increasing number of rural farmers in Africa and Asia move to urban areas, and this increases the demand for food production on urban soils by urban agriculture (FAO, 2015). Some studies concerning urban agriculture in African cities were also found. Mackay (2018) reported that the urban agriculture in two mid-sized Ghanaian cities is realized in backyard gardens and undeveloped private lots, as well as in urban parks, forests or farms, along roads, bridges, etc. Other authors stated that the urban allotments are essential for food security in periods of crises (Barthel et al., 2010; Barthel & Isendahl, 2013). For example, Altieri et al. (1999) found that urban gardens of Havana in 1999 have produced more than 8500 tons of fruits and vegetables, 7.5 million eggs and 3650 tons of meat.

Ornamental resources

Urban soil provides a substrate for development of various types of vegetation in different landscapes (parks, gardens, yards, along roads, etc.) (Wells et al., 2009). The chemical and physical properties of the soil are not often adequate for growing edible plants and a top layer substitution may be required. The selection of ornamental species should be carefully considered, because in urban environ-ments plant genotypes should have multiple tolerance traits that can allow growth (even in sub-optimal conditions) (Francini et al., 2022). Ornamental plants and relevant horticulture practices themselves provide multiple environ-mental, economic, social, and aesthetic benefits for human well-being, so urban soils have both direct and indirect significance for ESs delivery.

In a recent review Sharifi (2021) pointed out that urban vegetation has increased its signify-cance in settlements due to enormous potential to address some of the major urban environmental problems such as climate change, air pollution, noise pollution, flood mitigation, etc. Other studies revealed that urban green infrastructure provide many ecosystem services, such as clean air, microclimate regulation, spiritual and aesthetic inspiration to citizens (Brzoska et al., 2021; Chiesura, 2004; McClintoc et al., 2016; Pauleit et al., 2011; Petrova, 2020; Tzoulas et al., 2007). The present literature survey proved that although soil contributes to the ecosystem services of urban greenery as much as plants, its role and sustainable management, even in urban green spaces, are often underestimated and neglected and remain focused primarily on plant status (Hyun et al., 2022; Petrova et al., 2019; Petrova & Petkova, 2023).

Medicinal resources

Urban agriculture refers to food production systems inside city boundaries or densely populated areas and as we previously said the agrobiodiversity of urban gardens can be significant and not limited to fruit and vegetables. Some studies revealed that large numbers of medicinal plants (45%)were encountered in the backyard gar-dens in rural zone of Santarem, Brazil, probably served as local sources of pharmaceuticals (Lin et al., 2015). Madaleno (2000) found that in Belem 95% of garden space was devoted to fruit trees, 67% to medicinals, and 22% to vegetables.

Medicinal plants distribution over the urban areas is not found only in the back-yards where the soil is less affected by urbanization load, but also in all available public green spaces – along the roads, between buildings, in parks, etc., where increased amounts of potentially toxic elements in soils are usually found. These plants are easily accessible to everyone who wants to collect and use them for therapeutically purposes without having in mind the potential health hazard. Some studies explored the content of potentially toxic elements in underground and aboveground phytomass of *Plantago lanceolata* and *Taraxacum officinale* sampled from the city of Plovdiv, Bulgaria (Petrova et al., 2013; Petrova et al., 2014). Data obtained were compared with the maximal permissible content of these elements in herbal medicines, given by WHO (2007) and revealed an excess of Cd, Cr, Pb and Zn. The population generally uses the herbal medicine for a continuous period to achieve the desirable effects. A prolonged consumption of such plants, containing heavy metals at toxic concentrations, may cause a chronic health hazard. This fact highlights the significance of urban soil quality to the ESs provided and to the human well-being.

Relationship Urban soil properties - Regulating ecosystem services – Human well-being

Soils also provide regulating services which enable humans to live in a stable, healthy and resilient environment. The regulation that these services provide come from soil processes which in turn depend on soil properties. Soil regulating services included in our framework are as follows:

• Flood mitigation: soils have the capacity to store and retain quantities of water by transformation of surface water into groundwater. Soil properties as structure and more precisely macroporosity, as well as processes like infiltration and drainage will impact on this ecosystem service. Therefore, urban soils can mitigate and lessen the impacts of extreme climatic events and limit flooding. All of these ESs are closely related to some of the human basic needs like security from disasters, economic needs like safety infrastructure, and even environmental needs like low health risk due to toxics (if flooding).

• Filtering of nutrients: if the solutes present in soil (e.g. nitrates, phosphates) are leached, they can become a contaminant in aquatic ecosystems (e.g. eutrophication) and a threat to human health (e.g. nitrate in drinking water) [7-8, 40]. Soils have the ability to absorb and retain solutes due to their structure, texture, physicochemical properties, buffer capacity. Therefore, urban soils drive the quality of run-off and drainage waters and wider water bodies such as ground water, lakes, rivers, influencing various human needs like access to clean water, heath safety, etc.

• Biological control of pests and diseases: by providing habitat to beneficial species, soils can support plant growth (rhizobium, mycorrhizae) and control the proliferation of pests (crops, animals or humans' pests) and harmful disease vectors (e.g. viruses, bacteria) (de Groot et al., 2002; Dominati et al., 2010). Soil conditions (e.g. moisture, temperature) determine the quality of the soil habitat and thereby select the type of organisms present. This service depends on both soil properties and the biological processes driving inter- and intra-specific interactions (symbiosis, competition). Its significance is the most express in terms of low health risk for citizens, but also in relation to the plant and animal (e.g. pets) health.

• Recycling of wastes and detoxification: urban soils can self-detoxify and recycle wastes due to their high adsorption, retention and buffer capacity. Soil biota degrades and decomposes dead organic matter into more simple forms that organisms can reuse (de Groot et al., 2002; Dominati et al., 2010; Summers et al., 2012). Urban soils can also absorb (physically) or destroy chemical compounds that can be harmful to humans, or organisms useful to humans. These regulatory services depend mainly on some biological processes in urban soils like mineralization and immobilization and therefore is also related to the natural capital stocks of nutrients available for soil biota or for chemical reactions. The importance of such ESs to human well-being could be related to some basic needs (physical health, security), economic needs (access to goods), and environmental needs (low health risk due to toxics).

• Carbon storage and regulation of N_2O and CH_4 emissions: soils play an important role in regulating many atmospheric constituents (Dominati et al., 2010), therefore impacting on both air quality and climate. Perhaps most important is the ability of soils to store carbon as stable organic matter revealing at off-setting greenhouse gases emissions. These ecosystem services are mainly based on soil properties like organic matter stocks, moisture and temperature, which regulate soil biota activity and thereby the production of green-house gases like nitrous oxide (N_2O) and methane (CH_4). Their contribution is more important to the human health, security from disasters, etc.

From all four groups of ecosystems services provided by urban soils, namely the regulating ones could be regarded as the key factors of the transition to the urban resilience and sustaina-bility. Because of the indirect benefits of regulation functions, they are often not recognized until they are lost or disturbed, but they are nevertheless essential to human existence on earth. Some of the actual environmental problems that they address are discussed below.

Air quality regulation

There are many relationships between soil and atmosphere, so urban soils are involved in regulation of many atmospheric constituent, thus impacting on urban air quality (Haygarth & Ritz, 2009). According to some authors, this soil benefit comprises the greenhouse gases (GHG) production and sequestration, as well as an influence on the ground air chemical compo-sition (Haygarth & Ritz, 2009; O'Riordan et al., 2021).

Soil interacts with air in both positive and negative ways for people's wellbeing. It is critical for plant growth and vegetation is increasingly used to improve air quality in urban areas. However, soil can negatively affect air quality through being a source of particulates and gaseous pollutants. Human health effects are mediated by the size, mineralogy and compo-sition (both chemical and biological) of the dust particles. Atmospheric dust also influences the global climate through effects on radiative balance and cloud formation (Giltrap et al., 2021).

There are several gas fluxes from soils resulting from microbial, chemical and physical processes. These include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), NO_x and ammonia (NH_3). Soils can also produce smaller amounts of volatile organic compounds (VOCs), hydrogen sulfide (H_2S) and sulfur dioxide (SO_2). While these have little influence on air quality at a global scale, they can impact air quality locally.

Gases and particulates may be removed from the atmosphere by wet (via precipitation) or dry deposition and consequently interact with either plants or soil. Pollutants that enter the soil can be subject to physical (e.g. adsorption, leaching), biological (e.g. plant uptake, nitrification) or chemical (e.g. oxidation/reduction) processes. These can result in the deposited material being bound to the soil, taken up by plants, re-emitted to the atmosphere or transported to waterways. The incorporation of nutrients from atmospheric deposition can be a source of nutrients, but it can also have negative impacts such as acidification of soils, eutrophication and other ecological effects (Gao et al., 2015).

Climate regulation

Climate regulation as an ecosystem service derived from urban soils is a consequence namely of soils' capacity to sequestrate carbon and emissions of GHG, revealing at regulation of global temperatures and precipitation. This is confirmed by many authors such as, for example, Smith et al. (2013) who highlighted that the ability of eco-systems to regulate global and local climate is provided by the processes of GHG sequestration, evapotranspiration, solar radia-tion absorption and reflection, etc. The New York City Afforestation Project recorded higher N_2O emissions where shrubs and compost were not incorporated prior to tree planting, highlighting that plant and microbial uptake of inorganic N is important in regulating N_2O losses from urban soils (O'Riordan et al., 2021; Pierre et al., 2016). In urban lawns in Melbourne it was found that reducing irrigation and fertilizer helped mitigate GHG emissions in garden systems, however, this needs testing in other soil types and environ-mental conditions (O'Riordan et al., 2021; Livesley et al., 2016)

Microclimate regulation

Citizens suffer frequently during summer from high day- and nighttime temperatures. Evaporation from the soil surface together with the evapotranspiration from urban vegetation provides a cooling effect and results in humidify-cation of the air (Lehmann, 2010). Both effects make the urban climate more comfortable for human health.

We found only one study that calculates the cooling effect at the site "Echterdingen" in Southwest Germany (mean temperature: 9.6°C, annual rainfall: 746 mm), near the airport Stuttgart with a Luvisol from Loess.

Data revealed at an available field capacity of approx. 230 l per square meter surface and 1.2 m depth for the Luvisol. According to the input data (available field capacity, mean temperature and yearly rainfall) a cooling capacity of 1500 MJ*h^{-1}*m^{-2} or 420 kW*h^{-1}*m^{-2} was calculated for the soil volume of the Luvisol measuring 1*1*1.2 m. This cooling effect is equal to the cooling capacity of an air conditioner used in middle sized rooms of approx. 20 m^2. Such an air conditioner consumes 1120 kWh annually whereas the Luvisol consumes no electrical energy (Lehmann, 2010).

The influence of urban vegetation on a local level is most expressed in urban parks where trees actively impact on shadowing and regu-lating temperature and humidity. An increase in the phytomass of the tree stand results in a decrease in soil and air temperature and an increase in soil and atmospheric moisture in the summertime (Kunakh et al., 2022).

Furthermore, the process of evapotranspi-ration contributes to the reducing of temperature and heat island effect as the significant share of energy is used for warming and evaporation of water (it has higher heat coefficient than air) (Calzolari et al., 2016).

Filtering of nutrients and contaminants

Rainfall drops on soil surface and starts flooding both horizontally by surface runoff and vertically by filtering through the soil.

Ziter and Turner (2018) found that urban soils under different conditions have different nutrient content. The lowest available phosphor-rus (considered as a proxy for potential P runoff) they revealed in urban soils of grasslands and open spaces in Madison (USA) while maximum was measured in soils of urban forests and developed land. When regarding the water purification as an ecosystem service provide by urban soils, we should have in mind that water quality has two components – the suspended material and polluting solutes (Keestra et al., 2018). Soils can enhance water quality to some extent due to the huge absorption capacity for retaining, immobilizing and chemically transfor-ming various nutrients and contaminants by weakly to strongly bonding them to organic or mineral soil constituents, and by such processes avoiding their release in groundwater, rivers, etc. (Gómez-Baggethun & Barton, 2013; O'Riordan et al., 2021; Nikolov et al., 2019; Petrova et al., 2022). Filtering water through the soil reduces the capacity of water to transport sediments and simultaneously is a prerequisite to retain sub-stances by adsorption to organic matter and clay particles. When the solutes retained in urban soils (nitrates, phosphates, etc.) are leached, they can be transported to the aquatic ecosystems and threaten their equilibrium as well as human health. In this context, it is obvious that these buffering and filtering services of soil are crucial for maintaining sustainable water reserves.

Water flow regulation

One of the major ecosystem services is related to the water flow regulation and pro-visioning of cities with clean water for drinking and other human uses.

A cycle of water circula-tion in nature consists of the following phases: precipitation, infiltration, runoff, evaporation. In the case that rainwater falls on natural terrain, most water infiltrates to the soil and becomes a part of subsoil water. Only about 20% of rainfall water comes to rivers or is carried to rainwater drainage. The problems associated with urbani-zation originate in the changes in landscape, the increased volume of runoff, and the quickened manner in which it moves (Markovič et al., 2021).

Soil water storage and underground water storage have significant effects on water flow regulation and these two processes are linked with each other temporally and spatially. Guo et al. (2000) quantitatively assessed the capacity and economic values of water flow regulation by forest ecosystems in Xingshan County of western Hubei Province in Central China. During the rainy period, the amount of rain intercepted by the canopy, the amount of water absorbed by litter, and the amount of water stored in soil/underground were 0.68 mm, 5.65 mm, and 13.56 mm, respectively.

However, as development of urban areas increases, the paving of pervious surfaces with new roads, shopping centers, driveways and rooftops all adds up to mean less water soaks into the ground and more water runs off. When rainwater reaches these surfaces, almost 80% of this water flows to the wastewater disposal system or rivers and only 20% infiltrates to the soil. A simulation model assessed that the catch-ment capacity of the soils from urban green infrastructure impacts significantly the quantity of available water (Higgens et al., 1997).

The other disturbance of the natural water cycle is due to the impact of buildings and sealed surfaces, as a result, natural water flows are altered and stormwater is created. When water comes in contact with urban surfaces such as roofs, roads and foot-paths, it becomes contaminated with oil, metals, litter and other pollutants (so called stormwater). Due to its adsorption and buffer capacities urban soils could filter some of these contaminants and enhance the underground water quality.

Natural hazard mitigation

Urban soils due to their ability to retain enormous quantities of water can play an important role in the natural hazards mitigation and in the water flooding limitation (Gómez-Baggethun & Barton, 2013). The capacity of urban soils to provide such services are in relation to the land use type and land surface treatment (Haase, 2009; Haase et al., 2014). As rainwater falls onto the soil surface, it may percolate into the soil or run off the surface, depending also on soil properties. Studies have demonstrated that soils in urban parks (under trees) can provide higher runoff regulation than soils on other urban land uses (residential or commercial land) (Higgens et al., 1997). Shuster et al. (2011) examined a sample set of 56 vacant lots and 14 city parks or cemeteries located in the drainage areas and demonstrated how urban soils may be used to provide a myriad of ecosystem services in the United States. They validated a protocol on the possibility of using vacant land mass to infiltrate and otherwise absorb excess storm water runoff quantity as a sustainable and putatively cost-effective way of managing combined sewer overflows.

The soil capacity for flood mitigation depends also by the extent of anthropogenic pressure, soil compaction and addition of anthropogenic material into the soil. Some authors have found that adding the compost into the subsoil could significantly increase the hydraulic conductivity of soils (Chen et al., 2014). Such experiments clearly show that there are many variants for soil treatments that can be applied in order to enhance their storm water mitigation potential (O'Riordan et al., 2021).

Waste treatment

Construction of urban soils may include adding natural substrates like relocated soil material or rocks (Lehmann & Stahr, 2007). Mixing of urban soils may be accompanied by the incorporation of anthropogenic material like garbage rich in organic matter. Minor compo-nents of construction waste which contain orga-nic matter are ash, coal, leather and plastics. Ash may be strongly alkaline (pH 8–12) and low in carbonates if originating from the burning of coal, but may be rich in carbonates when produ-ced by waste incineration (Lorenz & Lal, 2009).

One of the main feature of soil is the ability of self-detoxification and waste recycling. It is a consequence by both the retention capacity of soil and soil biological processes. So, waste's detoxification and recycling proceed when various compounds are bonded in soil particles or degraded by soil biota (mainly dead organic matter) (Gómez-Baggethun & Barton, 2013). Soil functions related to the detoxification of inorganic contaminants and biological degrada-tion organic residues impact directly on health prevention. By these processes, another benefit of urban soils is derived – support to human health. Different soil organisms play different roles - macrofauna like earthworms first incor-porate wastes into the soil, after that mesofauna and microfauna decompose the organic substances in the residues up to simple organic and inorganic compounds, releasing carbon dioxide (CO_2). Some authors declare that the process of waste biodegradation is depending manly by the availability of nutrients in the soil (C:N ratio) (Gómez-Baggethun & Barton, 2013). It should be noted, that in some cases when the concentrations of waste or contaminants in soil exceed the critical level, urban soils can pose a risk to people living in cities. For example, the heavy metal pollution of urban soils is one of the widely documented ecological and health problem (Bullock & Gregory, 2009; Li et al., 2018).

Noise attenuation

The intensive urban traffic, construction, industry and other human activities generate significant noise pollution in the urban environ-ment. Noise affect human health through physiological and psychological disturbances, so there are many approaches on its mitigation. Besides the engineering approaches, the experiments have highlighted the that urban soil and urban vegetation can significantly contribute to noise attenuation through absorption, devia-tion, reflection, and refraction of sound waves (Aylor, 1972; Gómez-Baggethun & Barton, 2013; Li et al., 2018). The presence of soil can lead to increased direct noise contribution to the recei-ver, as sound is reflected in the soil (CEC, 2006).

Reducing noise pollution by vegetation present in urban green areas constitutes a regulating ecosystem service, which can be considered as a Nature-based Solution (NbS) for the urban environment but urban soils role in noise attenuation also should be taken in count. De Oliveira et al. (2022) studied the relationship between the biophysical characteristics of two green areas of Curitiba, Paraná, Brazil, with the attenuation of noise propagation. First one was with 66.6% grass cover and 16.55% impervious area, while the second one was with 75% exposed soil and 24 trees (400 trees per ha). The evaluation of the relationship of soil with the mitigation of noise propagation showed significant results. The presence of forest soil alone compared to sound propagation over grassland is considered to be responsible for a reduction in traffic noise level close to 3 dB(A). As other authors (Atten-borough et al., 2016) stated also, this is due to the interaction between direct sound traveling from the noise source to the receiver plus sound from the source to the receiver that is reflected on the ground. The ground can have destructive interference or cancellation and constructive interference or reinforcement. Thus, with an acoustically harder ground the frequencies at which cancellations and reinforcement occur only depend on the difference between the direct and reflected path lengths in the ground. There may also be a decrease in the surface flow resistivity as the result of the soil cultivation and roughening.

Biological control of pests and diseases

Biological control function of urban soils arises from its role as a habitat for existence of a number of beneficial species (Dominati et al., 2010). Biotic interactions in soil ecosystem such as competition, predation and parasitism between various soil communities keeps no pests and harmful disease vectors (Barios, 2007; Dominati et al., 2010; Ishii, 1994; Paliy et al., 2019). Such biological control of pests and dis-eases is scarcely commented in the literature but is of great importance especially in the urban environment where the significant concentration of humans is a problem.

Several important pests are either soil insects or have soil dwelling stages as pests, e.g. cutworm, wireworms, grubs, armyworms, etc. Below ground natural enemies can prey on soil-dwelling stages (eggs, larvae, pupae and adults) of such diverse insect pests often reducing the frequency and intensity of pest outbreaks (Grewal & Grewal, 2012). The major biocontrol activity in the soil food web is provided by predators like ants, microbial pathogens, and by entomo-pathogenic nematodes (Denno et al., 2007).

Microbes may exhibit biological control activity through antibiosis, competition, para-sitism or production of plant growth promoting compounds. Ants have been identified as one of the major generalist predators and ecosystem soil engineers due to their ability to suppress pest activity and cause physical changes in biotic and abiotic materials thus directly or indirectly affect-ting other species (Way & Khoo, 1992).

The study of Way & Khoo (1992) found a high level of naturally occurring biocontrol service in urban landscapes (51–98% mortality of baited insects) suggesting that the use of chemical pest control measures can be minimized if natural biocontrol services provided by the soil food web can be harnessed for the management of insect pests affecting urban agriculture. Higher biocontrol services provided by ants in vacant lots as compared to urban gardens supported the hypothesis that reduced habitat heterogeneity, increased moisture, and greater disturbance reduces natural biocontrol services rendered by ant communities.

Carbon storage and greenhouse gases (GHG) regulation

Main emissions of GHG in urban areas consist of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), as well as of chlorofluoro-carbons and ozone (O_3) which result by tropospheric interactions and transformations (Gómez-Baggethun & Barton, 2013). Perhaps one of the most important ecosystem service of urban soils is related to their ability to store carbon as stable organic matter and such impact on GHG emissions (Dominati et al., 2010). Many soil processes emit and consume CO_2 which results in carbon sequestration and retention. Soil can also regulate the emissions nitrous oxide (N_2O) as gaseous N losses are a result of both biological and chemical denitrifications. The biological denitrification process is proper to the specific group of nitrobacteria which can produce NO_2 in anaerobic conditions (under waterlogging and poor drainage), while chemical denitrification reveal at N2 emissions (Dominati et al., 2010). Soil can regulate also the methane (CH_4) concentration in the atmosphere due to its degradation by soil biota (Dominati et al., 2010; Gómez-Bag-gethun & Barton, 2013; O'Riordan et al., 2021).

Urban soils are playing an increasingly important role in the global carbon cycle as in last few years a number of studies are focused on carbon sequestration and storage as a regulating ecosystem service (Balabio et al., 2016; Ghosh et al., 2016; Lorenz & Lal, 2015). The link between soil and carbon storage is the soil organic matter (SOM). This term includes all organic matter in soil (living and dead) and all organic compounds (degraded at different extent). SOM represents an extremely valuable resource for both the environment and the economy as its contribute to soil fertility. Organic substances supply nutrients to the soil, they are stored in the humus and then provided to plants. SOM provide a habitat to various soil organisms (bacteria, protozoa, worms and insects). Organic substances maintain the soil structure, so they indirectly improve water infiltration, increase water retention (due to significant imbibition capacity) and prevent soil compaction. As was mentioned above, many of soil contaminants can be bonded in organic matter, thus SOM contribute for reducing the risk of toxicity (Cienciala et al., 2006; Lal, 2004).

It is known that carbon accumulates in soils as a result of slower rates of mineralization of plant and animal residues and subsequent transfer of products compared to the process of deposition of organic matter. All other things being equal, the same type of soil is a carbon reservoir and a source of carbon emissions, and the dynamics of these processes is closely related to the type of vegetation cover and the land use (Jo, 2002). For example, the urban greenspace in Chuncheon, Korea, stored 56.5% of the C emissions from fossil fuel use in woody plants and soil, and urban soils accounted for 54.9% of the total C pool (Pouyat et al., 2006).

The overall C storage in urban landscapes depends on urban soils due to relatively high belowground to aboveground C ratios and high SOC densities (Pickett et al., 2001). The SOC pool in urban ecosystems is highly variable (Pouyat et al., 2002; Schlesinger, 1995). For example, in 0.3 m depth in Stuttgart, Germany, the SOC pool varied between 31 and 232 Mg C ha^{-1}. On the other hand, the SOC pool in 1 m depth in New York City, United States, varied between 29 and 285 Mg C ha^{-1} (Edmonson et al., 2012).

The soil retains two fold more organic carbon in comparison with vegetation. Globally, the carbon accumulated in the soil is about three times higher than that in aboveground plant biomass (Edmonson et al., 2013). Overall, global carbon stocks are estimated at 1,500–1,550 Pg C (Edmonson et al., 2013; Ghosh et al., 2016), making soil one of the largest carbon reservoirs in the biosphere, along with vegetation and oceans. It was estimated that the organic carbon stored in EU soils is more than 70 billion tons (about 7% of the total carbon budget on Earth). That is why the carbon storage in the biosphere, including the soil, via reforestation and improved agricultural and practices can be regarded as a possible mechanism to address the anthropogenic C emissions (Eaton et al., 2008).

Some studies have found that the degradation of soil in urban areas can reveal to a significant reduction of soil organic carbon (SOC) (Edmonson et al., 2013). Simultaneously, they have demonstrated that an effective management of urban soils (with water and nutrient supplies) can enhance SOC in them much more than in natural soils (Eaton et al., 2008). Recent studies estimated that the organic carbon stored in urban soils (Leicester, UK) represents almost 82% of the total OC and a significant share of OC (13%) is stored into a soil with sealed surface (Eaton et al., 2008; Edmonson et al., 2013).

Vegetation type is very important for the carbon accumulation in soil together with other factors of soil formation - climate, relief, weather, soil-forming rock, human activity (Jonsson & Davíðsdottir, 2016). Anthropogenic activity, such as changes in vegetation cover (e.g. conversion of forest to agricultural land) or changes in land use (from agriculture to construction), can also lead to changes in the carbon balance of the soil (Cienciala et al., 2006; Edmonson et al., 2013). The transformation of agricultural and forest areas into urban land use leads to changes in carbon accumulation and flow. Calzolari et al. (2020) have estimated that the unsealed soils of the green areas within the city of Carpi (NE Italy) (193 ha) store within the first 30 cm of depth 15,067 Mg of organic carbon (55,246 Mg CO_2 eq.) corresponding to an average carbon density of 78.0 Mg ha^{-1}, which is significantly higher than the corresponding average of the agricultural soils of the area (43.4 Mg ha^{-1}). In this context, urban areas play a key role in changing the biogeochemical cycles of the elements (Jonsson & Davíðsdottir, 2016).

The process of urbanization of soils affects both directly and indirectly the accumulation and cycle of carbon. The direct impact is expressed in disturbances, degradation or backfilling of the soil with dense materials, impermeable surfaces and waste. Indirect influences include changes in the abiotic and/or biotic component of the urban environment. In urban parks and recreation areas, the lack of direct impacts on soils increases their potential for carbon storage (Schlesinger, 1995). Therefore, urban SOC content can signifi-cantly vary in space depending on the type and extent of anthropogenic impact as well as on other urban local environmental factors, such as differences in temperature and rainfall. At the same time, the soils in urban parks are character-rized by altered physical and chemical properties as a result of urbanization (Eaton et al., 2008).

In addition, the contamination of urbanized soils with heavy metals and toxic elements from diffuse sources confirms the presence of changes in soil properties. Studies confirm the presence of spatial variations in the properties of urbanized soils. Pouyat et al. (2002) emphasize the importance of regional changes in land use patterns and in the distribution of land cover for carbon sequestration in urban soils.

Relationship Urban soil properties - Supporting ecosystem services – Human well-being

Soils are complex dynamic systems consisting of soil components (abiotic and biotic) interconnected by biological, physical and chemical processes. Soil processes support soil formation, which is the development of soil properties and soil natural capital stocks (Dominati et al., 2010). These properties of urban soils are related to the following ecosystem ser-vices which in turn deal with the majority of human well-being components (Fig. 2):

- Nutrient cycling, which refers to the processes by which a chemical element moves through both the biotic and abiotic compartments of soils. Nutrient cycles are a way to conceptualize the migration and/or transformations of elements in a soil. The transformation, or cycling, of nutrients into different forms in soils is what maintain equilibria between forms, e.g. soil solution concentrations of nitrate drive many processes such as plant uptake, exchange reactions with clay surfaces or microbial immobi-lization. These relationships are crucial especially in urban soils where many chemical elements are missing or abundant thus posing a risk to plants, animals and humans in settlements.

• Water cycling, which refers to the physical processes enabling water to enter soils, be stored and released. Soil moisture is the driver of many chemical and biological processes and is therefore essential in soil development and functioning. The continuous movements of water through soils carrying nutrients disturb chemical equilibria, and thereby drive transformations. If this service of urban soils is missing, the effect on both basic and environmental human needs will be catastrophic.

• Soil biological activity: soils provide habitat to a great diversity of species, enabling them to function and develop. In return, the activity and diversity of soil biota are essential to soil properties and processes like structure, nutrient cycling, and detoxification. Maintaining biological activity as an ecosystem service provided by urban soils is crucial for the many human well-being components, even that ES is hard to understand and acknowledge by people.

Soil biological activity

Soils are inhabited by millions of species and that is why they are regarded as the most species rich habitats of terrestrial ecosystems. Many of these species significantly contribute to the functional diversity and resilience of the soil (Jonsson & Davíðsdottir, 2016). Some authors have noticed that although the soil biology is often studied, the biota of urban soils represents only 2–3% of all relevant literature in the field (Biswal &Malik, 2021; Groffman et al., 2002). Urban soils provide a habitat to various organisms, enabling them to function and develop, so to support biological activities are one of the crucial ecosystem services in urban landscape. By the other hand, the activity of soil biota is crucial to maintain soil structure, functions and processes (Dominati et al., 2010).

Urban soil microbiota is a key component of all urban ecosystems. Bacterial communities are involved in various soil processes, such as organic matter degradation, humus formation, nutrient release, nitrogen fixation (Burylo et al., 2007; Petrova et al., 2022a) and because of these characteristics have a strong influence on soil characteristics and fertility. At the same time, microbiological and biochemical soil indicators show high sensitivity not only to the impact of abiotic and biotic factors, but also depending on the guidelines in soil resource management (Budakova et al., 2021; Reese et al., 2015). Therefore, they are reliable indicators of ecological status and soil quality (Petrova et al., 2022ab). Budakova et al. (2021) have assessed the effect of transformation of soil physical properties on the ecological properties of micromolluscs in an urban park. Soil micromolluscs' abundance and diversity were significantly higher in undisturbed conditions when compared to the urban park where living conditions deteriorated, leading to a sharp decline in micromolluscs' presence and community's structure. Similar findings were reported by Kunakh et al. (2022) for the Botanical garden (Dnipro city, Ukraine) where the level of recreation was correlated statistically significantly with the apparent soil electrical conductivity.

The ecological group of soil decomposers is quite susceptible to external factors. So, the anthropogenic activities in urban areas can alter the soil community structure, reduce some trophic groups or replace the dominant species (Guilland et al., 2018). Degraded urban soils are characterized by low biodiversity, deteriorated soil functions, and thus disabled ecosystem services. By this reason, the biodiversity decline is highlighted as a major threat to soils in Europe (Rawlins et al., 2015).

Another benefit of urban soils is related to their functioning as a media for existence of different types of flora (planting by roots) and fauna (on soil surface) (Eaton et al., 2008). Most of studies in this filed revealed that the biodiversity is highest at intermediate levels of urbanization and declines with the intensification of urban areas (Gómez-Baggethun & Barton, 2013).

Nutrient cycling

Urban soils are a key part of the global cycle of nutrients due to their significant ability to filter, absorb and retain different substances. Nutrient cycles could be regarded as a way for elements transformations in urban soils. Such transformations, especially of available nutrients forms for plant uptake, maintain urban vegetation and soil equilibria (Dominati et al., 2010). Nutrient cycling in the soil is a part of biogeochemical cycling of chemical elements in the environment and it is closely interrelated to the soil fertility. Nitrate retention is one of the most studied process as an elevated nitrate level in groundwater, especially when supplies the drinking water, is a well-known health hazard. Nitrate absorption and transformation in urban soils are important ecosystem services to the municipalities. Beside importing material while constructing urban soils, humans directly affect the biogeochemical cycling of C and N during vegetation management by adding inorganic and organic fertilizers (Lehmann & Stahr, 2007). For example, large quantities of chemical fertilizers are sometimes used in urban lawns with consequences to N transformations (Baker et al., 2001; Pavao-Zuckermann & Coleman, 2005). Soil sealing is a serious problem in urban soils and constitutes a major anthropogenic impact on biogeochemical cycling of C and N (Zhu et al., 2004).

Water cycling

The water cycling in soil is a part of the global water cycling and consists of the physical processes of water movement (mainly vertically, but also horizontally) through the soil mass. Water movement affects various soil processes (geological, chemical, biological, biochemical) and functions as well as soil ecology and biodiversity (Dominati et al., 2010). These fundamental processes enable the water to be filtered, absorbed, stored and released by soil. When regarding the water cycling in urban areas, it should be noted that it strongly depends on the impermeable surfaces coverage, soil drainage and evapotranspiration capacity of urban vegetation (Kaye et al., 2006). In this context, all factors leading to increased heterogeneity of urban soil, compromised soil horizons or soil compaction contribute to altered soil water cycling and reduced ecosystem services potential.

An attempt to identify mapped infiltration rates for Hannover (Germany) was made by Bartsch et al. (1997), which have studied areas covered by roads and buildings as well as open soils and vegetation covered areas. In a modelling study in Leipzig, Haase (2009) found that water cycling had accelerated due to increased sealing with impervious surfaces, leading to reduced water holding capacity in favor of increased runoff.

Water is well-known to be a driver of many soil chemical and biological processes, as well as a prerequisite for soil biota and vegetation. Some studies have analyzed the effect of different permeable surfaces in cities (pavements, concrete, etc.) on soil moisture dynamics (Mcgrane, 2016; Revelli & Porporato, 2018), as well as the effects of developments on groundwater re-charge and its resilience in the context of existing climate scenarios (Mann et al., 2017; Revelli & Porporato, 2018; Schils et al., 2008).

Relationship Urban soil properties - Cultural ecosystem services – Human well-being

The cultural ecosystem services provided by soils are often underestimated although that soils alone, as part of landscapes that support vegetation, have across many cultures been a source of aesthetic experiences, spiritual enrichment, and recreation (subjective well-being). Many deities and religious beliefs refer specifically to the earth and its sacredness and soils also have various cultural uses across the globe from being a place to bury the dead, a material to build houses or a place to store and cook food (Dominati et al., 2010). So, we could summarize that at a non-physical level, urban soils as a part of urban habitat, provide aesthetics, spiritual and cultural benefits through cultural services, thereby fulfilling self-actualization needs.

Heritage conservation

Despite the role of soils in maintaining our geological, ecological and archaeological heritage, the studies on such cultural services are scarce. It this category ecosystem services we could mention some landscapes associated with an important historical event, sacred sites, religious places, archaeological findings, etc. (Dominati et al., 2010).

Leisure, science and education

Urban landscapes are widely used for leisure, pleasure and relaxation (walking, recreation, sport, kids' entertainment, etc.). They provide a lot of possibilities for environmental observation and education – in parks, school yards, allotment gardens and much more (Andersson et al., 2007; Barthel et al., 2010). Furthermore, the emotional perception of urban ecosystems by people contribute to develop affective links to their cities (Gómez-Baggethun & Barton, 2013).

Gaps and opportunities for the future

There is a crucial need for sustainable design of urban areas to address both the anthropogenic load and natural hazards in order to benefit human well-being and enhance the quality of life from local to global scales. To best mobilize the transition to urban sustainability, we have identified the following essential directions for future studies in the field. Furthermore, addressing these questions will help advance these disciplines more broadly, including in non-urban ecosystems (MA, 2005; Dominati et al., 2010; Gómez-Baggethun & Barton, 2013; Andersson et al., 2014; Primmer & Furman, 2012; Summers et al., 2012).

We summarized the current research providing insight into these questions thus far and recommend approaches for future research (Andie Nugent & Allison, 2022; Ates & Erinsel, 2021; Bibri, 2021; Blanchart et al., 2019; Bristow & Mohareb, 2020; Bruzone et al., 2021; Calzolari et al., 2020; Chelleri & Bararvikova, 2021; Drobnik et al., 2018; Fabriccatti et al., 2020; James et al., 2009; Kumar et al., 2020; Manna et al., 2017; Rawlins et al., 2015; Revelli & Porporato, 2018; Schindelbeck et al., 2008):

1. Are ecosystem services of urban soils sufficiently recognized and how much variation do they tolerate within the urban environment?

As urban areas dramatically increase globally, more studies on the effects of urbanization on biogeochemical cycling are urgently needed. The design of urban areas has enormous impacts on soil C and N storage and cycles. By strengthening SOM de-pendent soil ecological functions such as retention of nutrients and hazardous com-pounds, urban planners and ecologists can improve the quality of urban ecosystems. A greater understanding of subsoil processes is needed to evaluate urban soil quality as burying of SOM or covering the soil by impervious surface may alter C and N dynamics deeper in the soil profile.

2. If differences in urban soils' ecosystem services and function exist, what are the associated drivers?

It is obvious that there are differences between urban and rural soils ecosystems' services and functions, as well as among soils within the urban matrix. What environmental variables are driving these differences? How do different soil communities respond to these drivers? How do the essential physio-chemical properties of soils change under the influence of these drivers? Answers to these questions are essential to manage for healthy and beneficial urban soils.

3. How might urban areas be better designed/managed to boost ecosystem services by urban soils while minimizing harms?

Taking into account urban soil quality into urban planning strategy would con-tribute to the mitigation of the major environmental issues and to the development of sustainable and resilient cities by optimizing ecosystem services. This goal requires a reconsideration of the management of urban areas, and the development of a full chain of knowledge, techniques and tools. Hence, cooperation should be promoted between soil scientists and urban planners.

Conclusions

The concept of sustainable cities incorporates a wide spectrum of technologies and management practices into the urban environment aiming to enhance cities' resilience. All of these should enhance the quality of life in urban areas, to prevent human health and to reduce the cities' carbon footprint. Sustainability of urban areas is becoming more and more essential in the increasing load of dynamic climate change. In this con-text, despite its unique characteristics and challenges, each city needs to take effective actions and to prepare for the impact of global climate change.

The challenge of enhance the resilience of urban ecosystems while meeting urban sprawl and increasing demands of their inhabitants can be overcome to some extent following the Millennium Ecosystem Assessment scenarios. For this purpose, some significant change in policies, institutions and urban planning practices should be ad-dressed. Many options exist (but are underused) to conserve or enhance ecosystem services provided by urban soils allowing to reduce their disservices as well as to strengthen their positive synergies with other ecosystem services. Although this review revealed that there are significant number of studies concerning ecosystem services in urban areas, urban soils contribution to sustainability remains not so deep understood. The number of studies exploring biophysical and economic properties of urban soils is much greater than those of studies addressing the so-called non-economic benefits. Furthermore, the social, cultural and insurance values of urban soils are formally recognized but they remain still underestimated and underused in sustainable urban planning at operational level.

To address this gap, it is crucial for both urban soil properties and ecosystem services derived to be studied; and research into multifunctionality of urban soils is high-lighted as a key direction for the future. This would also address other gaps found in the literature, such as water dynamics and cultural services rarely being identified as services provided by urban soils. We hope that addressing these gaps will enable urban soils to be better understood and accounted for in the planning, design and sustainable management of urban areas in order to support future human well-being and urban ecosystem resilience.

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