Soil Ecosystem Services (SoES) in Urban Planning

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Abstract

Urbanization as a global transition process of socio-economic dynamics has been the burning issue of spatial science related disciplines for the last few decades. The complex system of urban mechanisms and the changes in population patterns have provided scientists from various domains a multi-dimensional research lab where land use and land cover change (LULCC) has become one of the most important issues affecting natural systems at different scales (Bajocco et al., 2012). All among the problems caused by anthropogenic activities and ongoing urbanization process, climate change came into prominence as one of the most critical environmental concerns due to its widespread effects threatening species, ecological systems and the sustainability of urbanizing landscapes. The relationship between urbanization and climate change has been most notably articulated by the greenhouse gases emit due to human activities and fossil fuel consumption. Herein, the study presented in this paper intends to focus on another variable that was not highlighted clearly in the process of fighting and adapting to climate change, yet, play an important role in climate regulation on surface and subsurface layers. Soil, as a defining component of ancient and recent cultures provides critical ecosystem services (ES) that enables life on Earth. Its role in climate and water regulation systems has tremendous effects on ensuring the equilibrium between surface and subsurface interactions. However, likewise other natural systems in urban areas, soil has been exposed to critical human intervention and lost its characteristics temporarily or irreversibly. This paper, at that point, aims to reveal the significance of soil ecosystem services (SoES) in adaptation and mitigation to emerging environmental challenges on the basis of climate change and stormwater management in urban areas. In accordance with this purpose, the scientific literature examining the relationships between urban planning, LULCC and SoES will thoroughly be analyzed to identify the research gaps and develop strategy options for making the integration of SoES into urban planning mechanisms possible.

1. Introduction

'Land, then, is not merely soil; it is a fountain of energy flowing through a circuit of soils, plants, and animals' (Aldo Leopold, A Sand County Almanac, 1949).

Soil is a vital part of the natural environment and it is essential for the continuity of life. The United Nations Food and Agriculture Organization (FAO) has declared 2015 as the International Year of Soils, "paying tribute to the life-giving ground beneath our feet" (Pantsios, 2014). Similarly, United Nations Sustainable Development Goals (2030 Agenda) has highlighted the importance of land, soil and water relationship through land and soil degradation, flood risk and integrating ecosystem values into national and local planning processes under the Goal-15: Life on land. Soils are also given an earlier emphasis in the Millennium Ecosystem Assessment (MEA) Report (MEA, 2005a), which popularized the term 'ecosystem services' and inspired by a number of researchers. The report provides a clear nomenclature for ES framework under 4 major function groups (provisioning, regulating, supporting and cultural) and assesses the consequences of ecosystem change on human well-being. Divergences of opinions regarding the most suitable classification of ES has brought some revisions made by the 'Economics of Ecosystems and Biodiversity (TEEB)' committee and 'European Environment Agency (EEA)' under 'Common International Classification of Ecosystem Services (CICES)' in 2009. However, both in the MEA Report and the studies in literature regarding the definition and classification of ES, very little attention was devoted to soils and insofar they often left out many of their common uses and services (Baveye et al., 2016). As Dominati et al. (2010) mentioned, a large-scale ecosystem approach was adopted by the MEA Report in which soil received little or no attention (Figure 1) apart from its role in soil formation. From this point of view, this research aims to emphasize the significance of 'below-ground mechanisms' as much as the services provided by above-ground systems and it particularly focuses on the SoES with a special attention to stormwater management and climate regulation in urban areas.

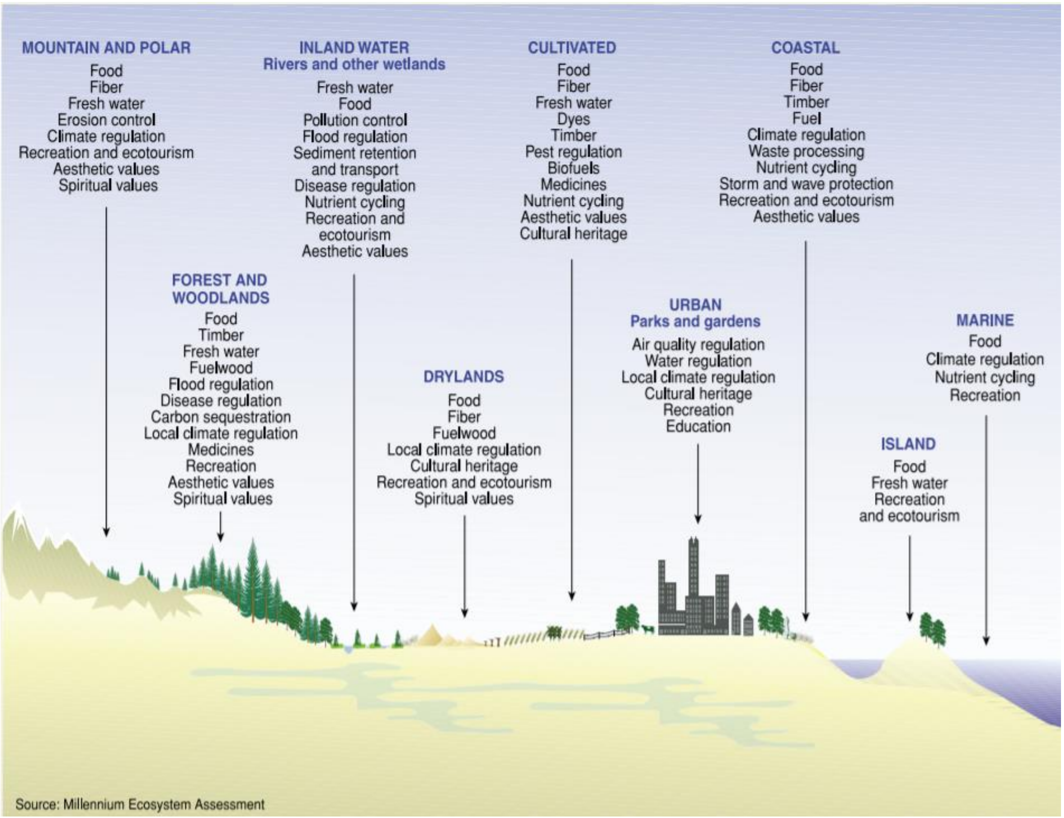

Figure 1: Multi-contexts of Ecosystems and Their Basic Services (MEA, 2005b)

2. Human-dominated Landscapes

We are living in a rapidly urbanising world. This has been revealed once again by the findings of United Nations indicating the rate of urban population which was 30 % in 1950 has reached 55 % of the world population today and it is expected to increase 68 % by 2050 (UN, 2018).

Urban areas are innovative catalysts and frontrunners of development. They provide greater access to social, educational and medical services, commerce and economic activity, public transportation network and enhanced opportunities for cultural and political participation for their citizens. However, at the same time, they are the hubs for environmental conflicts where natural hazard risks and environmental disturbances have accelerated. The process of urbanisation is defined by Mosel et al. (2016, p. 9) as:

> the increase in the proportion of the population living in urban centers that is overwhelmingly the result of net rural to urban migration caused by economic growth and industrialisation, political and social conflicts, rural impoverishment, and natural disasters

which stimulates dramatic changes on land. The expansion of urban areas due to rise in population and economic growth increases the additional demand on natural resources thereby causing land transformations especially in megacities and peri-urban areas. According to CBD Report (2012), the land area occupied by cities increases at a higher rate than the increase in urban population. Likewise, a global sample of 120 cities observed between 1990 and 2000 shows that while the population grew at a rate of 17 %, the built-up area grew by 28 % (NYU, 2015). Rapid urbanization and inadequately managed urban expansion lead to urban sprawl and unplanned urban patterns (UN, 2014), where the communities become more vulnerable to water and climate-based problems (Tezer et al., 2012).

2.1. Transitions in Land use and Land Cover; A Growing Threat for Natural Capital

Land use and land cover (LULC) are one of the key determinants of landscape's structure, functions, and dynamics in all around the world (Wu and Hobbs, 2002). Land cover defines the '*biophysical state of the earth's surface and immediate subsurface, including the soil material, vegetation, and water status*' while the land use differs from land cover as a result of anthropogenic behavior to change land cover to their benefit (Verheye, 2006, p. 337). The Food and Agriculture Organization (FAO, 1995, p. 21) describes land use as *'the human activities which are directly related to land, making use of its resources, or having an impact on them*'.

The negative environmental impacts associated with urbanization, such as loss of cultivated land, habitat degradation, biodiversity loss and urban flooding are linked to the unplanned changes in LULC caused by poorly designed and coordinated urban sprawl (Pauleit et al., 2005). Today, urbanization is among the most important land-use change trends globally and the conversion of land to built-up is often considered as one of the most problematic trajectories of LULCC (Elmqvist et al., 2013) due to its distinct impacts. The urban-growth driven changes in LULC have direct or indirect impacts on urban ecosystems including air quality, habitat and landscape fragmentation (Sala et al., 2000), soil degradation (Tolba et al., 1992), flood/drought risk (Carlson and Arthur, 2000), surface runoff and consequently the hydrological cycle with an influence on climate processes at local, regional and global levels (Chase et al., 2000). The interactions between urban ES and the response of ES bundles to the changes in LULC are complicated and variable. Therefore, the research intends to highlight the services provided by soil and the consequences of LULC on the regulative (climate and water regulation) soil services in rapidly urbanizing landscapes.

2.2. Soil in Urban Landscape

Soils are complex mixtures of minerals, water, air, organic matter, and countless organisms (FAO, 1985) which interact and contribute to the global cycles that make all life possible (Govers, 2015). However, due to changing consumption patterns, global demographical dynamics, population growth and urbanization, soil is coming under increasing pressure resulting in physically, chemically and biologically altered characteristics in comparison to nonurbanized soils (Pavao-Zuckerman, 2008).

Soil as a dynamic and multifaceted life support system is affected by five major factors (climate, organisms, relief, parent material and time) interact to create different soil types (Brady and Weil, 1996). Recently, human activity is accepted as the sixth factor has an influence on soil formation (Pickett and Cadenasso, 2009) due to direct anthropogenic disturbance and indirect impacts of urbanization. Previously, Jenny (1941), described soil formation in the absence of humans, while Effland and Pouyat (1997) and Pickett and Cadenasso (2009) considered the anthropic factor influence to modify natural soil formation processes (Figure 2). Indeed, the term 'Urban Soil' can be defined as:

> a soil material having a non-agricultural, man-made surface layer more than 50 cm thick, that has been produced by mixing, filling, or by contamination of land surfaces in urban and suburban areas (Craul, 1992, p. 86)

which indicates a disturbed soil structure by human interference. Jim (1998) identifies the characteristics of urban soil as: modified soil structure (compaction), presence of a surface crust on bare soil, restricted aeration and water drainage, interrupted nutrient cycling, modified soil organism activity, anthropic materials and other contaminants and modified soil temperature regimes. According to BIO Intelligence Service Report (2014), soils in urban system are mostly compacted, sealed, and modified. Their characteristics are temporarily or irreversibly lost and their biophysical properties such as structure, soil temprature and organism activity are partially or completely interrupted due to critical human intervention.

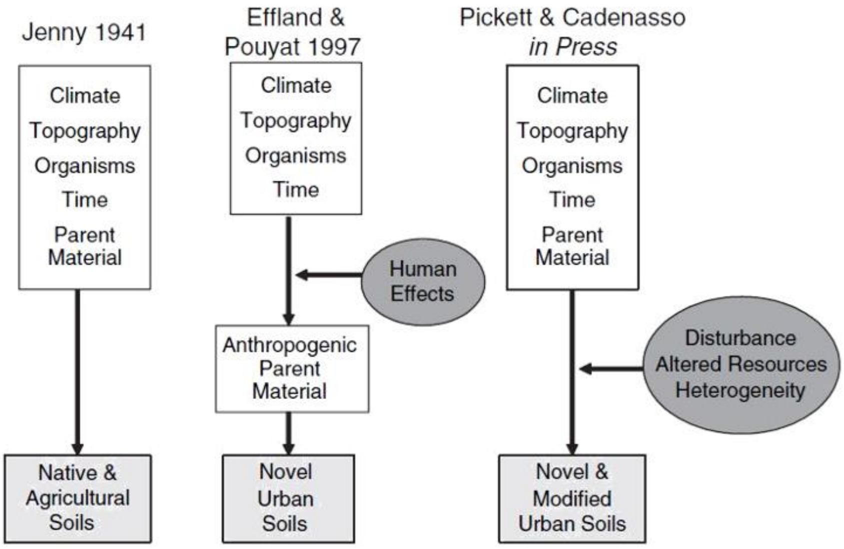

Figure 2: Factors Effecting the Modification of the Soil Formation Process (Pickett and Cadenasso, 2009).

Although soils in urban landscapes are predominately altered, they still can provide many of the same ES as unaltered soils (Pouyat et al., 2010). The potential of ES provision by modified urban soil has been confirmed by the studies conducted under Baltimore Ecosystem Study (BES) (2010) as well. The study revealed that urban effects on soils occur at multiple scales. Yet, urban landscapes are biologically active in pervious areas and still have a high potential for water filtration, carbon storage, and nitrogen retention which are significant for, thus climate and water flow regulation.

3. Ecosystem Services (ES) Provided by Soil

Ecosystem services are defined as *'the benefits people obtain from ecosystems*' in the Millennium Ecosystem Assessment Report (MEA, 2005a) with an emphasis on the dependency of human well-being to the Earth's natural capital (Costanza et al., 1997) including the most biologically active zones of soil (Barrios, 2007).

Soils are one of the species-rich habitats and the foundation off all terrestrial ecosystems (Finvers, 2008; Jónsson and Davíðsdóttir, 2016). They moderate the majority of ecosystem processes while providing a range of ecosystem goods and services mostly driven by the soils biotic community. Healthy soil contains a myriad of organisms (microbes, fungi, bacteria, invertebrates), whose activity in soil is central to support and moderate nutrient balance, biogeochemical recycling, primary production, water regulation and biomass production (Brady and Weil, 1996; McKinney, 2002; Jónsson and Davíðsdóttir, 2016). Soil Thematic Strategy (EC, 2012) identifies soil biodiversity as the key component of soil quality and sustainability. Although soil microbial diversity has a critical role in ecosystem processes, key functions of soil are not limited with the services provided by its microbial community. Due to environmental interactions take place among the surface and sub-surface layers of the land, soil serve as a gene pool and source for food and other biomass production. It constitutes a physical support for man-made structures while regulating Earth's fundamental processes (retaining carbon, water and nutrients, regulating greenhouse gas emissions, global and local climate, hydrological cycle, air purification etc.) and contributing to cultural heritage (Barrios, 2007; Dominati et al., 2010; Pereira et al., 2017).

The role of soil in providing these crucial services is mostly neglected in ES framework, which has been formed in various classifications (Costanza et al., 1997; de Grooth et al., 2002; MEA, 2005a; CICES, 2009; TEEB, 2010) and still could not formulate a consensus regarding the classification and valuation of SoES (Robinson et al., 2009). In Figure 3, the services provided by soil is illustrated based on the categories defined by MEA (2005a).

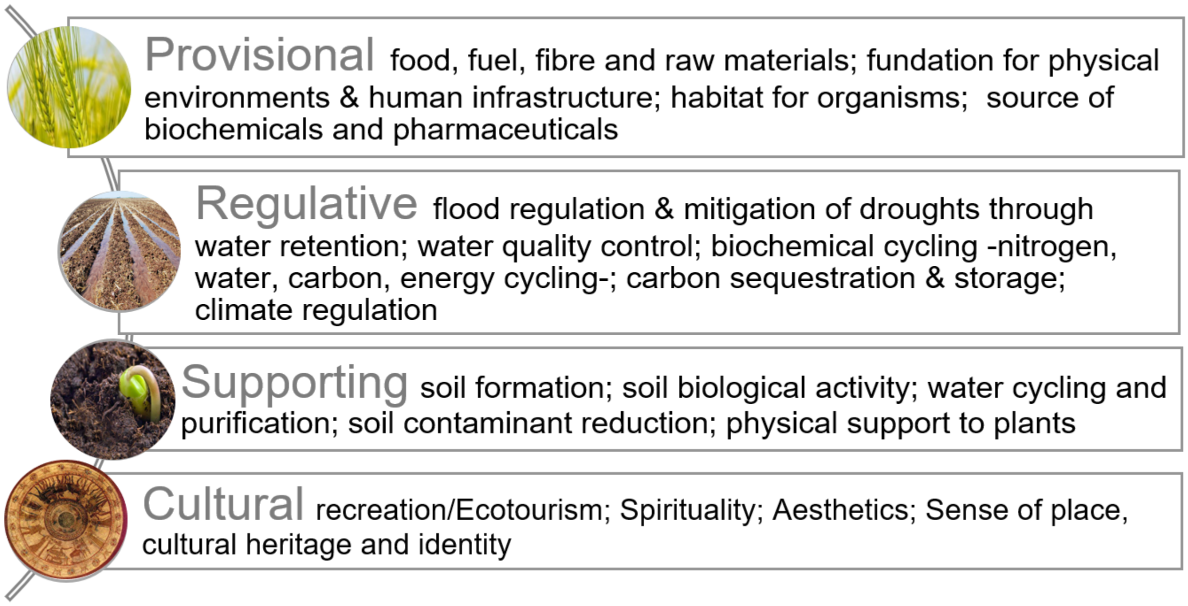

Figure 3: ES Provided by Soil (compiled from Daily et al., 1997; Dominati, 2013)

According to Jónsson and Davíðsdóttir (2016), recent developments have underpinned the importance to include multiple aspects of SoES in ES framework due to their critical role in to climate change mitigation and flood risk management in urban areas. As such, soils can function in urban landscapes by reducing the bioavailability of pollutants, storing carbon and nutrients and moderating the hydrologic cycle through absorption, storage, and supply of stormwater (Pouyat et al., 2010)

3.1. Soil in Hydrological (Water) Cycle

Soil and water system are inherently connected. They directly or indirectly affect each other and contribute to the continuity of life. The continuous and vital movement of water on, above, and below the surface of the Earth is defined as hydrological cycle (USGS, 2017), where soil play a critical role.

Soil is responsible for the infiltration, transpiration, storage, percolation and distribution of water flow in the hydrological cycle. According to BIO Report (2014), soil retains 67 000 km^3 of water globally that is mostly used for root uptake, plant growth, groundwater recharge and soil organisms (Quinton, 2015). Altough infiltration and storage of water in soil media mainly associated with gravity, precipitation, hydrological characteristics (saturation level, moisture content, capillarity etc.), soil texture and structure (particle size, porosity etc.) (FAO, 1985), the condition of soil surface regarding the land cover, vegetation type and human activities is one of the primary determinants of water-soil relationship (Mangala et al., 2016). In the context of the natural flow of hydrological cycle, water naturally seeps down by gravity during the precipitation/irrigation while there are no physical barriers such as impermeable layers at soil surface. In urban landscapes, however, sealing of soil and the conversion of land pattern from permeable surface to impermeable cover surfaces (roads, pavements, buildings, asphalts etc.) is closely associated to soil's capacity to store and infiltrate water (Veerbeek et al., 2011; Quinton, 2015), which increase the surface runoff and flash-flood risk.

The causes of antropogenic interventions on soil can be summarised as: decrease of water infiltration and chemical activity; reduced storage of water and carbon; cut down of soil evaporation; increase in local temprature (surface and sub-surface) and water erosion; biomass and organic matter loss; pollution; impeding soil water and atmosphere exchanges (biochemical cycling) together with the negative affects on the functions of soil organims, groundwater replenishment and natural water balance in urban areas (BIO, 2014; Pouyat et al., 2010; Scalenghea and Marsan, 2009; Pavao-Zuckerman, 2008; Grimm et al., 2008). In natural systems, permeable surfaces prevent or limit runoff by capturing part of the rainwater, while reduction of this ability (soil sealing, compaction, saturation) and the existance of impervious surfaces reduce the amount of water infiltrates into soil (Figure 4). This can lead to high levels of stormwater runoff resulting in fluvial (river overflowing) or pluvial (urban) flooding with higher magnitude and frequency (Rambaldini, 2009; Bacchin et al., 2013) mostly in poorly planned urban settlements.

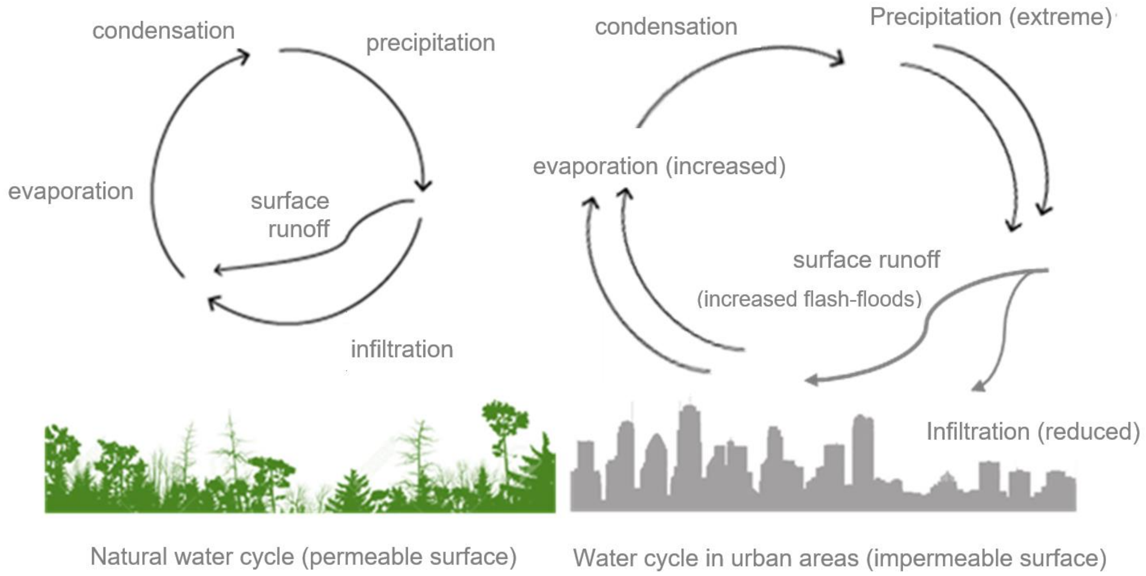

Figure 4: Hydrological Cycle in Natural and Urbanized Areas (adapted from Bacchin et al., 2014)

3.2. Soil in Climate Regulation

According to UNEP (2012), urban areas comprise only around 3% of the land surface of the earth, but they use approximately 75% of the earth's natural resources and emit 60% to 80% of greenhouse gas emissions. Greenhouse gases (GHGs) play a vital role by trapping the solar energy in the atmosphere and influence the climate of the planet; known as 'greenhouse gas effect' (EPA, 2017). This naturally occurring process is vital and provides higher and livable temperature ranges on the Earth. However, the increase of atmospheric GHGs in exponential ratios intensifies GHG effect, alters the energy balance and cause an increase in Earth's temperature, which threatens the continuity of human welfare and ecosystems health.

The Intergovernmental Panel on Climate Change (IPCC) defines climate change as *"statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer)'* and it emphasizes the distinct influence of human on climate change (IPCC, 2013). Due to greater amounts of GHGs emissions mainly caused by energy generation, vehicles, industry, biomass use and human alteration on LULC (EPA, 2017), the global surface temperature in the past decade was detected 0.8 °C higher than the beginning of the 20th century (Carter et al., 2015). According to NOAA (2018), carbon dioxide (CO_2) is of greatest concern in all of the GHGs, since it contributes the most to the climate change. Atmospheric CO_2 levels in 2009 were measured higher than at any time in the past 800,000 years and currently, it is continuing to increase at an accelerating rate (EPA, 2017). Scharlemann et al. (2014) indicated that carbon emissions resulting from changes in LULC are the second largest source of human-caused carbon emissions to the atmosphere after emissions from fossil fuel combustion. Researches conducted under the Global Carbon Project (GCP) (Le Quéré et al., 2016) also revealed that the global CO_2 emission sources have grown in the industrial era primarily from fossil fuel combustion, cement manufacturing, and land-use change from activities such as deforestation (Figure 5).

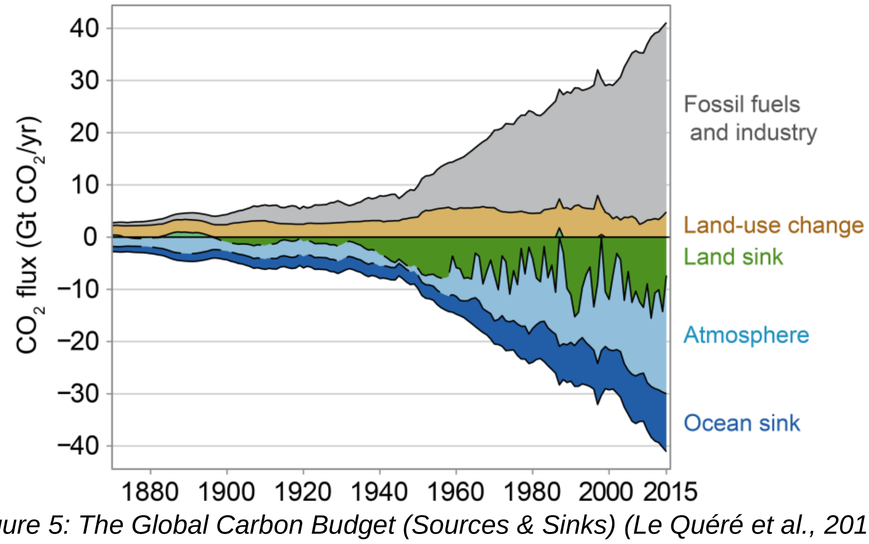

Figure 5: The Global Carbon Budget (Sources & Sinks) (Le Quéré et al., 2016)

CO_2 naturally emitted by the oceans, plants and land, where 80 % of the total carbon in the terrestrial ecosystem is found in soil (Lal, 2008). Soil as the second largest carbon reservoir after oceans (EPA, 2017) captures and stores the carbon in the form of soil organic carbon (SOC). Sequestration of carbon by healthy soils and vegetation is an important part of continual (exchange) cycle of CO_2, and crucial for key soil functions such as stabilization of soil structure (erosion control), flow of plant nutrients (productivity) and water infiltration and storage in soil (Pereira et al., 2017). SOC supports soil organisms to perform in biogeochemical cycles and help soil to regulate the microclimate (surface and sub-surface) as well (FAO, 1995).

The significant role of soil in climate regulation could be a critical link to mitigate climate change particularly in urban areas, where the transition of land cover in the form of built-up or paved-over areas leads to modifications in surface microclimatic and hydological conditions including urban heat island effect and changes in surface runoff pattern (Jiang et al., 2015). Currently, unsustainable land management practices and increase of urbanization-driven LULCC alter soil carbon balance while endangering the capability of soil to store and sequestrate carbon (FAO, 1995). Nevertheless, in addition to the strategies imposing to reduce the dependencies on fossil fuels, it is also critical to contribute to carbon dioxide-driven climate change mitigation efforts by increasing the carbon stocks in urban areas.

4. Discussion: Considering SoES in Urban Spatial Planning

Traditionally SoES have not been thoroughly studied in urban planning. Hence, tools are needed to incorporate SoES into urban land management and spatial planning processes.
The purpose of this paper is to reveal the significance of SoES in urban planning and spatial decision-making process through the following objectives: (1) analyzing the effects of urban growth-driven LULCC on soil; (2) identifying the role of urban soil in climate change mitigation and urban stormwater management; (3) proposing a conceptual framework illustrates the basic stages for building SoES-friendly urban planning and design strategies.

In accordance with this purpose, scientific literature examining the relationships between urban planning, LULCC and SoESs is systematically analyzed. The results obtained illustrate that although subsurface system has not been fully incorporated into ES framework, recent studies (e.g., Pavao-Zuckerman, 2008; Robinson et al., 2009; Pouyat et al., 2010; Dominati, 2013; Baveye et al., 2016; Silva et al., 2018) several international organizations (e.g., United States Environmental Protection Agency, United Nations Environment Programme and Food and Agriculture Organization) and some relevant policies (e.g., United Nations Sustainable Development Goals, European Commission Soil Thematic Strategy) have pointed out the great influence of SoES on urban sustainability. Particularly, the critical role of soil in urban climate regulation and flood risk is explicitly underlined with an urgent need for adaptive, comprehensive and multi-disciplinary spatial planning process. From this point of view, a 'multi-layered' approach has been adopted in this study (Figure 6) based on the 'Dutch Traditional Layer Approach' introduced in 1998 (Van Schaick, 2011). The perspective classifies the land basically under three layers; substratum, networks and occupation patterns, where the natural subsurface systems are incorporated with aboveground urban development as a part of 'human' and 'natural' system connections. The framework proposes to understand the status quo at the first stage. Following studies investigate the ES potentials of the area and reveals the critical zones of selected SoES provision. Herein, the permeability of the surface (soil) and subsurface (geology/hydrogeology) layers are crucial for water infiltration -and accordingly circular movement of stormwater- while the areas with high capability to store carbon are critical for carbon sequestration to combat climate change. At the last stage, the critical zones of substratum are overlapped with the occupation and network layers (spatial configuration and the changes in LULC) to detect the areas necessitates protection and/or improvement.

The framework illustrates a generic perspective and necessitates tailor-made strategies for the area/region to be studied. Accordingly, the results obtained need to be translated into spatial planning practices with an overall aim to integrate SoES-friendly measures into current urban planning processes at different scales. Thus, the framework can provide normative principles guiding for future studies, which intends to increase the resilience of urban environments to emerging environmental problems. Considering the functions of soil in climate and surface runoff regulation within the constructed environments should be taken into account in planning processes of both existing or future developments. Developing and implementing SoES-based urban spatial planning approach is significant to enhance (i) functioning of SoES in urban landscapes; (ii) resilience of urban areas to climate change and storm water runoff problems; (iii) sustainability of urban ecosystems and related services in long-term.

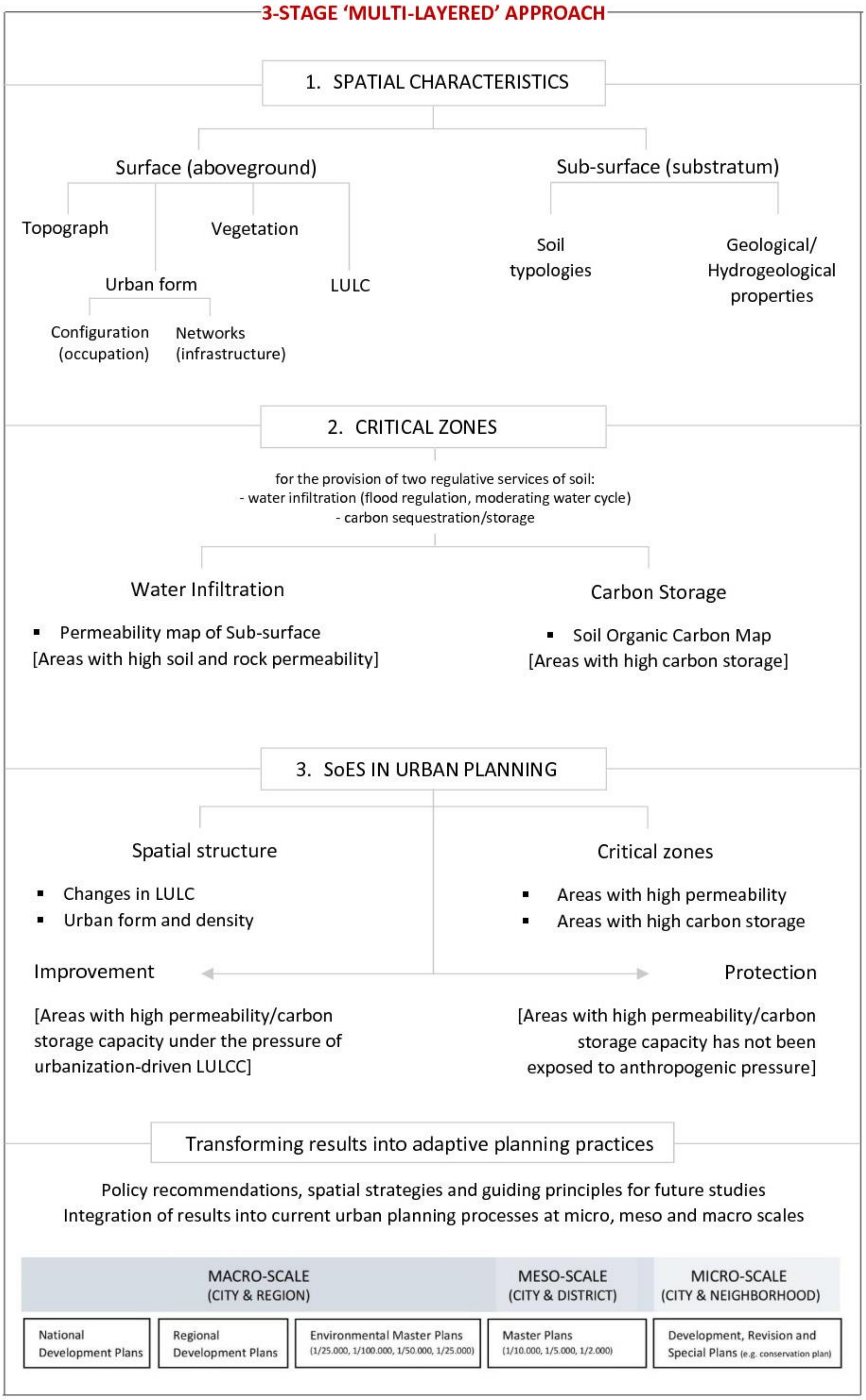

Figure 6: Flowchart of the Conceptual Model Framework

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