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GREEN INFRASTRUCTURE SOLUTIONS AS PART OF CLIMATE CHANGE ADAPTATION IN CITIES

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GREEN INFRASTRUCTURE SOLUTIONS AS PART OF CLIMATE CHANGE ADAPTATION IN CITIES

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CONTENT

ABBREVIATIONS

C	Carbon
CoM	Covenant of Mayors
İTÜ	Istanbul Technical University
KENTGES	Integrated Urban Development Strategy and Action Plan
NO_2	Nitrogen dioxide
O	Ozone
PM	Particle Matter
SO_2	Sulphure dioxide
US	United States

EXECUTIVE SUMMARY

A great population of the world live in cities and this rate has been increasing. Climate change lead to the occurrence of sudden an unexpected weather conditions on the earth. Cities are the areas where the impacts caused by climate change are felt the most. These impacts arise in the form of increase of heat island effect in cities, air pollution, heat waves and water scarcity, changing precipitation regime, increasing number of arid days, and the rain waters causing floods or overflows.

Ecosystems provide human beings and other living things with various benefits in the environments they are located. These benefits which arise as a part of natural processes ongoing in the ecosystems are called the ecosystem services. The regulatory ecosystem services provided by the ecosystems have an important role in the decrease of effects caused by climate change in the cities and the increase of resistance against these impacts. These services are the benefits provided from ecosystem processes where the ecosystems act as regulatory (for example improvement of air and earth quality, climate regulation, mitigating the impacts of natural disasters such as floods and overflows, disease control, water treatment, waste management, pollination, biological decomposition or control of the pests).

The fact that the constructed areas are intense in the cities makes the cities more fragile against the impacts of climate change. In order to mitigate the negative impacts of sudden and unexpected weather conditions caused by global climate change and to make the cities more resistant against these impacts, the benefits provided by the ecosystems should be protected and/ or increased. The ecosystem services provided by a green area network (green infrastructure) created by natural, semi-natural and cultural areas connected with each other that protect the ecosystem values and functions in the cities (with high ecologic quality) play a significant role in mitigating the impacts of climate change.

Integrating into the green infrastructure a part of the spatial planning process, having the components constituting this system involve storm water management solutions, protection of fragile ecosystems of cities, developing smart solutions towards improving the ecosystem services provided by green areas, will have positive contributions in making the city resistant against the impacts of climate change.

1. GREEN INFRASTRUCTURE SOLUTIONS AS PART OF CLIMATE CHANGE ADAPTATION IN CITIES

The earth that we live on is a living organism and it needs certain temperature conditions in order to live healthy like all living things. Human borne impacts that distort the composition of the atmosphere lead to increase of temperature on the earth. Since the atmosphere temperature demonstrated an increase of one degrees compared to 1800s as a result of the change of climate out of its natural order, the operation of the natural systems on the earth incurs damage. The life of all living things on the earth depends on the healthy processing of ecologic processes and cycles on the earth.

A great population of the word live in cities and this rate has been increasing. In order to mitigate the negative impacts of sudden and unexpected weather conditions caused by global climate change and to make the cities more resistant against these impacts, the benefits provided by the ecosystems should be protected and/ or increased.

1.1. Green Infrastructure and Its Components

Demands for infrastructure and construction towards creating new residential and commercial areas in connection with the impact of urbanisation, create a significant pressure on natural ecosystems and urban green areas. Cities of our country heavily comprise construction areas with densely located multi-layer buildings. The rate of green areas, which are in the form of small and isolated areas between the building islands in this pattern, is very low.

Healthy and livable cities are the cities that have open – green area system (green infrastructure) which have a balanced distribution between green area – constructed area, where green areas with high ecological characteristics are located together.

Green infrastructure is defined as a network of green spaces composed of interconnected natural, semi-natural and cultural areas that protect ecosystem values and functions (Benedict, 2000; European Commission, 2013). This network of parts (centers) and corridors include forests, bushes, meadows, wetlands, river corridors with natural areas such as parks, sports fields, school gardens, campuses, public and private gardens, roof gardens, vertical gardens, zoos, botanical gardens, farmlands, cemeteries, vegetated roads and other semi-natural and cultural components (Figure 1, Table 1).

Figure 1: *Integration of Green Infrastructure Components into Landscapes (Arup, 2019).*

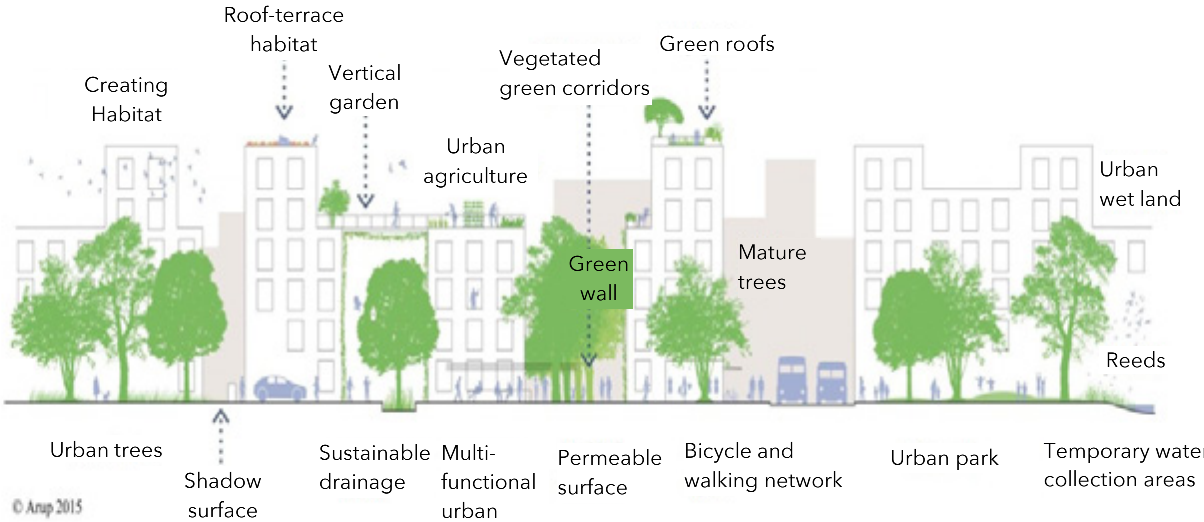


Table 1. Urban Green Infrastructure Components	
	**Natural areas** located at the urban areas are the areas coated with natural vegetation cover such as forest, bushes, empty parcels covered with herbal plants, watery areas. These areas are rich in terms of biodiversity as they involve various natural plant species at different size and ages.
	**Urban parks** are the green areas which involve natural and cultural ecosystems that could be of various sizes, providing the people of the city with recreational possibilities.
	**Urban Squares** at the open gathering areas inside the city used for different purposes.

Table 1. Urban Green Infrastructure Components	
	**Public and private gardens** are the green areas that are rich in terms of plant intensity and diversity of species.
	**Botanic gardens** are the plant collections that keep different plant communities together.
	**Agricultural areas** could be in the form of wide parcels where production is made for commercial purposes, fruit gardens or small-scaled hobby gardens. The agricultural areas include single and multi-annual plants which are not present on the green areas.
	**Cemeteries** are the wide green areas with intense vegetation that involve mature trees in the cities. They create a habitat for many living species.
	**Vegetated parking lots** are the areas created by vegetating or forestating the open parking areas in the cities through various methods.

Table 1. Urban Green Infrastructure Components	
	**School gardens** and education campuses are the areas which could have vegetation, involving education buildings, play and sports areas.
	**Green roofs** decrease the solar radiation with the vegetation cover, reduces the speed of rain water and ensures isolation.
	**Vertical gardens** are formed by covering of vertical structural elements such as buildings, wars and fences with plants, thus mitigating the energy consumption in the buildings.
	**Street trees**, which are located on the pavement, refuge and vegetated lanes create linear corridors in the cities. These are the elements that create connection in the open green area system.
	**River corridors** are the natural corridors which host land and water ecosystems together. They have important tasks in water cycle and rain water management.

Table 1. Urban Green Infrastructure Components	
	**Water canals**; these structures which are created by human beings are the corridors used for recreational and transportation purposes.

2. ECOSYSTEM SERVICES

With the vegetation they have, green areas provide such functions as air cooling, heat island effect reduction, carbon capture and storage, air purification by removing pollutants, soil enrichment with organic materials, providing nutrient and shelter environment for wildlife, supporting biodiversity, preventing the surface runoff, recharging ground and surface water resources, reducing wind and rainfall erosion, noise filtering, reducing energy consumption, providing recreational opportunities, and increasing the real estate value of land (Forman, 2014). These ecological, socio-cultural and economic functions contribute to the preservation of the health of the urban dwellers and the improvement of the quality of life.

Ecosystems provide numerous benefits to humans and other living things in their environment. All of these benefits, products and services that emerge as part of the ongoing natural processes in ecosystems are defined as **ecosystem services**. Supply services are classified into four groups: regulatory services, habitat or supportive services and cultural services (MEA, 2005).

The ecosystem services provided by each component of the green infrastructure vary depending on the ecological characteristics (location, size, spatial distribution, vegetation structure, density, etc.) of these areas. It is important that cities are built with green networks, in other words, the components of the green infrastructure are in physical connection with each other. The ecosystem services provided by the green infrastructure, which is designed to create functional connections with each other and includes green areas with high ecological qualities, reduces the effects of climate change.

The regulatory ecosystem services provided by the ecosystems have an important role in the decrease of effects caused by climate change in the cities and the increase of resistance against these impacts. These services are the benefits provided from ecosystem processes where the ecosystems function as regulatory. Improvement of air and soil quality, climate regulation, mitigation of natural disasters such as floods and landslides, disease control, water treatment, waste management, pollination, biodegradation or control of pest species can be listed among regulatory services (MEA, 2005).

2.1. Improving Air Quality

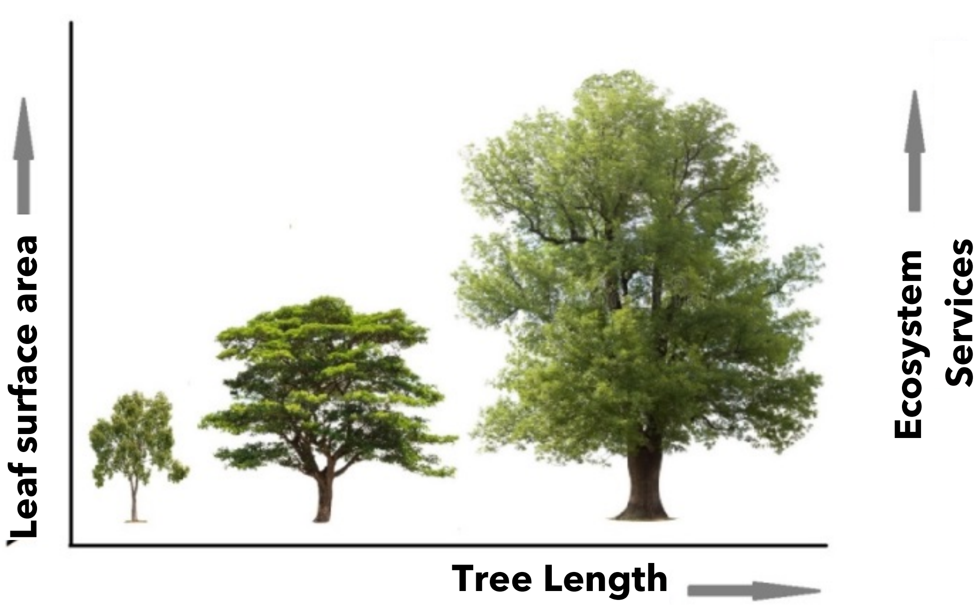
Air pollution has become a common problem in many cities. Polluted air causes many health problems, especially respiratory and cardiovascular diseases. The incidence of these disorders is higher in urban people. Especially the elderly and children are at risk.

The pollutants are present in the atmosphere in the form of particles (PM-particulate matter) or gas (C-carbon, NO_2-nitrogen dioxide, O-ozone, SO_2-sulfur dioxide). Particulate substances are one of the most important pollutants affecting human health. These substances suspended in air are called PM2.5 (size less than 2.5 μm) and PM10 (size 2.5-10 μm) according to their grain size (Scott et al., 2016).

Trees and plants improve the air quality of the city by removing pollutants from the atmosphere (Nowak & Dwyer, 2000). Trees are capable of filtering air pollutants by absorbing them or keeping them on leaf surfaces. Trees hold the carbon by making photosynthesis and store it in wood tissue. After the death of the organs or itself, the stored carbon returns to the atmosphere. Long-lived trees are capable of storing more carbon than short-lived ones. The pollutants held on the leaf surfaces remain on the plant until the tree decays or the leaves are washed by rain.

The air quality improvement function of the trees is depend on the size of the canopy cover. The green areas where large-leaved trees with large crown structures have more air purification function (Roupsard et al., 2013) (Figure 2).

Figure 2: *Relationship Between Tree Size and Ecosystem Services Provided by It*[1]



[1] See https://www.emeraldnecklace.org/park-overview/emerald-necklace-map/

2.2. Climate Regulation

Sun lights hits the surfaces on the earth and turns into heat energy. Structural surfaces such as concrete, asphalt and metal heat up with solar energy during the day and warm the surrounding area. Surface temperature is high in areas where vegetation is weak and roads, buildings, roofs and parking lots are intense. Since the building density is high, the urban areas are a couple of degrees hotter compared to rural and less developed areas. This microclimatic situation is defined as the heat island (Roth, 2013).

Green spaces are an important factor in controlling urban temperatures. Plants, especially trees, affect the climate of their environment. Trees cool down surfaces in the city by transpiration and creating shadows. The facts that the vegetation is tall, the crown density is high, increases the shading and transpiration functions, which leads to cooling of the environment. The surface temperature and cooling effect of the green areas covered with grass, shrubs and trees are different. Among these areas, the cooling effect of the area covered with broad-leaved trees is higher than the others. The heat island effect is low in cities where there is a high density of green areas with high ecological characteristics, a low rate of built-up area / green area, and spatial distribution of the components of green infrastructure is evenly distributed. The low heat island effect means that road and building surfaces are under heated in summer and undercooled in winter. This reduces the energy consumption for heating and cooling systems in buildings and vehicles.

2.3. Improvement of Soil Quality – Biodegradation

Soil is a valuable natural resource and a living organism that requires centuries of formation. The presence of microorganisms, soil organisms and fungi in the soil increases the biodegradation and enables the soil to become rich in nutrients. This is an indication of a living and healthy ecosystem.

In cities, soil surface is mostly covered with built-up areas. Natural processes continue in soil layers in urban landscapes as well as in rural landscapes. However, the physical and chemical structure of the soil in cities varies compare to the soils in natural areas. Construction activities and underground and above ground transportation systems cause soil layers to become compacted and reduce air and water retention capacity of the soil. In addition to this, leaking into soil of lead, fuel oil, oil, detergent and other chemicals arising from industrial and domestic wastes, salt application performed in winter months, chemicals and fertilizers used in green areas pollute the soil, damage the soil organisms and microorganisms.

Vegetation roots ensure aeration of the soil and water infiltration. Decomposition of the organic substances in the soil such as branches, leaves, fruit and flowers will feed the soil organisms, enrich the soil in terms of nutrients and increase microorganism activities.

Removing the organic materials such as leaves, branches, fruit, flower that fall on the soil surface in urban green areas, lead to deprivation of soil of the nutrients and decrease in the number of soil organisms in connection with that.

2.4. Pollination

Pollination is vital for the sustainability of ecosystems and living communities (UNEP, 2010). Maintaining the balance of ecosystems depends on the healthy and continuous relationship between plants and their pollinators.. In this respect, pollinators are the key components of global biological diversity (Potts et al., 2010).

Green areas that include large old growth trees with wide canopy cover, and different forms of trees, shrubs and climbing plants varying in terms of color of leaves, flowers and fruits and as well as time period of producing leaf, flower and fruit have high ecological value (Coşkun Hepcan et al., 2015). Green areas with high ecological quality include bird, rodent, and insect species that provide pollination not found in many parts of the city. These species enrich the biodiversity of green spaces and the city.

2.5. Flood and Overflow Prevention

Water that infiltrate into the soil and is not used by the plants flows parallel to the surface under the soil, feeding a water structure, such as nearby rivers and lakes, or penetrating deeper into the ground water. Vegetation, especially trees, decreases the speed of precipitation by their branches and leaves and gradually release it to the ground and reduces the surface runoff. Maintaining the natural form of the trees is very important in terms of slowing down the precipitation water and infiltrating the soil.

Changing the topographical structure due to urbanisation, decrease of the permeable surfaces and increase of the impervious surfaces, ignoring / disregarding the natural drainage pattern, taking the river beds into concrete channels, narrowing the cross section or completely closing it, lead to the change of flow system of the water, interruption of the water cycle, and failure of recharging of underground and surface water resources. This situation often causes the water not to be drained during rainfall and roads and streets to be covered with water. Changing the river beds within and around the urban landcapes adversely affects the ecology of the river and interrupts the ecological processes. Streams flowing in the natural bed and having vegetation cover along the banks serve as the collector of surface runoff. Vegetation both in water and on river bank provide natural water filtration. The flow rate the microorganisms of the engineered rivers are lacking of self-cleaning function.

Most of the precipitation in urban areas turn into the surface runoff in impermeable areas. Due to extreme climatic events, it has become increasingly common that the cities receive heavy downpours in a short period time and the amount of surface runoff increases. It may cause flooding and overflowing when the amount of water surface runoff exceeds the capacity that water natural and artificial drainage systems. Since there is generally no separate rainwater collection systems in cities, surface runoff is collected by waste water (sewage) systems. This leads to the loss of large amounts of water as waste water . In cities with rainwater collection systems, this water is used in two ways. In some cities, it is discharged to water bodies such as sea and river. In this case, the aim is to remove water as quickly as possible from the city and reduce the burden of the waste water treatment plants. In cities where treatment is targeted, runoff is delivered to sustainable stormwater facilities such as bioswales and wetlands where biological treatment processes take place (Strom et al., 2013). Similarly, wetlands act as sponges and help prevent flooding by absorbing water .

3. GREEN INFRASTRUCTURE MANAGEMENT

Green infrastructure is planned, implemented and managed at different scales. Regional planning (river corridors, natural ecosystems), basin, city (urban parks, large tree boulevards, groves), neighborhood (neighborhood parks, vegetated streets and streets) and area (rain gardens, vertical gardens, bioswales) scales can be based on.

The implementation and management process is a costly and long-term process that requires many actors to work together in harmony. However, this cost is not more than the budget spent on construction and maintenance expenses of grey infrastructure components such as transportation and communication lines, clean and waste water systems in cities. Since the completion of the implementation process requires time and budget, these studies are gradually programmed in stages.

Although local and central government are mainly responsible for the management of green infrastructure components, the participation of non-governmental organizations, local people and volunteers in the management phases contributes to the adoption and protection of practices and increases the chances of success. In addition, users can adopt and protect the green infrastructure components by raising awareness and developing solutions to raise public awareness.

In the management process, rules regarding operation and supervision are determined, and in some cases solutions such as land acquisition or long-term leasing are developed. In addition, these areas should be monitored regularly for maintenance and improvement works.

The management of the green infrastructure also includes the mapping of the green areas, the identification of biological diversity, the detection of diseases and problems, the development of solutions and the maintenance and monitoring stages. In this context, rules are defined for the maintenance and management of urban green infrastructure components and guidelines involving these rules are prepared.

Cities such as Tokyo, Seattle, Portland, Eugene, New York, New Jersey have successful practices in stormwater management. Details of the implementation of stormwater management in these cities are described in the **stormwater management guidelines** (NYSSMDM, 2005; Hinman, 2013; NJSM, 2004; CPSMM, 2016). Workshops are organized at regular intervals to introduce these guides, to give information about techniques and practices, and to bring together users, experts, practitioners and users.

In Vancouver, Toronto, New York, San Francisco, Portland, London, Barcelona, rules and standards related to the types of street trees to be used in the city, planting, maintenance conditions and so on are specified in **Street tree guides** (Street Tree Guidelines Vancouver, 2011; NYC, 2016; Toronto Street Trees, 2010).

Drought-resistant natural plant species in the cities of Albuquerque (New Mexico, USA) and Las Virgenes (California, USA) with arid climatic conditions and details of how these species can be used are given in the **arid landscaping guides** (Las Virgenes Municipal Water District, 2017).

Mapping the green infrastructure components of cities and processing them into information systems provides important data for management studies. In particular, obtaining green area and street **trees inventory**, processing these data in information systems, updating them regularly greatly simplifies the management of green infrastructure. In this system prepared in cities such as Rome, Portland, Eugene, Seattle, New York, London, Amsterdam, Rotterdam, the position, age, height and general conditions of the trees are followed and the processes are carried out from here.

Similarly, **preparation of biodiversity inventory** provides for determining the measures to be taken for the protection and improvement of biodiversity in cities. Biodiversity inventory has been prepared in many cities such as Toronto, London and Vancouver.

The management of green spaces is not solely the responsibility of local governments. There are also rules that should be applied in private property areas. For example; rules are determined under regulations in relation to mowing of herbaceous plants and lawns at regular intervals, keeping their height below the specified level, combating the proposed ecological methods if invasive species are observed and detected, not polluting the water resources, and so on.

Green areas with private ownership play an important role in the protection of ecosystems in urban landscapes (Ramos-González, 2014). In some cases, non-governmental organizations take over and manage these areas in order to prevent the conversion of ecologically important areas into urban uses such as urbanisation and to ensure their protection in the current way. For example, "Birdlife International" has acquired a large number of wetlands in Europe, particularly in the UK and the Netherlands, ensuring the protection of a wide range of natural ecosystems.

Similarly, the Rivers to Ridges partnership in the US city of Eugene has provided protection for these areas by acquiring wetlands and natural meadows (expropriation) or long-term leases for over 20 years, and has developed successful solutions for improving ecosystems through management efforts. In this process, open-green areas representing different landscapes and habitats were transformed into a green/ecological network system throughout the region. (West Eugene Wetland Partnership, 1995; The Rivers to Ridges Partnership, 2013). These non-governmental organizations are also supported by national and international funds, conducting scientific projects in these fields and providing support to science and researchers.

The Dutch government also acquired or long-term leased some lands to ensure the creation and protection of ecological corridors during the implementation of the national ecological networks.

In addition to this, some practices are being carried out in order to raise awareness of the urban dwellers about green spaces and their benefits and to raise awareness on protection. In order to improve the quality of life of the urban landscapes and to establish a green space system, various national or international organizations have developed awards and certificate programs to encourage local governments and residents.

In order to support the local administrations which engage in studies for creating ecological solutions and for increasing life quality by respecting the environment, the European Commissions has brought "**European Green Leaf**" award system for cities with a population between 20.000-100.000, and **European Green Capital** award system for cities with a population more than 100.000. Cities wishing to apply for an award are developing projects and applications by investing in climate change adaptation, biodiversity, conservation of natural resources, improvement of air and water quality, clean energy and environmental management. The practices provide ecological, economic and socio-cultural gains to the cities.

Similarly, **Green Flag Certificate** was developed in 1996 in order to create a national standard in the parks and green areas in the UK and this spread to the whole world. Within the scope of the award, green spaces are evaluated in terms of biodiversity, health, safety, accessibility, care, participation and management criteria.

Apart from these, there are supports given to applications that develop ecological solutions in private green areas. For example, in the UK, the size of pavement and paving material that can be used in private proporties (residential garden) are defined by regulations and details are given in the guidelines. The use of impervious pavement over 5 square meters in these areas has been subject to special permission. In addition, increasing use of pervious surfaces is encouraged by tax reductions (DCLG, 2008; Permitted Paving, 2013).

Similarly, Portland (OR), Seattle (WA) and Philadelphia (PA) are the cities where the residents get tax reduction due to using permeable pavements. The city of Portland (OR) also has provide other incentives. For example, project owners with ecological roofs and trees of more than 4.5 meters in length are awarded money to be used during the implementation process. In addition, stormwater management practices in the city are evaluated in terms of water holding capacity, flow rate of water, efficiency levels in pollution treatment and successful projects within the scope of the **Clean River Rewards** are given budget support up to 100% at the implementation stage or discount up to 35% in storm management taxes (GI Case Studies, 2010).

4. EXAMPLES FROM THE WORLD

There are cities around the world that have developed, planned and implemented a green infrastructure. The basis of this approach is the Emerald Necklace in Boston (USA) (Figure 3). This park system was established in the 18th century, where nine parks were connected by stream corridors and linear parks. In this park system, which includes pedestrian and bicycle paths covering an area of approximately 445.06 ha, it is aimed to protect natural ecosystems and meet the users in the city with nature-based solutions.

Successful practices also include Stockholm, London, Portland and Baltimore. In Stockholm, efforts to improve the environmental quality of the city began in 1976. 95% of the population provides access to green spaces less than 300 meters away. Taking into account the growth estimation for 2040 of Stockholm, which has received the title of first green capital of Europe in 2010, smart growth models have been developed against climate change in the city.

Figure 3: *Emerald Necklace*[2]

The model called Climate-Smart Model, which is planned to be applied to new development regions, has given priority to pedestrians, bicycle users and public transportation in urban transportation. In addition, in order to protect the natural and agricultural ecosystems in the city and its vicinity, the use of chemicals harmful to health is prohibited and biological control and organic farming practices are encouraged. The city also has maps of green infrastructure and ecosystem services integrated into urban plans (Jones, 2018) (Figure 4).

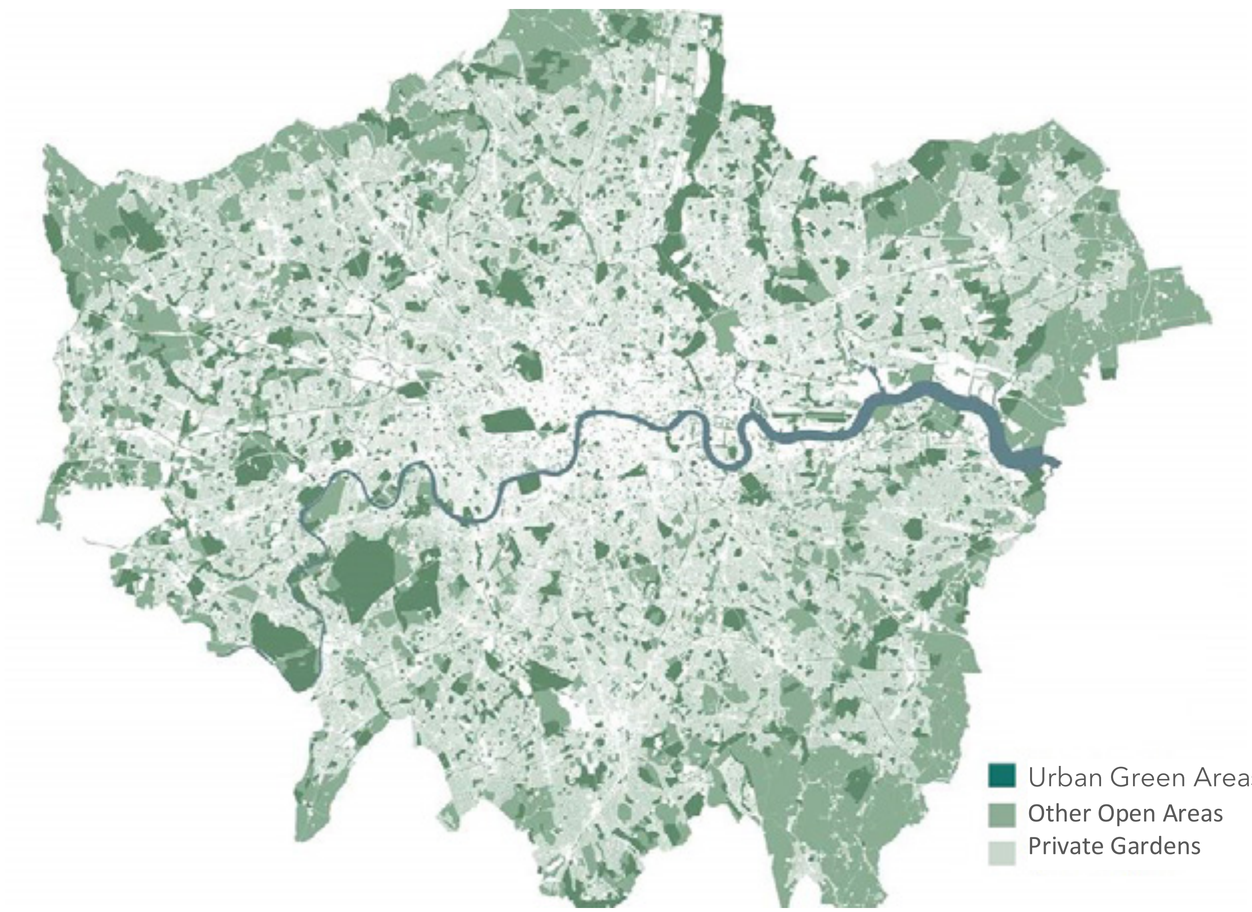
In 1943, the approach of the open space and park system, which aims to establish a connection between the green spaces in and around the city in London, was introduced . Then, with the plans prepared in 1992, 2004, 2008 and 2012, this system was developed considering the goals of conservation of natural ecosystems and biodiversity, creating pedestrian and bicycle paths and ensuring accessibility. Green areas constitutes 47% of the city. The ratio of open areas reaches 60% (Figure 5).

Figure 4: *Stockholm Green Infrastructure Map*[3]

[2] See https://www.emeraldnecklace.org/park-overview/emerald-necklace-map/
[3] See http://www.cardiff.ac.uk/archi/research/cost8/case/greenblue/stockholmgreen.html

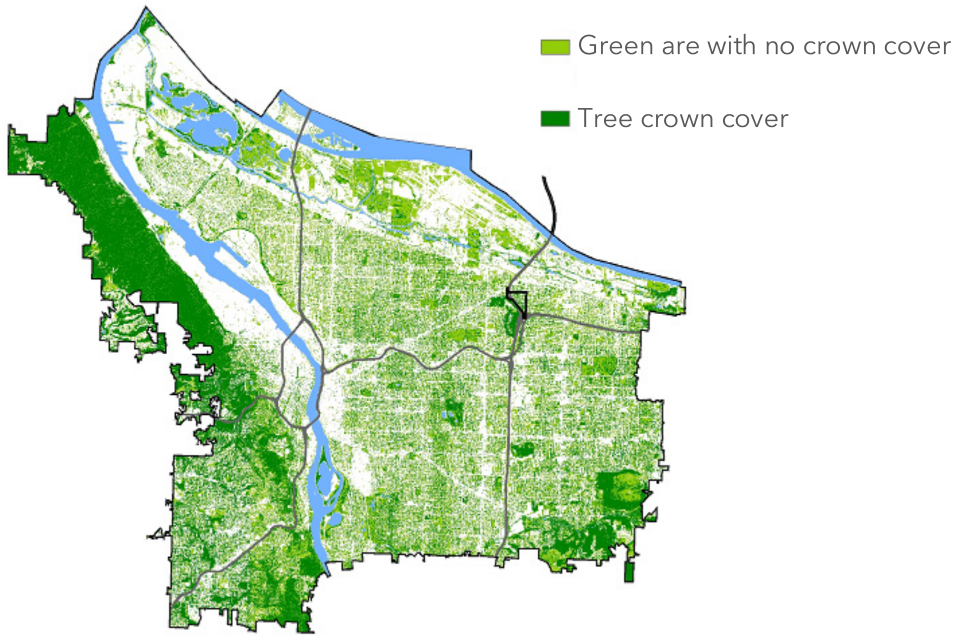
The city of Portland (OR) is one of the most comprehensive and developed green infrastructures in the United States. Within the scope of green infrastructure development activities, it was aimed to create green areas that contain homogeneous distribution of trees with large canopy cover and priority was given to the regions where the building density of the city is high. With the Green Street Project, projects and practices aimed at creating green corridors by planting street trees, increasing biodiversity and stormwater management were developed. The tree cover was raised to 26% of the city (Figure 6).

Figure 5: *London Open – Green Area System Map* [4]



[4] See https://www.gigl.org.uk

Figure 6: *Portland City Tree Crown Cover Map* [5]



In addition, with the watershed management project, studies aimed at protecting water ecosystems, preventing pollution and increasing biodiversity were carried out. The success level of these solutions, which increase the resistance of the city, is monitored regularly through monitoring programs.

In 2010, a program for the evaluation of open spaces aimed at the creation of green infrastructure components in parts of the city in need of renovation was initiated in Baltimore and in this scope 700 empty parcels were transformed. In addition, it is aimed to increase the tree canopy cover in the city and it is planned to increase the canopy cover, which is currently 28%, to 40% by 2037.

Almost all have one thing in common: increasing biodiversity, improving air and water quality, stormwater management, improving quality of life, and creating recreational opportunities for environmental management.

In many cities, the level of ecosystem services provided by the green infrastructure is estimated and solutions are proposed to improve these ecosystem services in order to improve urban ecology and improve the quality of life.

[5] See https://www.portlandoregon.gov/bes/article/509607

5. WATER MANAGEMENT WITH GREEN INFRASTRUCTURE

The effects of global climate change are manifested in the form of extreme weather events. Unlike the conventional climate regime, sudden, unexpected weather events occur such as, short or long-term heavy rains. This situation results in floods and overflows in most cities.

The high impermeable surfaces in the cities lead to the change of natural flow system of water, interruption of water cycle, and failure to recharge the underground and ground water resources. The rainfall that gets into the surface runoff becomes polluted and transmits this pollution to water resources and pollutes the water reserves. Stormwater management has become the priority of many cities in the world, aiming to keep the rainwater and transfer it to the water resources in accordance with the natural flow system. As a result of recent studies on this subject, the term sponge city has emerged. The sponge city is defined as the city where ecological solutions are developed for stormwater management including the reduction of dirty water flow, detention/retention of runoff by natural methods, and filtration and discharging to the water bodies. In these cities, the amount of impermeable surfaces are reduced, permeable road and pavements are increased, it is targeted to transfer the rain water to natural systems by means of rain gardens, water retention trenches, roof gardens, and ponds. In sponge cities that contain successful solutions and applications, the frequency and intensity of floods decrease, water quality increases, and ground and surface water resources are fed (Xu et al., 2018). Many cities develop and implement policies to become sponge cities.
The amount of clean water used in cities with arid climatic conditions is higher than the amount of rainfall received by the city. For that reason, it is very important to recharge the water resources. It is aimed to control surface runoff in stormwater management and to transfer(manage) water resources with nature-based solutions. Rainwater management systems, rain garden, permeable pavement, dry well, rainwater plant strip, rain trench (water holding and accumulation trench), infiltration pit, green roof (roof garden), rain barrels, cisterns, water treatment areas and wetlands can be achieved by creating green infrastructure components that contain rational solutions (Karakoçak, 2011; SPSMM, 2016).

5.1. Permeable (Porous) Pavement

It is a type of pavement produced from materials such as concrete or asphalt, etc., that can be used in vehicles and pedestrian roads, capable of penetrating water into the soil beneath it, allowing the water to be filtered by natural means, free of pollutants and recharging of groundwater resources (Figure 7).

Figure 7: *Example of Permeable pavement* [6] [7]

5.2. Rain Garden

Rain garden or bio-retention areas are shallow depressions with native and exotic plants collect rain water runoff without any treatment (Demir, 2012). Its basic function is the collection of surface - runoff that occurs after rain in such areas as roofs, vehicle - pedestrian roads, parking lots and treating the water with biological treatment methods to improve water quality (Jaber et al., 2012). With the surface runoff that reaches to the rain garden, the height of the water increases and a pond occurs.

The level of water in this pond varies depending on rainfall intensity, the soil infiltration capacity the vegetation type and the structure of the rain garden. Since generally, the rate of surface runoff is higher than the rate of water infiltration, a pod of 5 -10 cm occurs at the initial stage. Afterwards this water, which has formed into a pond, slowly drains from the bottom of the rain garden to the soil (Doğangönül & Doğangönül, 2008). Rain gardens are an extremely simple and cost effective stormwater management facilities that are used for reduction of the amount of surface runoff, improving groundwater recharge, and water purification; . Rain garden also provide convenient and sustainable solutionsfor private and public spaces (Figure 8) (Jaber et al., 2012).

[6] See http://www.constructionworld.in/News/Pervious-Concrete-Pavement-for-Smart-Cities/90126
[7] See http://www.craftontull.com/insights/insight_posts/view/46/how-do-permeable-pavement-systems-Compare

Figure 8: *Example of Rain Garden Eugene, US (United States)*

5.3. Stormwater Planter

Stormwater planter formed on the road and pavement to contain rainwater from curb openings have surface flow control, leakage and filtration functions (Figure 9) (Eugene, 2014).

Figure 9: *Stormwater planter Example, Eugene, US*

They are designed to include the plant species specific to the area in different shapes and sizes according to the characteristics of the area to be applied. It includes engineering and design solutions that allow water to be absorbed and purified from pollutants through its permeable soil structure and natural plant species.

Some lanes have water tanks that collect excess surface runoff. The collected water is used for plant irrigation or for the recharging of groundwater systems (Eugene, 2014).

5.4. Bioswales

Bioswale (biological channel) is a narrow and long planted trench formed on the side of the road, which collects, holds the surface flow water and filters the water by filtering the pollutants (Figure 10) (SPSMM, 2016).

Figure 10: *Rain Trench Example Seatle, US (EPA, 2017)*

5.5. Green Roof

Green roofs are structures that built on flat or slightly sloping roofs, consisting of vegetation, soil, drainage and waterproof membranes, directing excess water to rainwater drainage that holds part of the rainfall (Figure 11) (SPSMM, 2016).

Figure 11: *Green Roof Example Toronto*[8]

[8] See http://www.flatrooferstoronto.com/green-roof.html

5.6. Example Practices

Solutions for the establishing of green infrastructure components in the parts of cities that have completed their development are very limited. It is almost impossible to find available open spaces to create new green areas. In these areas:

- Increasing the amount of vegetation cover by creating vertical gardens, roof gardens or street tree plantation,
- implementing urban renewal practices in a part of the city that include green infrastructure components,
- Creating green infrastructure components by establishing ecologic restoration in all or part of the abandoned industrial areas (brownfield),
- By using all or part of the highways, railways or river beds which have lost their function as corridors, solutions could be created.

High line Park (New York), Boston Rose Kennedy Greenway, South Korea CheongGye river corridor, Tanner Springs Park (Portland) are among the successful examples.

5.6.1. High Line Park

High line is an urban park which was created by redesigning the 1,876 m long railway viaducts in Manhattan, New York, after being closed for use Part of the elevated railway, built in 1934, was partly demolished in 1960. Demolition decision was taken for the remaining part in 1980 and this decision was cancelled with the initiative of Friends of the High Line Association which was established in 1999 and a design competition was organized to transform this area into a park. The construction of the park, was started in 2006 and it was completed in three stages in 2009, 2011 and 2014 and cost approximately $ 188 million (FOHP, 2017) (Figure 12).

Figure 12: *High Line Park*[9]

[9] See http://juliotapiaphotography.com/highline-park

5.6.2. Boston Rose Kennedy Greenway

In order to provide a solution to the traffic problem in the city of Boston, in 1959 an elevated highway was built on viaducts and the physical connection of the port and the city was cut. However, due to the traffic jam, air pollution and noise problems, as a result of planning which lasted for more than ten years, in 1991, a project was put into life which was called Big Dig which aimed at creating a green corridor in the city by shifting the traffic under the ground.

With the project that has a length of 2.4 km greenway was completed in 2008 with the cost of aproximately 1.7 million USD, and is defined as the most comprehensive project of the USA due to construction of system of tunnels under the ground, Boston has become a pedestrian-friendly city. The project include stormwater management facilities and also solutions aims to increase urban biodiversity (ASLA, 2013) (Figure 13).

Figure 13: *Rose Kennedy Greenway 2002-2007 (ASLA, 2017)*

5.6.3. CheongGye River

The CheongGye Riverdissects the city of Seoul was taken to a closed canal in 1971 and elevated highway was built on it. In the course of time the city experienced problems such as air pollution, heat island effect, and noise because of the traffic because of the road and also the viaduct completed its lifetime. Between 2003 and 2009 the viaduct was completely disassembled, and ecological river restoration was conducted (Figure 14). The cost of restoration was approximately 380 million dollars. It provides flood protection for up to a 200-year flood event.

The monitoring studies showed that the restoration project increased urban biodiversity, reduced the air temperature 3-6 degrees along the river corridor, increased wind speeds moving through the corridor by 2-7%, and reduced particle pollution by 35 %.

In addition, as the river became a center of attraction, the number of tourists (64000 people/day) increased significantly, the property value increased and new business opportunities emerged (Lee, 2006).

Figure 14: *CheongGye River Restoration – Before and After (Lee, 2006)*

5.6.4. Tanner Springs Park in Portland

The wetlands in the Pearl District, northwest of Portland (OR), were filled at the end of the 1880s and an industrial zone was created. In 1994, a large-scale urban renovation project was initiated in order to transform this abandoned area into a residential area. In this area, a parcel of approximately 3700 m2 was excavated to create a Tanner Spring Park. The lowest part of the park is still 6 meters above the old lake floor. The park was established n 2002 with the cost of $ 3.6 million.,

In order to emphasize the ecological history of the region in the design of the park, it was aimed to reconstruct the meadow and wetland ecosystem before the industrial area. The park, established in a polluted industrial area, is considered as an example of sustainable park design and management experience. The park collects the surface runoff of the neigborhood. Water is filtered by wetland ecosystem of the park and transferred to the river system by using ultraviolet light without any chemical (Figure 15).

Figure 15: *Tanner Spring Park Ecologic Improvement– Before and After* [10]

[10] See http://www.landezine.com/index.php/2013/03/tanner-springs-park-by-atelier-dreiseitl/

In order to reduce the impacts of climate change in cities, in addition to efforts to create new green areas, flood protection systems are being developed to prevent floods in heavy rains. **Tokyo Flood Control System, G-Cans Project,** Kasukabe, Saitama, Greater Tokyo Area, which was prepared for the Saitama region on the North of the city in order to prevent the floods that occur during rain and typhoon times in Tokyo, is among the best examples in this scope. With the project which was launched in 1992 and completed in 2009, systems comprising giant tunnels and depots under the city were created. The system which comprises by connection of 5 tunnel shafts with a diameter of 32 meters and a height of 65 meters, to each other with tunnels with a length of 6.5 km going 50 meters under the ground, costed 1.5 billion Euro. The main rain water depot of G-Cans, which is called "underground temple", has a length of 177 meters, width of 78 meters and height of 25 meters. The depot has 59 colons, each with a weight of 500 tons, which have the capacity to discharge to Edogawa river 200 tons of water per second in connection with a pump that has a power of 10 MW. In the calculations a 200-year flood event has been taken into account (C-Cans Project, 2009).

6. EXAMPLES FROM TURKEY

In our country, there is no holistic example where green infrastructure is applied to include ecological solutions, but somelocal projects are established.

The "Adaptation to Climate Change Through Rain Harvest Project", which was implemented by the Landscape Research Society (PAD) in partnership with Çankaya Municipality and the Humanitarian World Association, and supported by IVth Environment Grant Program, was completed in 2017. Within the scope of the project, "Introduction to Rain Harvesting Practices Guide" has been prepared in order to raise awareness about the importance of rainwater retention in urban and rural landscapes, to introduce application techniques and to convey examples (Tokuş & Özdemir, 2017). In order to transfer the project experiences to the implementation, studies are being carried out by Çankaya Municipality with the aim to provide technical and physical transformations that will ensure the irrigation of nearly 500 parks throughout the district with the stored rainwater.

With the regulation made in 2018, permeable concrete was applied on the walkway in the central campus of the Ministry of Environment and Urbanisation and a rain garden was established in the green area along the road. It is aimed to discharge the surface runoff into the green area and the rain garden (Figure 16-17). The Ministry is working on similar practices in the gardens of public institutions.

Figure 16: *Ministry of Environment and Urbanisation Campus, Rain Garden Application* [11]

Figure 17: *Ministry of Environment and Urbanisation Campus, Permeable Concrete Application* [12]

[11] See https://mpgm.csb.gov.tr/yagmur-hasadinda-kucuk-ama-etkin-bir-adim-yagmur-bahceleri-haber-228890
[12] See https://mpgm.csb.gov.tr/yagmur-hasadinda-kucuk-ama-etkin-bir-adim-yagmur-bahceleri-haber-228890

In addition to this, landscape designs that integrate stormwater management solutions have been developed in Ayazaga Campus of Istanbul Technical University (ITU) within the scope of green campus applications and bioswales (biological canals) were established where the surface runoff could be kept on walkways (Figure 18).

Şekil 18: *İTÜ Ayazağa Campuse Bioswale Example*[13]

İzmir Metropolitan Municipality is working on developing green infrastructure strategies at the metropolitan scale. These strategies, which prioritize river corridors that establish physical relations with urban and peri-urban environments, have not yet been transformed into large-scale comprehensive plans and integrated into physical plans. In some parts of the city, small scale projects are developed. URBAN GreenUP supported by the Horizon 2020 program is one of them. The project aims to increase biodiversity, stormwater management and improve air quality with nature-based solutions in three demosites.

Unfortunately, due to the lack of holistic approaches to the establishment of a green infrastructure, it is not possible to develop a permanent solution to the problem.

[13] See https://www.hetpeyzaj.com/

7. LAWS AND REGULATIONS IN TURKEY

In the Regulation on Principles on Planning under Zoning Law No. 3194, the urban green area standart was defined as $10m^2$ active green area per capita. Unfortunately, in practice this issue has not taken into accound.

In the Country Spatial Strategy Plan, open-green areas are classified as social infrastructure components. In the plan notes for spatial plans, it is stated that "open- green area system" should be included. In the spatial planning process that is in force, more focus could be put on definition types and functions of open- green area system under the scope of implementation of landscape architecture

Since the legal regulations mentioned were not made, the planning and design of urban open-green areas were isolated from urban development plans, and these are carried out at a limited scale at the level of zoning parcel and under the initiative of municipality assemblies (Yilmaz, 2010).

In 2015, the Ministry of Environment and Urban Planning prepared a Manual for Urban Design Guidelines for Local Governments. Various sections of this manual, which is characterized as a recommendation, included the terms such as "open and green area, green area system, green network" were defined, however, the definition, content and components were not explained.

"Regulation on Rainwater Collection Storage and Discharge Systems" which came into force after being published in the Official Gazette dated 23 June 2017, is one of the pioneering steps taken in cities in relation to the management of rain water. The regulation includes principles and procedures related to planning, design, project design, construction and operation of rain water collection, storage and discharge systems prepared by the targets. In the regulation which includes the application provisions, the definition of "Open-Green Area System" could be extended and "Green Infrastructure" practices could be highlighted.

Integrated Urban Development Strategy and Action Plan, which is a roadmap for the central and local administrations in relation to urbanisation and zoning (KENTGES 2010-2023), the concept of "Open-Green Area System" is included in the strategies. It was foreseen in the plan that regulations should be made on the settlement plans which protect the existing green areas and in spatial plans which recommend open and green areas system. In this scope, the need to develop planning and design standards and to make legal regulations towards the preparation of guides, was emphasized. Ministry of Environment and Urbanisation. It was aimed at designing and constructing a model for Turkey with all of its elements. The regulation also targets at remedying the problems experienced in the realization of infrastructure investments and services, establishing standards towards cohesive and efficient operation of the data infrastructure, and providing contribution to the efforts towards developing the application tools (Official Gazette, 2017). However, the regulation does not specify that rainwater management solutions are components of green infrastructure they should be integrated as a part of it.

7.1. Recommendations for Turkish Cities

It will adequate to make relevant adjustments in the related laws, regulations and specifications for including the concept of "Open-Green Area system or Green Infrastructure" in the regulation, which includes national planning stages and implementation provisions (Zoning Law, Building Inspection Law, Municipality Law, Planned Areas Type Zoning Regulation, Regulation on Principles of

Plan Making, Engineering and Architecture Services Specifications, etc.) (Yılmaz, 2010).

Although issuing regulations is the first step of the solution to the problem, it is necessary to ensure that the regulations are implemented and audited correctly. In this scope, preparation of stormwater (rainwater) management handbooks / guides specific to each city or district in collaboration with central and local administrations will increase the chance of success in practices. A good example is the Rain Garden Preparation Guide, which includes the principles and procedures for the implementation of rain gardens prepared in April 2018 by the Ministry of Environment and Urbanisation. This guide will be a useful and guiding resource for local governments and practitioners.

The classification of green areas per capita size is an important problem for the creation of qualified green areas in cities. Green areas should be evaluated according to their ecological characteristics and spatial distribution, not their spatial size. The ecological value of an area varies depending on the size, form, species diversity (plant and animal) it possesses and the density of the species. As the number, density and mass of native plants increase, the ecological qualities of the area increase. Similarly, areas include trees, shrubs, and ground covers of different species and ages have high ecological value (Coskun Hepcan et al., 2015).
As the lawn areas are low in biological diversity and they require large amount water, fertiliers for growing, in the scientific literature the lawn areas are defined as “ecological deserts” in the scientific literature (Forman, 2014). The ecologic characteristics of the green areas determine the type and amount of ecosystem services provided by these areas. The principle **should be to create green infrastructure which has high ecological characteristics and demonstrates a balanced distribution in the urban tissue**. In this scope, it should be targeted to develop a holistic approach towards improvement of ecologic characteristics of open – green areas.

Each city has unique climate, natural, cultural, demographic and ecologic characteristics as well as green area planning – design policy and practice. For that reason, it will be appropriate to develop precautions on the basis of unique values of the cities.

As a priority, mapping the existing green infrastructure and defining the missing components of it will provide important data for determining the planning strategies. Solutions could be developed to complete the missing parts. For example;

- Green corridors could be created by planting trees in the streets and along the railways.
- Trees have large canopy could be planted in the large parking lots that owned by public or private in order to mitigate the urban heat island
- Tree canopy cover can be increased by using wheeled plant pots (parklets) in parts of cities where physical conditions do not allow planting trees.
- Dry stream and river corridors can be handled together with floodplains and designed as green corridors with ecological restoration. Especially in cities with streams and canals, these solutions can be developed.
- Urban renovation projects could have been an opportunity to develop urban green infrastructure in different scales. But unfortunately, many of the projects are local scale and they only aim to reconstruct the buildings without considering their neighbourhood. However, urban renovation practices should be planned and implemented to include the components of green infrastructure in neighborhoods, districts or larger scales in order to provide solutions for

the purpose of creating livable, healthy and planned cities. In addition, in order to create a new green space, it is necessary to find resources to eliminate property problems and to meet acquisation costs.

A rainwater management program should be prepared and solutions such as rain gardens should be spread throughout the city. The aim of the Ministry of Environment and Urbanisation to create rain gardens in the gardens of public institutions and organizations is an opportunity for strengthening green infrastructure and stormwater (rainwater) management in cities. The scope of this objective can be extended to the gardens of private institutions, educational and health institutions, residential areas.

Site-specific solutions of the components of green infrastructure and guidelines containing design, implementation and management details should be produced. These guidelines could be prepared at the scale of district municipalities. For example;

- Guidelines including design and application details for areas such as sidewalk, road, refuge, etc. involving stormwater management solutions;
- Guides which include the plant species, sizes, maintenance and management rules to be used in such areas as sidewalks, streets, refuges, vicinity of the buildings inside the city, should be prepared.

In order to encourage the local administration to prepare these guides, legal regulations could be developed. For instance the Urban Design Guide Preparation Manual could be transformed from recommendation into obligatory.

Besides, registering the existing vegetation cover in the cities will provide great ease for the preparation of park and street tree inventory in the areas under the responsibility of local administrations, processing the data into digital database (information systems), protection, management and maintenance works for these trees. Encouraging the participation of volunteers from urban dwellers to these inventory works will have positive contributions in improving the awareness.

Determination of the ecosystem services provided by urban green areas will facilitate taking precautions in order to ensure the services needed in the city. It will be appropriate to develop solutions for the improvement of ecologic qualities ofgreen areas in order to increase ecosystem services provided by them. Protecting natural ecosystems as much as possible and producing nature-based solutions will increase the ecological resistance of these areas. **For example, wetlands act as sponges and help prevent water retention and floods.** The presence of wetland ecosystems in the immediate vicinity of the city increases the resistance of the city. Therefore it is important important to protect wetland ecosystems not to convert them into other uses.

There are many native plant species resistant to temperature and drought in our country, which are mostly under arid and semi-arid climate. Preferring native plants which could live under arid conditions rather than foreign origin / exotic plants that require excessive water and maintenance in the landscape architecture practices in the cities, will have contributions in developing successful solutions in the process of adaptation to climate change (Dilaver, 2014; Barış, 2014).

In addition to these, solutions could be developed to increase tree caopy cover in the urban landscapes. Reducing the size of the tree canopy by unnecessary trimming**, lead to the breaking of ecological resistance of cities against climate change.** It is aimed to "increase the number of trees and size of canopy cover in the city" in many cities such as Toronto, London, Rome and Sydney, which are working on taking precautions against climate change in the world. Unfortunately, in many cities in our country, street, road and park trees are pruned in a way that almost no canopy cover is left within the scope of maintenance works or they are cut down. This practice, which adversely affects the health of trees and reduces its benefits, also constitutes an obstacle to local governments' goals of creating livable urban landscapes. In order to eliminate this problem, maintenance and management personnel should be trained. Additionally, legal arrangements such as drafting regulations by the central administration can be made or guide booklets containing technical solution details can be prepared by local administrations.

The ecosystem services provided by green areas increase when the ecosystems in these areas are healthy. For that reason, it will be appropriate to refrain from chemical fertilizers, pesticides, and insecticides use in the maintenance of green areas. These chemicals are not only polluting the soil and water but also damaging to human health. For this reason ecologic and biologic methods should be developed. Some cities such as Paris, London, Cambridge and Portland (OR) have developed pesticides and chemical free policies for urban green areas. It can be possible to develop similar for the cities of Turkey. Within this scope, local administrations could cooperate with the Ministry of Environment and Urbanisation, NGOs and volunteer participants and develop “clean environment” projects.

It is preferable to use permeable concrete or asphalt instead of impermeable material in the possible areas of the city. In many cities of Turkey, school gardens are mostly covered with impermeable surfaces and the plant cover in these areas is very weak. In order to improve the ecological qualities of school gardens and to enrich the vegetation by reducing the size of impervious pavings such as concrete and asphalt, “green campus” projects can be developed in cooperation with the Ministry of National Education, Ministry of Environment and Urbanisation, local administrations and non-governmental organizations.

Incentives such as tax reduction or reward systems in green infrastructure applications in urban landscapes will make these solutions attractive and increase awareness.

Providing trainings to increase the knowledge and awareness level of climate change adaptation solutions of technical personnel who is responsible for maintenance and management of urban green areas will increase the success. Similarly, raising awareness of urban dwellers will contribute to raising awareness on protection. For this reason, it is important to share the practices in various ways such as social media and local press. Solutions in Portland could be taken as an example. A walking and cycling route have been defined which includes stormwater management solutions of different types and scales in the city. In this way, it is possible for local people and tourists to see the applications and understand the benefits of these areas.

Many cities around the world are working to reduce the impacts of climate change. The Izmir Metropolitan Municipality signed the Covenant of Mayors (CoM) established by the European Commission and aimed 20% reduction of carbon emissions by 2020 (SEAP, 2016).

In order to mitigate the negative impacts of climate change in cities, it is not enough to take measures only in resources such as reducing greenhouse gas emissions. In addition, ecosystem services should be given priority in the development of green space planning, design and management strategies. These rational solutions for the improvement of ecosystem services will help to protect and improve the fragile ecosystems of cities and to make the city ecologically resistant to the effects of climate change.

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