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Review

A review on the role of green vegetation in improving urban environmental quality

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Abstract: The exacerbation of climate change impacts within metropolitan areas is a well-documented phenomenon, often leading to severe consequences that pose significant risks to human populations. The impact of urban vegetation and planting design on these factors can be observed. However, it is worth mentioning that while there is an extensive body of literature on the consequences of climate change, there is a relatively small number of studies specifically focused on examining the role of vegetation as a mitigating factor in urban environments. This review paper aims to critically examine existing studies pertaining to the role of urban vegetation in mitigating the detrimental effects of the urban environment. The objective is to offer practical recommendations that can be implemented by city planners. By conducting a comprehensive examination of the literature available in Scopus, Web of Science, and Google Scholar, employing specific keywords pertaining to urban vegetation and climate change, we have identified five prominent concerns pertaining to the urban environment. These concerns encompass particulate matter, gaseous pollution, noise pollution, water runoff, and the urban heat island effect. The present analysis highlights that the impact of urban vegetation on the negative consequences of climate change cannot be unequivocally classified as either positive or negative. This is due to the fact that the influence of urban greenery is intricately connected to factors such as the arrangement, makeup, and dispersion of vegetation, as well as the specific management criteria employed. Hence, this research has the potential to enhance comprehension of the multifaceted nature of urban green spaces and establish a solid groundwork for subsequent investigations.

Keywords: climate change; urban pollution; green vegetation; urban forestry; city resilience; mitigation

1. Introduction

The acceleration of urbanization on a worldwide scale, along with the occurrence of severe weather events, is intensifying the consequences of environmental hazards such as floods, tropical cyclones, and heat waves, which are frequently linked to periods of drought [1–4]. Cities worldwide are compelled to acquire knowledge regarding optimal governance and planning solutions to effectively tackle challenges related to equity, livability, and sustainability due to the substantial physical density and population of urban areas, which frequently lead to significant human and financial losses [5–9]. Urban green spaces are now widely recognized and implemented as a genuine public amenity in contemporary society. They are regarded as vital infrastructure, akin to aqueducts, schools, sewers, and highways, as they play a crucial role in enhancing the whole quality of life for individuals, encompassing both their mental and physical well-being [10–13]. Urban vegetation offers numerous ecosystem services, which can be described as the benefits that individuals derive from an ecosystem [14–17]. An illustration of this phenomenon is the role of trees in urban environments, wherein they effectively regulate temperatures through the provision of shade and the cooling of air via transpiration. Consequently, this ecological function serves to mitigate the potential hazards of heat-related illnesses for those residing in cities [18–22]. In addition, it should be noted that trees serve as carbon dioxide (CO_2) sinks through the processes of photosynthesis and the accumulation of biomass [23–29].

Furthermore, aside from the direct processes of carbon assimilation and storage, urban planting has the potential to indirectly contribute to carbon emissions reduction [7,8]. The net carbon emissions savings achieved per tree by urban planting can reach up to 18 kg CO_2/year. The aforementioned advantage aligns with the findings of a study conducted in Los Angeles, which compared urban trees to forest trees of comparable size and health [9,10]. The research indicated that urban trees contribute significantly to the sequestration of CO_2, consequently contributing to the mitigation of global warming [11,12]. Vegetation barriers and green roofs have been found to possess the capacity to mitigate noise levels, offer windbreak protection for structures, and intercept as well as filter stormwater runoff [30]. Green areas play a critical role in improving human well-being and mitigating climate change due to their decisive function in combating air pollution [31–35]. Consequently, urban planning initiatives are progressively including not just economic and environmental considerations but also public health goals. Consequently, urban areas are embracing agendas that place a growing emphasis on the interplay between urban landscapes, natural resources, and human well-being. **Figure 1** presents the different roles of green vegetation in improving the environmental quality of urban areas.

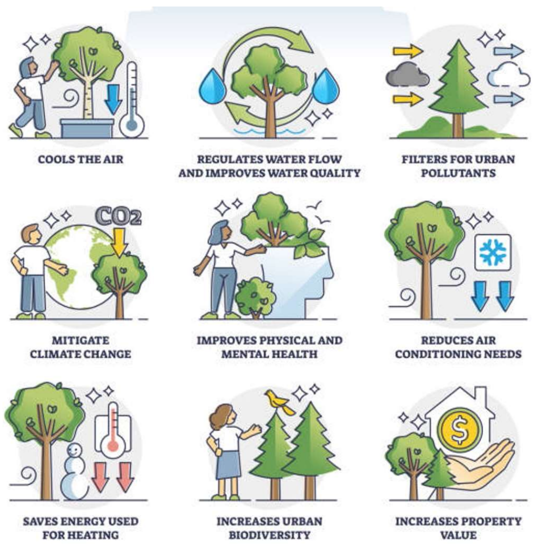

Figure 1. The different roles of green vegetation to improve the environmental quality in urban areas.

Nevertheless, despite the abundance of literature concerning the impacts of climate change, there exists a limited amount of research that expressly concentrates on investigating the contribution of vegetation as a means of alleviating the effects of climate change in urban settings. The primary objective of this review study is to provide a comprehensive analysis of current research papers that investigate the significance of urban vegetation in alleviating the adverse impacts of urban environments. This study aims to analyze the role of vegetation as a mitigating element in urban environments and offer practical advice for city planners to implement. This research specifically examines the significant challenges that posed a danger to the overall welfare of human populations in urban areas across the globe during the Anthropocene era. These challenges include solid, gaseous, and noise pollution, water runoff, and the urban heat island effect. The primary objective of this study is to provide a concise overview of the capacity of plants to mitigate the aforementioned stresses. This study has the potential to expand understanding of the complex characteristics of urban green spaces and lay a strong foundation for future research endeavors.

2. Particulate matter

Air pollution levels are concerning, especially in urban areas, leading to background contamination [36]. Particulate matter (PM_x) is an important pollutant because it has different effects on human health depending on its size, which makes it more complex than gaseous pollutants [37]. Studies have shown a link between increased mortality rates and exposure to PM in both developed and developing nations, but there is no specific threshold established for when exposure becomes harmless [38,39]. The World Health Organization (WHO) reported 4.2 million premature deaths due to PM in 2019 [40]. The figure could reach 6.6 million by 2050, with the biggest increase in Asia. Previous research has found links between daily changes in health outcomes, like daily mortality, and daily changes in ambient PM concentrations. Studies often use indicators like total suspended particulate matter (TSP) or PM_{10} [41].

PM, emitted by vehicles, factories, power plants, and heating systems, includes solid and liquid particles categorized as PM_{10}, $PM_{2.5}$, PM_1, and $PM_{0.1}$ based on their sizes (smaller than 10 µm, 5 µm, 1 µm, and 0.1 µm, respectively). PM concentrations in many cities exceed health standards. Over 85% of the urban population in the EU is currently exposed to PM levels that exceed the thresholds set by the WHO in 2005. PM concentrations are highest in China, India, and Southeast Asia [42]. Fine-particulate air pollution is a growing concern for human health. Several studies have shown a link between $PM_{2.5}$ exposure and an increased risk of hospitalization for cardiovascular and respiratory disorders [43,44]. PM_x contamination is linked to COVID-19 transmission. Conticini et al. [45] found that high pollution levels in Northern Italy may have contributed to the high fatality rate in the region. Thandra et al. [46] showed a link between PM exposure and lung cancer, specifically adenocarcinoma, in Europe. This finding increased the need for epidemiological investigations. $PM_{2.5}$ particles are linked to accelerated atherosclerosis and Alzheimer's disease [47].

The US Environmental Protection Agency (EPA) regulations have improved air quality in the past decade. $PM_{2.5}$ levels decreased by an average of 11% from 2000 to 2007. Reduced rates of premature mortality have been linked to this decline in the United States. Fine particulates cause around 130,000 deaths each year in the country, as per existing literature. Despite recent declines in $PM_{2.5}$ levels, there is still a need to further improve air quality to address health concerns. Pollutant concentrations can be reduced by implementing emission control measures and improving dispersion and deposition rates [48]. Insufficient emphasis has been placed on this approach to pollution management.

Vegetation in urban areas removes pollutants [49–55]. Studies have investigated PM composition and accumulation on leaves. Urban green spaces can help reduce PM pollution. Turbulent particles contact a leaf and adhere to its surface through dry deposition. Meo et al. [36] found that 1 m^2 of leaf surface can assimilate PM ranging from 70 mg to 2.8 g per year. Multiple models were developed for a project in Chicago, USA. 1 hectare with 11% tree coverage removed 9.7 kilograms of pollution in a year. The main pollutant targeted was PM smaller than 10 µm, accounting for about 3.5 kilograms. The removal rate was extrapolated to the entire city area of approximately 600 km^2, resulting in an estimated total pollution removal of 591 tons. Yang et al. [56] found that trees in central Beijing reduced PM levels by removing 1241 tons in 2002. Most of the removed PM was PM_{10}, totaling about 772 tons. Nowak et al. [57] found a correlation between reducing $PM_{2.5}$ through tree vegetation in ten US cities and its impact on public health. $PM_{2.5}$ elimination by trees varies across locations, from 4.7 tons in Syracuse (NY) to 64.5 tons in Atlanta (GA). Syracuse generates $1.1 million, and New York City yields $60.1 million from this annual removal. Most of these values come from the impacts of reduced human mortality. Death rate decreases vary by city, averaging around 1 person per year. The figure for New York City is 7.6 individuals per year. Similar models in Europe have also shown that trees are effective at removing PM compared to other types of vegetation and surfaces. McDonald et al. [58] found that increasing tree coverage by up to 54% could reduce PM_x concentration by 26% in the West Midlands region of the UK. Approximately 200 metric tons of PM would be removed annually. In Glasgow, increasing tree coverage from 3.6% to 8% would decrease concentration levels by 2%.

PM deposition occurs on various surfaces and is influenced by factors such as particle size, surface characteristics, wind speed, precipitation, and pollutant content [59]. Tree leaves can capture and retain polluting particles, acting as a "sink" for suspended PM [60]. Lindén et al. [61] found higher deposition rates on vegetation than on metallic and constructed surfaces. Particles deposit on leaves through mechanisms such as sedimentation, Brownian diffusion, interception, inertial impaction, and turbulent impaction [62]. PM_x can take two routes: assimilation through leaf stomata, or accumulation on the leaf's exterior, and subsequent transport to the ground or reintroduction into the air. Absorption is lower than accumulation, especially for smaller particles.

Research has explored factors affecting PM adsorption and accumulation on leaves. Leaf anatomy and canopy architecture are the main plant attributes that affect this process [63]. Leaf characteristics, like trichomes and epicuticular waxes, can enhance air filtration. Coarse-textured deciduous trees are better at trapping PM_x than smooth-textured ones. Elaeagnus is more effective than smooth-leaved species like Ligustrum. Elaeagnus has hairy and waxy leaves. A study in Poland found differences in trapping effectiveness among four shrub and climber species. *Forsythia x intermedia* and *Spiraea japonica* were more effective at catching tiny particles than *Physocarpus opulifolius* and *Hedera helix*. Diverse outcomes were observed with larger particles. *Hedera helix* was more effective at capturing PM than *Forsythia x* *intermedia*.

Leaf stickiness enhances retention efficiency [64]. Some tree species, like *Tilia platyphyllos* (lime) and *Betula pendula* (birch), often have a sticky honeydew layer due to aphid infestation. This phenomenon enhances pollutant particle adherence on trees. *Acer campestre* and other species can exude honeydew. Conifers' needles have a layer of epicuticular wax on their outer surface. Conifer leaves accumulate more PM_x than broadleaf leaves, especially in winter when pollution levels are high and broadleaf trees have no leaves [65]. Needles in most plants last longer than leaves in deciduous trees, which reduces the potential for recycling PM_x annually. Evergreen conifers may not be as effective as deciduous species, despite their efficiency in PM_x scavenging. Conifers should not be used in highly polluted areas due to their susceptibility to pollutant-related injuries [65]. Canopy architecture and leaf area density also affect deposition. The canopy's structure creates vortices and air streams due to disruptions in smooth flow caused by surfaces without aerodynamic qualities. These phenomena are strongly associated with PM deposition on tree foliage. Complex canopies increase the probability of microturbulence generation. Young plants with compound leaves, like *Aesculus* and *Fraxinus,* perform better in this regard.

Particle deposition increases with leaf area density until a threshold is reached. Excessively dense canopies decline. The decline is due to suppressed turbulence in dense canopies, resulting in reduced deposition [66]. Jin et al. [67] introduced the concept of the particulate matter attenuation coefficient (PMAC) and identified key characteristics affecting it. They found that canopy density, leaf area index (LAI), and rate of change in wind speed were the most influential predictors of PMAC. Further analysis showed that the optimal canopy density for aesthetically pleasing and ecologically beneficial tree-lined roads is between 50% and 60%, with a LAI of 1.5 to 2.0. Compact and perennial plants may not yield the expected results and could worsen pollutant accumulation. Most absorbed particles in trees can be dislodged by wind or washed away by rain. Particles are deposited on the ground. Organic constituents decompose, while inorganic constituents accumulate in the soil and soil solution [68]. PM deposition on plants helps remove particles from the atmosphere and reduce pollution levels. However, some of the trapped PM can be re-suspended by the wind. Minimal scholarly investigation has been done on the health concerns of inhaling resuspended particles. There is a lack of research on resuspension mechanisms in different species and urban micro-climates [69]. Wash-off refers to the transfer of PM from vegetation to soil during precipitation [70]. There is a lack of research on the resuspension and wash-off processes of PM by plants, specifically regarding different plant species and the impact of leaf features [71]. To accurately assess the impact of vegetation on air quality, more data on the resuspension and wash-off processes of adsorbed PM is needed [61]. Studying simulated rain and using in situ monitoring can provide valuable information on PM accumulation on leaves.

Urban green spaces are important for using plants to improve air quality [72]. Other factors, besides plant features, affect leaf deposition. Factors influencing adsorption coefficient and air quality include season, pollutant concentration, wind speed, rainfall, and site geometry [73]. The adsorption coefficient is determined by calculating the percentage of trapped particles compared to those that contact the leaf surface. These factors affect the quality of the air. Beckett et al. [74] studied this phenomenon in four locations in and around London. Sites were chosen based on differences in vegetation, pollution sources, and proximity to the source. Particle capture and retention effectiveness depended on location. Significant variations were seen among different species in the same location. In a 10-hectare park in Brighton, near a busy road, a 21-meter-tall English elm tree (*Ulmus procera*) absorbed 1071 kg of suspended PM in one season. The amount is 475 milligrams per square meter. A 12-meter lime tree absorbed 192 milligrams per square meter of particles in a similar location. In contrast, a plant with the same characteristics but in a different location (a 2-hectare city park) reduced pollutants by 488 milligrams per square meter. Poor park design can harm air quality by using inappropriate plantings, leading to the use of heavily polluted areas [75]. A well-designed park can mitigate health consequences. Therefore, it is important to integrate studies on air quality in parks with planning and design to establish new green spaces. Research studies suggest that roadside vegetation barriers can help reduce air pollution near highways [76]. Vegetation barriers must be dense for optimal effectiveness and to provide a large surface area for deposition. The barriers must be porous to allow air flow instead of deflecting it.

Few studies have explored how vegetation affects air quality in street canyons, which are streets surrounded by buildings. In these environments, people may be exposed to pollutant levels that exceed limits set by the WHO. Street canyons greatly affect air quality [77]. Pugh et al. [78] found that dense tree vegetation in street canyons can increase PM concentrations by up to 60%. Reduced air turbulence in congested road canyons hampers the dispersion of PM particles. Plants can hinder air flow, reducing air exchange compared to areas without vegetation. Jeanjean et al. [79] showed that trees improve air quality locally and regionally. Due to increased turbulence, pollutant concentrations decreased by approximately 7% at pedestrian height. Linden et al. [61] recommend using shrub vegetation in urban canyons to improve air quality by promoting pollution deposition and maintaining efficient air exchange. It's important to carefully select the height and density of vegetation based on the site's micro-climatic variables to improve air quality. Shrubs are important in this context [80]. Buccolieri et al. [30] found that placing vegetation along the roadside edge and increasing plant density can effectively reduce pollutant concentrations. This limits the spread of pollutants in the surrounding areas. Research in Italy and other countries has shown positive results for evergreen species, especially those found in the Mediterranean habitat [81]. Barwise and Kumar [82] found that plant species and site architecture affect urban vegetation's ability to filter PM pollution.

3. Gaseous pollutants

Urban environments primarily focus on gaseous air pollutants, including sulfur oxides (SO_x), nitrogen oxides (NO_x), and carbon monoxide (CO). These pollutants are categorized as primary pollutants and are emitted directly into the atmosphere from human activities [83–87]. Secondary pollutants are formed through chemical reactions involving primary pollutants like ozone, H_2SO_4, and peroxyacyl nitrates. Ozone is mainly formed in the lower troposphere through photochemical reactions involving NO_x and various volatile organic compounds (VOCs) [88]. Hydrocarbon combustion produces nitrogen oxides, sulfur oxides, and carbon monoxide [89]. These substances threaten human health and contribute to climate change [90–93]. Evaporative and exhaust gas emissions from car engines, specifically NO_x, are harmful to the local microclimate. Chen et al. [94] found that NO_2 is about 40 times more effective than CO_2 at retaining long-wave radiation reflected from the Earth's surface.

Plants primarily eliminate gaseous contaminants through stomatal absorption [95]. Stomatal uptake is influenced by photosynthetic activity and turgor pressure, which fluctuate based on environmental conditions. The plant's water-use strategy affects stomatal uptake. Anisohydric species can keep stomata open for longer periods of time. These species are more efficient at taking in gaseous pollutants compared to isohydric species, which close their stomata earlier in response to less water. Anisohydric species like *Populus* or deciduous oaks take in more gaseous pollutants through stomata compared to isohydric species like *Pinus* or *Platanus* [96]. Absorption through stomata increases when chemicals are quickly removed from intercellular spaces. O_3 and NO_2 quickly metabolize, leading to absorption that correlates with external concentrations. The relationship is valid if the pollutant inflow doesn't harm photosynthesis or membrane permeability. Leaf defense mechanisms influence the elimination of gaseous pollutants. The apoplast's detoxifying potential is the main mechanism for O_3 and NO_x [96]. For SO_2, important factors include transport resistance inside cells and the ability to neutralize pH variations.

About 16% of hydrocarbon emissions come from evaporation during daytime heating in stationary car fuel supply systems [97]. Urban vegetation can reduce the emission of anthropogenic VOCs by lowering the air temperature through shadowing [98]. Trees can lower the air temperature by up to 5–7 °C on hot summer days. Temperature moderation affects emissions of volatile hydrocarbons from stationary vehicles. Certain plants release biogenic volatile organic compounds (BVOCs), which have been extensively studied and are known to serve as important chemical messengers, aiding in plant reproduction and environmental survival [99]. Plants release chemicals that repel pests. These compounds may attract certain insects, including pollinators and predators of plant-eating insects [100]. Due to their molecular properties, BVOCs quickly interact with atmospheric components like ozone, hydroxyl radicals, and anthropogenic molecules such as NOx, especially in urban areas [101]. Ghirardo et al. [102] found that terpene oxidation with O_3, OH, and NO_x produces secondary aerosols, PM, and organic acids. These byproducts can increase acid deposition and air pollution. BVOC emissions may cancel out or exceed the benefits of reducing gaseous pollution on air quality.

To address these drawbacks, careful species selection is crucial [82]. BVOCs come from urban trees like *Populus*, *Platanus*, and *Salix* (which emit isoprene) and *Malus*, *Pinus*, and *Quercus* (which release monoterpenes). In addition, BVOC emissions can vary among different species [82]. Donovan et al. [103] created a quality score to measure how well urban trees reduce gaseous pollutants compared to their emission of BVOCs. The species with the highest scores among those tested were Acer campestre, *Acer platanoides*, *Alnus glutinosa*, *Betula pendula*, *Chamaecyparis lawsoniana*, *Crataegus monogyna*, *Larix decidua*, *Prunus laurocerasus*, and *Pinus nigra*. Categorizing a plant species as advantageous based on its emission of BVOCs is challenging. The challenges come from species variability and the atmospheric reactions of BVOCs in different environments [104]. Integrating plant aspects into air chemistry models can help understand the BVOC-NO_x-O_3 relationship at different scales. This understanding can help city planners and landscape architects choose suitable vegetation for urban areas with high pollution levels, known as "hotspots".

4. Noise pollution

Living in a peaceful environment improves well-being. Studies compare the quality of life in peaceful and noisy environments. Living in peaceful environments like rural areas or green spaces is associated with a better quality of life [22]. Urban vegetation can help reduce noise from human activities, improving acoustic well-being [7]. Sound waves dissipate energy as they travel through the air due to particle displacement, resulting in degradation through the conversion of mechanical energy into thermal energy via friction. The obstacle course includes pathways in soil, plant structures, and holes in man-made barriers. Impediments affect energy attenuation across frequencies. Green building elements can absorb approximately 50% of incident sound energy [105]. Plant barriers and green roofs reduce sound intensity due to factors like composition, morphology, structure, arrangement, and phytosanitary issues.

Noise reduction varies near the road margin with different types of barriers. Beyond distances of 100–150 m, noise reduction barriers are ineffective. Individuals engage in an action within a confined geographical setting [106]. Noise reduction can reach 10–12 dB for bands deeper than 100 m [106]. Attenuation depends on factors such as species, barrier structure, and proximity to the detection point. Remember the barrier's behavior with different noise frequencies? Research shows that vegetation is effective in a frequency range of 0.5 kHz to 2 kHz and becomes effective again at higher frequencies (5 kHz to 8 kHz). Increased vegetation efficacy reduces human ear sensitivity between 2 kHz and 5 kHz. Car sounds mainly occur between 0.25 and 2 kHz and are not fully reduced by vegetation.

Vegetation is only an effective noise barrier if it is thick [107]. To achieve the same noise reduction as a 1.5-meter conventional noise barrier, plant vegetation that is at least 15 meters thick, with a planting distance of 1 to 3 meters. The impact of trees and shrubs on noise reduction is cumulative. Pluri-stratified vegetation belts are more effective at reducing noise than single-layer vegetation belts. Choose shrub layers that are either less than 0.5 m or greater than 2 m in height to reduce noise. Rectangular planting plans are better than square or triangle layouts when designed properly. Rectangular designs with meticulous planning have shorter planting distances parallel to the traffic source than perpendicular to it. Biocca et al. [108] recommend planting the vegetation belt near the noise source for better attenuation. Moreover, adding soil to vegetation can enhance noise reduction more effectively than vegetation alone, as vegetation alone has a limited impact on reducing low-frequency sounds [109]. It is recommended to strategically incorporate green spaces, like embankments, alongside roadways to reduce noise pollution. This approach is useful in areas with limited space for vegetation barriers. Recent reports suggest that vegetation in urban areas can indirectly reduce noise. The effects include plant restoration, natural sounds, and visual noise concealment. These factors improve how people perceive noise and have a similar effect on well-being as reducing noise intensity by 10 dB [110].

5. Water runoff

Urbanization has led to land use changes, including the construction of buildings and transportation system expansion [7]. Soil sealing and impermeabilization negatively affect gas exchanges between the soil and the atmosphere. It indirectly affects soil fertility. Tree lifespan may not be limited by these factors [111]. Soil sealing can worsen the urban heat island effect and increase temperatures in cities. Managing water extremes is a growing concern due to impermeable terrain. Impermeable materials, such as soil cover, limit water infiltration, causing more surface runoff. This can have both direct and indirect effects. In recent years, there has been a significant increase in flood events, especially flash floods, in different regions worldwide [112].

Enhancing vegetation can help reduce impermeable soil. Trees, shrubs, and lawns help delay rainwater outflow by intercepting it [113]. It can be eliminated through surface lamination, draining ducts, or absorption into the soil. Trees and other vegetation create an underground network that helps with infiltration. Plant foliage and natural mulching help reduce the negative impacts of heavy rainfall [114]. This reduces soil erosion and maintains fertility. Urban trees can reduce stormwater runoff by intercepting 15% to 27% of annual rainfall [113]. Tree precipitation can be divided into throughfall, stemflow, and interception [115].

Throughfall is the precipitation that goes through the canopy and falls from leaves and branches. Stemflow is the portion of precipitation caught by the canopy that then travels down the stems and branches to the ground. Interception is the portion of precipitation that is caught by the canopy and does not reach the ground, thus not contributing to surface runoff [113,114]. Nytch et al. [116] found significant variability in rainfall interception among different tree species. Asadian and Weiler [117] studied throughfall losses from urban coniferous trees in Vancouver. Researchers found variations in average canopy interception among different species. The range for *Pseudotsuga menziesii* is 20.4 mm, and for *Thuja plicata,* it is 32.3 mm. Xiao and McPherson [113] studied the interception losses of 20 urban trees in central California's Mediterranean environment. The surface storage capacities varied among the trees mentioned. *Lagerstroemia indica* had a capacity of 0.59 mm, and *Picea pungens* had a capacity of 1.81 mm. Papierowska et al. [118] found that species with high leaf surface storage have low hydrophobicity and water droplet retention. Consider leaf roughness, shape, and slope. Bark characteristics and branch arrangement affect water retention capabilities in different species [113]. Dowtin et al. [119] reported a disparity in bark water storage capacity between *Quercus rubra* and *Betula lenta*. An example can illustrate this. The former has tripled the attribute compared to the latter.

Measuring rainfall interception accurately is difficult because it depends on various factors, including climate conditions like rainfall intensity and wind speed [120]. Trees intercept and retain rainfall, reducing the amount of water that reaches the soil. Trees can change how rainwater is distributed in their canopy. There are variations in this phenomenon among different tree species. Human interventions and extreme weather events can disrupt rainfall interception by trees, such as through defoliation. Vegetated regions have a significant impact on water quality in aquifers. Vegetation is better at removing pollution compared to unvegetated soil, especially when it comes to stormwater. Biofiltration and simple filtration can reduce pollutants and sedimentation in rainfall [120]. Biofiltration uses plants to remove impurities, while simple filtration mechanically reduces impurities from soil.

These mechanisms use engineered green areas to reduce erosion and prevent flash flooding, which can cause significant damage and endanger lives. Soil beneath impermeable pavements has higher moisture levels than bare soil, especially without trees [121]. Impermeable pavements accelerate infiltration, leading to increased moisture content in sealed soils by restricting evaporation. This phenomenon reduces latent heat dissipation and increases perceptible heat in sealed soil compared to unsealed soil. Sealed soil reduces evaporation, leading to higher soil temperatures, especially in summer when unsealed soil experiences evaporation due to high air and soil temperatures [122]. Limited research attention has been given to the impact of deep soil layer warming on surface energy flux and its role in influencing regional climate variation over extended periods of time. This creates a “sub-surface urban heat island”. Mitigating stormwater runoff through rainfall interception is becoming more important [120]. Climate change will lead to more annual precipitation, but in fewer events. Urban vegetation reduces runoff caused by intense precipitation events. Tree planting reduced impervious surface area by 35% and runoff by 18% in a parking lot [123]. There is a lack of scholarly understanding of the best species, planting techniques, costs, and benefits of urban vegetation in regulating water runoff.

6. Urban heat island effect

Urban areas have concrete and asphalt, which contribute to the urban heat island effect. This effect is more noticeable when non-irrigated urban landscapes replace previously irrigated agricultural land [124]. This phenomenon causes a temperature increase of several degrees (up to 12 °C in rare cases) compared to nearby rural areas, affecting humidity levels at the same time. The urban heat island effect usually increases in larger cities. According to the EPA, many US cities have air temperatures 5–6 °C higher than surrounding non-urban areas. Onishi et al. [125] found similar results (up to 7.26 °C) when studying different parking configurations with and without trees in Japan. Urban heat islands are less intense during the day but become stronger at night due to heat dissipation from urban infrastructure. The peak timing depends on factors like urban and rural surfaces, season, and weather conditions [126]. Surface temperatures indirectly affect air temperatures. Air mixing in the Earth’s atmosphere affects the correlation between surface temperatures and air temperatures. Air temperatures are generally less variable than surface temperatures in a specific geographical region [127]. Population and infrastructure in a limited area can create a unique microclimate that differs from the surrounding rural regions [128,129]. This phenomenon affects meteorological factors, including wind patterns, temperature distribution, intensity, and the urban water cycle. Urban heat islands are influenced by surface roughness and construction materials. Factors affect surface permeability and contribute to energy storage and release as sensible heat. This process reduces energy dissipation as latent heat by preventing water evaporation from the ground. **Figure 2** shows the causes of the urban heat island effect.

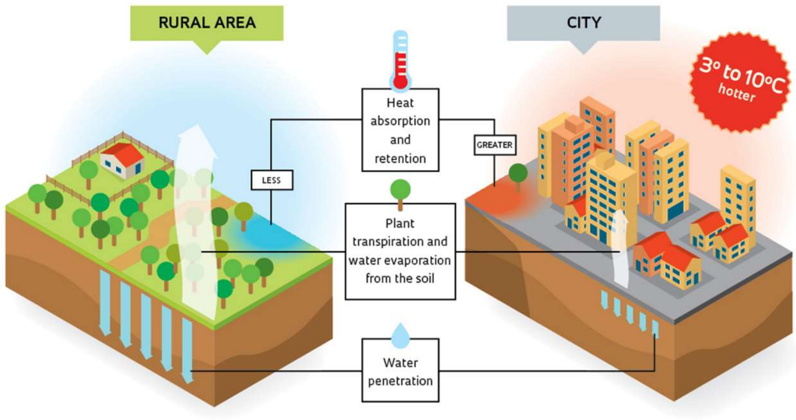

Figure 2. The key reasons behind the urban heat island effect.

Extreme weather events due to climate change can have significant impacts on cities and their residents [130–138]. Heat waves are a significant concern [139]. The effects mentioned in the text are evident through various indicators. The indications include more sick days, more emergency calls on hot days, and higher mortality among seniors during extreme events [140–149]. One of the major causes of global warming and heat waves is the increased use of fossil fuels [150–159]. Thermal comfort in urban settings is crucial for the well-being of people. Green spaces with comfortable temperatures have a positive effect on public health [160]. Surface air moist static energy is an alternative method for assessing heat stress by combining temperature and humidity. Low humidity can reduce the severity of certain heat waves. Understanding the urban climate is important for planning future urban development. More research is needed to understand the thermal dynamics of urban areas. It emphasizes the need to share this knowledge with urban planners and public administrations. Stakeholders can use this information to create sustainable and healthy urban environments.

Vegetation can improve the climate and reduce energy consumption [152,161]. Vegetation near a building can reduce the impact of solar radiation on the walls. This leads to lower energy consumption for air conditioning, reducing overall energy demand and the environmental footprint of buildings in the community. Scholarly investigations have studied the effects of vegetation and green spaces on urban microclimate [162,163]. Contradictory data exists, but green spaces generally reduce urban temperatures. This is mainly due to shading and evapotranspiration. These mechanisms reduce the conversion of solar radiation into sensible heat, promoting the generation of latent heat [164]. In winter, windbreak species on the northern side protect buildings from cold winds, reducing the need for excessive heating fuel. Planting trees near buildings reduces energy consumption and provides financial benefits [165].

Lawrence Berkeley National Lab and Sacramento Municipal Utility District studied tree coverage's impact on air conditioning costs. The study found that having trees around homes saved energy by 7% to 47%. Trees on the western and southwestern sides of the buildings reduced costs the most. Plant broadleaved species 3–9 m from the west side of a building for shading in the summer. To prevent shade effects in winter, choose trees that lose their leaves early and avoid those that keep dry leaves, like hornbeam and oak trees. Some species retain their foliage in late winter or just before new leaves emerge in spring, despite being rare. In summary, having 20% tree cover can reduce air conditioning needs by 8% to 18% and heating needs by 2% to 8%. Trees in urban areas reduce the air temperature by 4.1 °C [166]. The pavement temperature decreases by 15.9 °C and the building wall temperature decreases by 8.9 °C. Strategic tree placement near buildings is crucial for reducing incident radiation and lowering temperatures. The positive impact on the thermal environment can be seen in parks and individual trees, especially when strategically placed. Studies have measured the energy benefits of having trees near buildings, mainly due to reduced radiation on walls [167]. Shaded walls can lower temperatures by 5 to 20 °C, saving 10% to 35% on air conditioning in the summer. Reductions can reach up to 80%. These phenomena have macroscopic effects, benefiting regions and beyond, leading to significant economic savings. **Figure 3** shows the urban heat island effect on temperature.

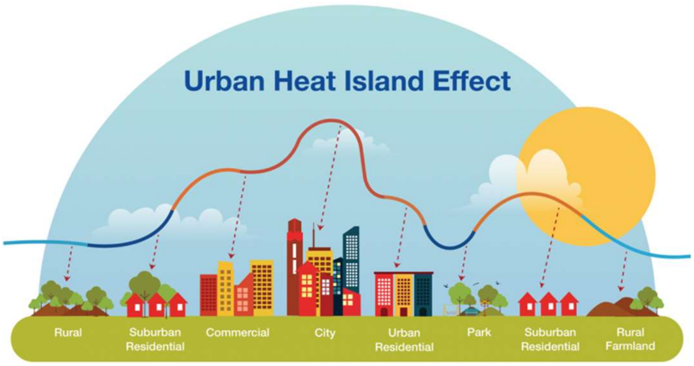

Figure 3. The temperature trend due to urban heat island effect.

Green spaces have permeable surfaces that help water infiltrate the soil. This contributes to temperature mitigation through evapotranspiration [168]. Under certain circumstances, the maximum air temperature may not vary significantly between paved regions and green areas. Avoid choosing herbaceous plant-only parks in Mediterranean regions. Parks don't provide much air temperature relief. They may have expenses for upkeep and increased water usage. Using xeric species in hot and arid regions can greatly reduce water needs for vegetation. Research on urban parks consistently shows lower air temperatures compared to surrounding urban areas. These parks also help reduce temperatures in nearby urban areas. The temperature decreases the most in the streets near the park, especially downwind. Previous experiments have studied the effect of parks on cooling and found temperature reductions of 1 to 5 °C, depending on park size. In Singapore, the temperature difference between a park and the outside is about 1.3 °C. In Mexico City, a large urban park of about 2 km in width has been shown to cool the surrounding urban area by 2–3 °C. The cooling effect extends up to 2 km from the park, which matches its width. A study in China shows that even small green spaces have a significant impact on temperature and humidity, especially in the afternoon and summer. Plant communities significantly affect temperature and humidity compared to non-tree-lined areas. Temperature reduction ranged from 2.14 to 5.15 °C, while humidity increased by 6.21% to 8.30% [169].

Vegetation in urban areas helps reduce the heat island effect. To inform city planners and administrators effectively, accurate evidence on vegetation species and their optimal placement in the urban landscape is crucial [170]. A US statewide project could save about $1 billion annually on heating and cooling costs. This would reduce fossil fuel consumption and decrease carbon dioxide emissions [171–188]. The urban heat island effect can be reduced in new cities by applying the basic urban planning principles pointed out below:

- Optimization of concrete-to-non-concrete urban surface areas through well-defined simulation models.
- Optimization of vertical to horizontal expansion of cities or urban areas through well-defined simulation models.
- Urban planning and development of green belts or green covers, considering the aerodynamics of the region from the concept stage.
- Ensuring and maintaining the air ventilation of urban areas.
- Balancing the albedo effect in urban areas, reducing the albedo factor of asphalt by applying high reflectivity coatings to asphalt, and, above all, reducing soil sealing wherever possible.
- Installation of green roofs in buildings in urban areas includes the development of plants and vegetation to harness evaporative cooling, thereby restricting heat island.
- Planning and development of green buildings (i.e., a building that, in its design, construction, or operation, reduces or eliminates negative impacts and can create positive impacts on the climate and natural environment) in the urban area.

7. Conclusion

Urban green spaces are a key requirement in the environmental programs of major international institutions. Plant selection for urban areas should not only prioritize aesthetics but also consider global changes beyond climate change. Consider the environmental benefits and maintenance costs of these species. Expanding urban vegetation is crucial to mitigating the impact of global change. It is important to establish guidelines for planting in specific locations, such as urban parks, peri-urban parks, and streets. Consider plant selection, including native or exotic species and cultivars, while acknowledging biodiversity. It is important to understand why people choose to engage in planting initiatives. Topics to be addressed: climate mitigation strategies, pollution reduction, visual concealment, and various planting techniques (e.g., concentrated massive plantations, scattered or widespread planting with ecological corridors and steppingstones).

The responsibility for planting and managing green areas involves public institutions, volunteers, private owners, and other stakeholders. Options should be chosen based on characteristics like pollutant elimination, daily release of volatile organic compounds, pollen generation and allergies, impact on mitigating the urban heat island effect, and energy efficiency in the surrounding area. Consider the principle of “the right plant in the right place and with the right management.” Plants need more than just survival; they should also have desirable traits like high photosynthesis and growth rates to make a bigger environmental impact. Carefully selecting plants is crucial for sustainable urban programs that promote the well-being and vitality of cities. More work needs to be done to determine the best green infrastructure setup in cities. There is a lot of information available to take proactive measures against climate change.

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