

The Impact of Tree and Shrub Vegetation on the Ecological Condition of the Urban Environment

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Abstract

This article examines the role of woody vegetation in the development of an ecologically sustainable urban environment, using Baku (Azerbaijan) and Ufa (Russia) as case studies. The principal natural, climatic, and anthropogenic factors affecting the condition of urban green spaces are analyzed, including atmospheric air pollution, arid climate, high wind exposure, soil salinization and compaction, altered hydrological conditions, overheating of artificial surfaces, mechanical damage, and recreational pressure. The urban environment is considered as a multi-stress system, in which multiple adverse factors act simultaneously and interact synergistically, amplifying their overall impact on vegetation. The sanitary-hygienic, climate-regulating, soil-protective, noise-reducing, biological, and recreational functions of trees and shrubs are characterized. Particular attention is paid to the tolerance of different tree species to the specific environmental conditions of the Absheron Peninsula. Morphological and physiological responses of plants to water deficit, air pollution, soil salinity, heat stress, and restricted root-growing space are discussed. The study demonstrates that the ecological effectiveness of urban greening depends not only on the extent of green areas and the number of planted trees but also on appropriate species selection, soil quality, efficient irrigation management, proper silvicultural and horticultural practices, and regular monitoring of urban vegetation. The necessity of developing a multifunctional and species-diverse green infrastructure based on native species and promising introduced taxa adapted to arid climatic conditions and intensive anthropogenic pressure is substantiated. Recommendations are proposed for improving the urban greening system with the aim of increasing the longevity and resilience of urban plantings and enhancing the ecosystem services they provide.

Keywords: woody vegetation, urban greening, urban environment, ecological sustainability, green infrastructure, ecosystem services, anthropogenic pressure

1. Introduction

The current stage of social development is characterised by rapid urbanisation, the expansion of urban development and an increase in the anthropogenic pressure on the natural components of the environment. The development of transport infrastructure, industry, the energy sector and housing construction is accompanied by the transformation of natural landscapes, the sealing of soils with artificial surfaces, changes to the hydrological regime, air pollution and a reduction in the area of natural plant communities (Məmmədov & Xəlilov, 2005; Goryshina, 1991; Gill et al., 2007).

A city is a complex techno-natural system in which natural and man-made components are in constant interaction. Unlike natural ecosystems, which possess a marked capacity for self-regulation, the urban environment depends on a continuous supply of resources and targeted management interventions. Disruption of the natural cycle of matter, high-density development, the prevalence of asphalt and concrete surfaces, significant emissions of pollutants, and intensive land use create specific conditions for plant life (Goryshina, 1991; Kolesnikov, 1974; Kulagin, 1974; Mozolevskaya et al., 1984).

Trees and shrubs are one of the key natural components of the urban environment. They help to purify the air, trap dust particles, absorb some gaseous pollutants, regulate temperature and humidity, reduce wind speed, stabilise the soil, mitigate noise pollution and provide habitats for urban wildlife (Bukharina et al., 2007; Gill et al., 2007; Liang & Huang, 2023; Livesley et al., 2016; Roy et al., 2012). At the same time, green spaces fulfil architectural, planning, aesthetic and recreational functions, shaping the city's visual appearance and enhancing the comfort of the urban environment.

However, the trees themselves in the city are subjected to prolonged exposure to a range of adverse factors. Urban air may contain nitrogen and sulphur oxides, carbon monoxide, hydrocarbons, aerosol particles and heavy metal compounds. The soil is characterised by compaction, structural disruption, a lack of organic matter, poor aeration and localised salinisation. Artificial surfaces restrict the penetration of atmospheric precipitation to the roots, whilst the heating of tarmac, buildings and engineering structures raises the temperature of the air and soil (Qasimova & Hacıyev, 2008; Alekseev, 1989; Mozolevskaya et al., 1984; Nikolaev, 2003; Perel'man, 1975; Rozanov, 2004).

In addition to the factors listed above, there is mechanical damage to trunks and root systems, incorrect pruning, a limited number of planting sites, the impact of construction work, vibration from traffic, shading caused by buildings, and artificial lighting at night. The combined effect of these factors gives rise to a phenomenon which, in urban ecological research, is characterised as 'urban tree syndrome' or a state of chronic multi-stress (Alekseev, 1989; Mozolevskaya et al., 1984; Rozanov, 2004; Escobedo et al., 2011).

Issues relating to environmentally sound landscaping are of particular relevance. The natural and climatic conditions of the Absheron Peninsula (Republic of Azerbaijan) and the city of Baku are characterised by low levels of precipitation, prolonged dry spells, high summer temperatures, intense solar radiation and significant wind loads. Further factors include the salinity of certain soils, marine aerosols, high-density urban development, heavy road traffic and the local impact of numerous industrial sites (Məmmədov, 2010; Qasimova & Hacıyev, 2008; Məmmədov & Xəlilov, 2005; Məmmədov & Gülməmmədova, 2007; Baki Sheherinin Bash Planı, 2040).

The natural conditions of the city of Ufa (Republic of Bashkortostan, Russian Federation) are characterised by a temperate continental climate, with moderately harsh winters ((-14) – (-16) °C) and warm, humid summers (17–19 °C). The weather is characterised by high variability and unpredictability. At the same time, the city of Ufa is a major centre of industrial activity, making a significant contribution to the Russian economy, chiefly as a result of the high level of development of the petrochemical and chemical industries, as well as the engineering sector. Other issues include population size, the condition of road surfaces, a lack of public transport, and a lack of attention to environmental issues on the part of business owners (Kamynina, 2026; Khalikova & Isyanyulova, 2019).

Given the variety of conditions, the viability of green spaces is determined not only by the quality of the planting stock and the intensity of maintenance, but above all by the suitability of the plants' biological characteristics to the specific conditions of the site. The species used along major transport routes must be particularly resistant to gas, dust, salt and drought. Plants planted in parks and recreational areas should, in addition to being environmentally sustainable, be highly ornamental, have a well-developed canopy and be capable of creating a favourable microclimate. For coastal areas, such as Baku, resistance to wind and the effects of salt spray is particularly important (Məmmədov, 2010; Məmmədov & Gülməmmədova, 2007; Baki Sheherinin Bash Planı 2040).

Consequently, a modern urban greening system should be based not only on the decorative selection of plants, but also on ecological and functional principles. It involves taking into account natural and climatic conditions, the intensity of human impact, soil properties, moisture availability, the functional purpose of the area, and the resilience of each species to a combination of stress factors (Alekseev, 1989; Kulagin, 1974; Akbari et al., 2001). The relevance of this study stems from the need to carry out a comprehensive assessment of the ecological role of tree and shrub vegetation in an urban environment, to identify the factors limiting plant growth, and to develop scientifically sound recommendations for the creation of a sustainable urban green infrastructure.

2. Aims and objectives of the research

The aim of the study is to assess the impact of tree and shrub vegetation on the ecological condition of the urban environment, to analyse the conditions under which green spaces function, and to identify the main ways of improving their sustainability and ecological effectiveness.

To achieve this objective, the following tasks were set:

1. to characterise the urban environment as a specific ecological system;
2. to identify the main natural and human-induced factors affecting tree and shrub vegetation;
3. to examine the morphological and physiological responses of woody plants to complex urban stress;
4. to analyse the main ecological functions of green spaces;
5. to assess the resilience of individual tree species to drought, air pollution, salinisation and soil compaction;
6. to compare the condition of tree stands in the city's various functional zones;
7. to draw up practical recommendations for improving the greening scheme.

3. Materials and methods

The subject of the study was the trees and shrubs used in the city's landscaping scheme. The study examined green spaces serving various purposes: city parks, public gardens, boulevards, inner-neighbourhood areas, roadside plantings, areas along major transport routes, and green spaces located within industrial impact zones. The subject of the study was the patterns governing the influence of natural, climatic, and anthropogenic factors on the condition, resilience, development, and ecological functions of tree and shrub vegetation.

The methodological framework for this work was based on a systemic and comparative-analytical approach. The study drew on material from a dissertation, the results of route surveys, visual assessments of tree stands, an analysis of the literature, and a synthesis of data relating to dendrology, plant physiology, urban ecology and landscape architecture (Məmmədov & Xəlilov, 2005; Alekseev, 1989; Bukharina et al., 2007; Goryshina, 1991; Kolesnikov, 1974).

The surveys took into account: the species of the plants; their general health and condition; crown density and uniformity; the presence of dry and damaged branches; the condition of the foliage; signs of necrosis, chlorosis and premature leaf fall; mechanical damage to the trunk; the condition of the root zone; the degree of soil compaction and salinisation; the nature of the surrounding built-up area; and the intensity of traffic and recreational pressure.

The assessment of the trees' health was carried out taking into account generally accepted indicators of tree decline: a reduction in crown density, a decrease in annual growth, branch dieback, leaf damage, the formation of dead tops, and a general deterioration in ornamental appearance (Alekseev, 1989). When comparing tree species, their tolerance to gas, drought, and salinity, as well as their ability to thrive in compacted urban soil, were taken into account (Kulagin, 1974; Mozolevskaya et al., 1984; Rozanov, 2004; Akbari et al., 2001).

The data obtained were categorised according to the main groups of urban stress factors. For each group, the nature of the impact, the possible reactions of the plants and the consequences for their viability and ornamental value were determined.

4. Results and Discussion

The urban environment differs significantly from natural ecosystems in terms of its high spatial heterogeneity, intense human impact and the simultaneous influence of a multitude of adverse factors. In natural conditions, plants grow under a relatively stable combination of soil, climatic and biotic conditions, whereas in an urban environment most of these parameters have been altered by human economic activity (Goryshina, 1991; Kulagin, 1974).

The main components of the urban environment are air pollution, degraded soils, altered hydrological conditions and local climatic anomalies. The air is constantly exposed to emissions from motor vehicles, industrial plants, power stations and construction dust. The soil cover consists mainly of urbanised soils, characterised by high density, disturbed structure, low biological activity and limited water and air exchange.

A distinctive feature of the urban environment is the emergence of multi-stress exposure, in which the physiological condition of plants is determined not by individual factors, but by their combined effect. For example, soil compaction restricts root system development and reduces water absorption, high temperatures increase transpiration, and soiling of the leaf surface reduces the rate of gas exchange and photosynthesis. The combined effect of these factors leads to chronic physiological stress, reduced growth rates, premature leaf ageing, thinning of the crown and a shorter lifespan in woody plants (Table 1).

Table 1. Key factors in the urban environment and the nature of their impact on tree and shrub vegetation

Group of factors	Specific effects	Main plant responses	Possible consequences
Air pollution	NO _x , SO ₂ , CO, dust, aerosols, heavy metals	Leaf damage, impaired gas exchange, increased oxidative stress	Necrosis, chlorosis, reduced photosynthesis and growth
Soil conditions	Compaction, salinisation, alkaline reaction, organic matter deficiency	Lack of oxygen in the root zone, impaired water absorption	Root hypoxia, physiological drought, desiccation
Water regime	Insufficient rainfall, poor infiltration, uneven irrigation	Stomatal closure, reduced transpiration and photosynthesis	Wilting, reduction in leaf area, premature leaf fall
Temperature conditions	Heat from asphalt and buildings: the urban 'heat island'	Tissue overheating, increased evaporation, metabolic disturbance	Heat-related injuries, dehydration
Light factor	Shading caused by buildings, artificial night-time lighting	Changes in photoperiod and seasonal rhythms	Slowing growth, delayed preparation for dormancy
Noise and vibration	Transport, construction, industrial equipment	Additional mechanical and physiological strain	Weakening of plants following prolonged, combined exposure
Mechanical impact	Damage to trunks and roots, incorrect pruning, vandalism	Damage to conductive tissues, wound formation	Infection, rot, crown deformation
Biotic factors	Pests and plant pathogens	Damage to leaves, shoots, roots and wood	Accelerated decline and dieback of trees

A comprehensive assessment of the environmental characteristics of plants is required for each functional zone of the city (Kulagin, 1974; Mozolevskaya et al., 1984; Rozanov, 2004; Akbari et al., 2001).

Prolonged exposure to adverse conditions gives rise to a range of morphological, anatomical, and physiological changes. In the early stages, these mechanisms are adaptive in nature; however, if the stressors persist over a long period, the compensatory mechanisms gradually become exhausted. This is accompanied by a reduction in shoot growth, a decrease in leaf area, impaired root system development, and a decline in the plants' overall vitality.

One of the most informative indicators of the condition of tree stands is the structure of the crown. In healthy trees, it is characterised by an even distribution of skeletal branches, dense foliage and the absence of dry shoots. In urban environments, it is common to observe dry tips, crown asymmetry, a reduction in leaf size and a decrease in foliage density. Such changes are caused by disturbances in the water regime, atmospheric pollution, nutrient deficiencies, mechanical damage, and restricted root system development.

The condition of the root system is one of the key factors in the resilience of woody plants. Unlike natural ecosystems, where roots develop in loose, biologically active soil, in urban environments their growth is restricted by engineering structures, road surfaces, building foundations and underground utilities. Soil compaction impairs aeration, reduces water infiltration, and causes oxygen deprivation in the roots, thereby reducing the supply of moisture and mineral nutrients to the above-ground parts of the plant.

Even when there is sufficient moisture in the soil, plants may experience physiological drought. It most commonly develops when the soil solution becomes saline, as the increase in osmotic pressure restricts the flow of water into the root system. This factor is of particular significance for areas characterised by naturally mineralised soils, the influence of marine aerosols and the accumulation of salts when irrigation practices are disrupted.

The primary physiological response of plants to water stress is the closure of their stomata, which helps to reduce water loss. However, at the same time, the supply of carbon dioxide to the leaves is restricted, which leads to a reduction in the rate of photosynthesis and a decrease in the synthesis of organic compounds. Prolonged exposure to drought leads to a reduction in leaf area, increased leaf fall, thickening of the cuticle and increased development of a waxy coating, which helps to reduce transpiration and increase resistance to overheating.

An important component of the stress response is the accumulation of reactive oxygen species. When exposed to high temperatures, drought, atmospheric pollution and salinisation, their concentration increases significantly, causing damage to cell membranes, proteins and photosynthetic pigments. To prevent oxidative stress, plants activate an antioxidant system comprising enzymatic and non-enzymatic defence mechanisms (Nikolaev, 2003; Perel'man, 1975).

Air pollution remains one of the main factors contributing to the deterioration of urban green spaces. The main sources of pollution are road transport, industrial plants, energy facilities, construction sites, and the accumulation of waste. The long-standing operation of the oil and gas industry has placed an additional environmental burden on cities such as Baku and Ufa, affecting the condition of certain urban and suburban areas (Məmmədov, 2010; Qasımova & Hacıyev, 2008; Məmmədov & Xəlilov, 2005; Məmmədov & Gülməmmədova, 2007; Baki Sheherinin Bash Planı 2040; Khalikova, & Isyanyulova, 2019).

Motor vehicles contribute to comprehensive atmospheric pollution caused by nitrogen oxides, carbon monoxide, hydrocarbons, soot, and fine particulate matter. Other sources of heavy metals include wear and tear on tyres, braking systems, and road surfaces. Dust that settles on the leaves reduces the light reaching the photosynthetic tissues, lowers the rate of gas exchange, and impairs the physiological condition of the plants. At the same time, toxic elements accumulate in the soil, its acidity changes, and the soil microbiota is suppressed (Table 2) (Savo et al., 2025).

Construction waste and de-icing agents have a significant impact, altering the chemical properties of the soil, increasing its density, and reducing the available volume of the root zone. As a result, root system development is impaired, and the plants' ability to adapt over the long term is reduced.

Table 2. The main sources of urban pollution and the potential damage to trees and shrubs

Source	Main pollutants	Area of impact	Possible consequences
Vehicles	NO _x , CO, hydrocarbons, soot, heavy metals, rubber dust	Leaves, bark, roadside soil	Necrosis, stomatal blockage, reduced photosynthesis
Oil and gas facilities	Hydrocarbons, sulphur compounds, petroleum products	Air, soil, root system	Toxic damage, reduced soil aeration
Construction work	Mineral dust, cement particles, building rubble	Leaves, soil, roots	Alkaline load, compression, mechanical damage
Waste	Filtrate, organic and inorganic contaminants	Soil and groundwater	Toxic effects, disruption of soil properties
Power plants	Nitrogen oxides, sulphur oxides, combustion particles	Atmospheric air and the phyllo mass	Oxidative stress, damage to pigments
Reagents and salt aerosols	Ions Na ⁺ и Cl ⁻	Soil, leaves, young shoots	Osmotic stress, burns, malnutrition

The climatic characteristics of arid regions significantly exacerbate the impact of human activities. The main limiting factors are low levels of precipitation, prolonged dry spells, high solar radiation, intense evaporation, and frequent strong winds (Məmmədov, 2010; Məmmədov & Gülməmmədova, 2007; Baki Sheherinin Bash Plani 2040). Plants' peak water requirements coincide with the period of lowest rainfall; consequently, the resilience of urban greenery is largely determined by the effectiveness of artificial irrigation.

Strong winds have mixed effects. On the one hand, they help to disperse pollutants; on the other, they increase moisture evaporation, cause mechanical damage to shoots and contribute to the transport of dust and salt aerosols. The most unfavourable combination is that of high temperatures, low humidity and strong winds, which leads to a sharp increase in transpiration and the development of chronic water stress.

Table 3. Extreme climatic factors and requirements for woody plants

limatic factor	Environmental impact	Required plant characteristics
Low levels of rainfall	Chronic soil moisture deficit	High drought tolerance, economical water use
High summer temperatures	Tissue overheating and increased perspiration	Heat tolerance, thick cuticle, robust foliage
Intense solar radiation	Photo-oxidative stress and sunburn	Light-loving, tolerant of direct sunlight
Strong winds	Wilting, crown deformation, broken branches	Wind resistance, strong wood, flexible shoots
Low humidity	Accelerated water loss through the leaves	The ability to regulate transpiration
Marine salt aerosol	Damage to leaves and young shoots	Salt tolerance
Abrupt local changes in the microclimate	Alternating exposure to overheating, shade and wind loads	High environmental adaptability

Therefore, the selection of plants for landscaping should be based on environmental conditions. Using a species solely on the basis of its ornamental qualities, without taking environmental requirements into account, increases the risk of widespread weakening and death of the plant population (Table 3).

A comparative analysis shows that the resilience of woody plants in an urban environment is determined by a combination of their morphophysiological characteristics and ecological plasticity. The species that demonstrate the greatest resilience are those capable of withstanding water shortages, atmospheric pollution, soil compaction and salinisation, as well as high temperatures.

In the context of the city of Baku (Republic of Azerbaijan), these types include Tree of heaven (*Ailanthus altissima*), Chinese scholar tree (*Styphnolobium japonicum*), Russian olive (*Elaeagnus angustifolia*), Honeylocust (*Gleditsia spp.*) Oriental plane (*Platanus orientalis*), and certain species of poplar (*Populus spp.*). These plants are characterised by a well-developed root system, high drought tolerance, and a relatively good ability to maintain physiological activity when exposed to adverse conditions over a prolonged period. Among the species with moderate hardiness that are suitable for

planting in parks and public gardens are the lime (*Tilia spp.*), the maple (*Acer spp.*) and the chestnut (*Aesculus spp.*).

Less resilient species include the small-leaved lime (*Tilia cordata*), the Norway maple (*Acer platanoides*), birch (*Betula spp.*) and most coniferous species, which are sensitive to a combination of atmospheric pollution, soil salinisation and water stress. However, resilience is not an absolute characteristic of a species. Even the most well-adapted plants can quickly lose their vitality if their root zone is restricted, they are not watered, they are planted incorrectly, or they are not cared for properly

The city of Ufa (Republic of Bashkortostan, Russian Federation) ranks third amongst the 16 cities in Russia with a population of over one million. In terms of green space (30.9% of the city's area), Ufa is second only to Perm and Yekaterinburg. The area of green spaces in public areas in Ufa per capita is 25 m², which is 1.6 times higher than the standard for large cities (16 km²) (Kamynina, 2026).

The following key species predominate in Ufa's urban landscape: small-leaved lime (*Tilia cordata*), Bashkir pyramid poplar (*Populus nigra var. pyramidalis*), Norway spruce (*Picea abies*), field maple (*Acer campestre*), silver birch (*Betula pendula*), box elder (*Acer negundo*), Siberian larch (*Larix sibirica*), Scots pine (*Pinus sylvestris*), common rowan (*Sorbus aucuparia*), common lilac (*Syringa vulgaris*) and others.

Other species found in urban plantings include the common ash (*Fraxinus excelsior*), blue spruce (*Picea pungens*), Russian olive (*Elaeagnus angustifolia*) and common ninebark (*Physocarpus opulifolius*) (Kamynina, 2026).

The condition of tree stands varies significantly depending on the functional purpose of the urban area. The most favourable conditions are found in parks, public gardens and boulevards, where plants have a large volume of soil at their disposal, are less likely to suffer mechanical damage and receive regular care. Under these conditions, the trees have a higher foliage density, better growth and a longer lifespan.

In the courtyards within the estate, the environmental impact is of an intermediate nature. Although air pollution levels here are lower than along major transport routes, plant growth is restricted by shading, soil compaction, a lack of bare soil, root damage caused by repairs to utility networks, and human activity.

The most adverse conditions occur along motorways and in industrial areas. Constant exposure to vehicle emissions, dust, vibration, high temperatures, salinisation and soil compaction leads to a deterioration in the physiological condition of plants, a reduction in crown density and an increase in the proportion of weakened and dying trees. In industrial areas, this negative impact is exacerbated by the presence of petroleum products, sulphur compounds, heavy metals and other toxic substances, which alter the physical and chemical properties of the soil and disrupt the functioning of the root system.

The results of the surveys indicate a direct correlation between the level of human impact and the condition of the tree stands. In recreational areas, the proportion of healthy trees is significantly higher than in industrial areas, where the number of weakened and dying trees is on the rise. At the same time, foliage density declines, crown density decreases, and annual growth slows. These changes reflect not only the impact of atmospheric pollution, but also the long-term degradation of the soil environment.

When designing urban green spaces, the correct selection of tree species for different functional areas is of particular importance. Along major transport routes, preference should be given to species that are highly resistant to gas and dust, drought-tolerant, able to withstand soil salinity, and resistant to mechanical damage. The use of environmentally sensitive species in areas subject to high human impact significantly reduces the longevity of green spaces and increases the costs of maintaining them.

Tree cover performs a wide range of ecological functions that ensure the sustainability of the urban environment. One of the most important is the sanitary and hygienic function. Leaves, shoots and bark trap dust particles, adsorb gaseous pollutants and help to improve air quality. At the same time, plants absorb carbon dioxide, store carbon in their biomass and release oxygen, thereby maintaining the gas balance in the urban atmosphere.

Equally important is the climate-regulating function of green spaces. Woody plants lower the ambient temperature through shading and transpiration. The evaporation of water from leaves is accompanied by the absorption of thermal energy, which reduces the warming of the air and mitigates the urban ‘heat island’ effect.

Green spaces also have an impact on wind patterns and the water balance of the area. Protective strips reduce airflow velocity, limit the spread of dust and create a more favourable microclimate. The root system helps to improve soil structure, increase its water permeability and make more efficient use of rainfall and irrigation water, which is particularly important given the limited water resources on the Absheron Peninsula.

The environmental sustainability of urban green infrastructure increases when mixed and multi-layered plantings are established. The use of tree and shrub species with varying root depths, crown shapes and growth rates enables more efficient use of soil and climatic resources, reduces the likelihood of widespread pest and disease outbreaks, and enhances the overall resilience of plantations to adverse factors.

As well as their environmental functions, green spaces play an important role in recreation. Parks, squares, boulevards and green public spaces create a pleasant visual environment, provide opportunities for the public to relax and help to reduce psychological and emotional stress. Tree and shrub vegetation is therefore a vital component of urban green infrastructure, ensuring the environmental sustainability and comfort of the urban environment.

Table 4. The ecological condition of woodlands in various functional zones of Baku

Type of area	Average quality of life score	The proportion of healthy Category I trees, %	The proportion of dying trees in categories IV–VI, %	Crown density, score	Soil pH	Salt content (%)	Lead (Pb) content in soil
Parks, boulevards, public gardens	1,9–2,3	45–55	3–5	4,0–4,5	7,5–8,0	0,15–0,25	Does not exceed TLV
Courtyards within the estate	2,7–3,1	15–20	15–20	2,8–3,2	7,8–8,3	0,30–0,50	1,5–2 TLV
Main roads	3,4–3,8	8–12	25–30	2,1–2,4	8,2–8,7	0,60–0,90	3,7–5,6 TLV
Industrial estates	3,6–4,0	5–7	40–45	1,8–2,2	8,5–9,0	1,0–1,2	9–15 TLV

The data in Table 4 demonstrate a consistent relationship between the intensity of anthropogenic pressure and the deterioration in plant health. In parks and public gardens, the proportion of healthy trees is as high as 45–55%, whereas in industrial areas it falls to 5–7%. At the same time, the proportion of plants dying back increases from 3–5% to 40–45%. Soil parameters are also changing significantly. In major transport corridors and industrial areas, the concentration of lead in the soil exceeds the maximum permissible level by several times. These findings confirm that the deterioration in the condition of the tree canopy is linked not only to air pollution, but also to long-term degradation of the root environment.

The reduction in crown density from 4.0–4.5 points in recreational areas to 1.8–2.2 points in industrial areas indicates a marked impairment of growth and foliage. A thinned-out canopy reduces trees’ ability to trap dust, provide shade and dampen noise.

Major roads are characterised by high concentrations of nitrogen and sulphur oxides, high levels of particulate matter, heavy metal pollution, soil compaction and a limited number of parking spaces. The main selection criteria are therefore resistance to gas and dust, drought tolerance, tolerance to salinity and the strength of the timber (Table 5).

For such areas, sycamore, sophora, gleditsia, poplar, loch and tamarisk are recommended. The use of birch, spruce, lime and sycamore maple along the busiest main roads is considered less suitable due to their sensitivity to a combination of pollution, salinity and lack of moisture.

Table 5. Recommended selection of plants for various functional areas

Functional area	Key stress factors	Recommended breeds	Breeds that are less recommended	The main principle of selection
Main lines	NO _x , SO ₂ , dust, salts, seal	Sycamore, sophora, gleditsia, poplar, oleaster, tamarisk	Spruce, lime, sycamore maple	Resistance to gas, dust and salt
Local roads and courtyards	Shading, lack of moisture, trampling	Globosum maple, hornbeam, lime, ailanthus, cotoneaster	Chestnut, magnolia, forsythia	Shade tolerance and drought tolerance
Parks and boulevards	Wind, sea spray, recreational activity	Chestnut, rowan, lilac, spirea, magnolia	Determined by the site conditions	Aesthetic appeal and microclimatic function
Industrial estates	HF, NH ₃ , heavy metals, petroleum products	Ailanthus, white poplar, oleaster, black locust	Mesophytes and sensitive conifers	Tolerance to toxicants

Improving the effectiveness of greening requires a shift from a predominantly decorative approach to a scientifically based system for managing green infrastructure. When selecting a range of plants, it is essential to take into account the climatic characteristics of the site to be landscaped, the functional purpose of the area, the level of human impact, the ecological characteristics of the species, and projected climate change. The primary objective of urban greening should be not only to increase the area of green spaces, but also to ensure their longevity, sustainability and ability to fulfil public health, climate-regulating and recreational functions.

An integral part of effective management is the regular monitoring of the condition of trees. Regular inspections enable the timely detection of signs of weakness, damage, disease, reduced stability and the risk of trees falling, which is particularly important along major transport routes, in areas frequented by large numbers of people and in areas subject to high wind loads.

Thus, the sustainability of green spaces in an urban environment is determined by the complex interplay of climatic, soil and human factors. The selection of tree species based on scientific evidence, the preservation of favourable soil conditions, the rational organisation of irrigation and the systematic monitoring of the condition of the plantations are of paramount importance. Implementing these measures will enhance the environmental performance of urban green infrastructure, increase the longevity of trees and shrubs, and improve the quality of the urban environment in the face of increasing human impact and climate change.

5. Conclusion

The study confirmed that tree and shrub vegetation is one of the most important components of the city's ecological infrastructure. Green spaces have a multifaceted impact on the quality of the urban environment, helping to purify the air, regulate temperature and humidity, reduce wind and noise pollution, stabilise the soil, preserve biodiversity and create recreational spaces.

It has been established that the urban environment constitutes a multi-stress system. Woody plants are simultaneously exposed to air pollution, water stress, high temperatures, strong winds, soil compaction and salinisation, mechanical damage, shading and light pollution. The combined effect of these factors leads to a reduction in photosynthetic activity, disruption of water balance, deterioration of the root system and a gradual thinning of the crown.

Particularly challenging conditions for plant growth arise along busy transport routes and in industrial areas. Here, air pollution is compounded by soil degradation, restricted root space and high thermal stress. As a result, the proportion of weakened and dying trees is increasing, and the ecological functions they perform are gradually diminishing.

A comparison of functional areas revealed that the best condition of the plantings is found in parks, public gardens and boulevards, where the plants have a greater volume of soil and receive more regular

care. In courtyards within residential blocks, significant factors include shading, trampling and damage to the root zone. Air pollution, salinisation, soil compaction and water scarcity are the predominant issues along major roads and in industrial areas.

It has been found that plant resilience is determined not by a single characteristic, but by a combination of tolerance to gas, dust, salt, heat, wind and drought. The species most promising for areas subject to high human impact are those capable of remaining viable whilst exposed to multiple stressors simultaneously. However, even hardy species require proper planting, sufficient soil, sensible watering and professional care.

The environmental effectiveness of green infrastructure depends not only on the number of trees, but also on their age, health, crown size, spatial structure and species diversity. Healthy, multi-species and multi-layered plantings are significantly more effective at trapping dust, providing shade, regulating the microclimate and supporting urban biodiversity.

Based on the research carried out, it is recommended that a differentiated approach be adopted to the greening of various functional zones in large cities. For main roads and industrial areas, species that are resistant to pollution and salinity should be selected; for parks and boulevards, plants that combine environmental resilience with high ornamental value; and for inner-neighbourhood spaces, species capable of tolerating shade, limited soil volume, and recreational use.

The key areas for improving the urban greening system are increasing species diversity, improving soil conditions, introducing water-saving irrigation technologies, protecting root zones, professional pruning, and regular monitoring of tree health. The creation of a digital register of green spaces and the development of a unified green framework for the city are promising initiatives.

Consequently, the sustainable use of woody and shrubby vegetation should be regarded as a key priority of environmental policy. Preserving existing mature trees, creating sustainable mixed plantings and applying scientifically sound management techniques will help to enhance the environmental sustainability of the urban environment and improve the quality of life for the population.

Author's contribution

The sole author is responsible for conceptualizing, collecting, and analyzing data, and writing and editing the manuscript.

Conflict of Interest

The authors declare no conflicts of interest.

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