Обзор / Review

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Alemitu Worku Beyi*

Ethiopian Forestry Development Mekelle center, Production forestry and urban forestry Research Division
Ethiopia

***Correspondence:** alemituworku13@gmail.com

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A Review of Opportunity and Challenge in Growing Street Trees in Paved Urban Environments

ABSTRACT

Street trees have long been recognized as a contributing factor to increased residential property values and offer numerous environmental, economic, and social benefits in both residential and commercial areas. This review article aims to examine the opportunities and challenges associated with planting street trees in urban environments. However, the rapid pace of urbanization has resulted in a significant rise in impermeable surfaces, which can intensify the environmental pressures faced by street trees. Street trees play a crucial role in urban life by delivering a wide array of advantages in residential and commercial zones, and they contribute to the well-being of communities by offering environmental, economic, and social benefits. Nevertheless, the expansion of impermeable surfaces can exacerbate the strains placed on urban ecosystems and urban forests. These strains often force tree roots to proliferate in areas that provide more favorable conditions for growth, but unfortunately, these areas also cause damage to infrastructure and uplift pavements. This damage incurs substantial costs, prompting the exploration of various preventive measures aimed at preserving tree health and minimizing pavement damage. This paper presents a comprehensive review of the benefits provided by street trees, their perceived value within communities, the expenses associated with uncontrolled root growth and pavement damage, and, most importantly, by implementing these preventive measures, urban areas can maintain the numerous benefits provided by street trees while mitigating the negative consequences associated with their growth, the latest research on proven measures to prevent pavement damage and enhance street tree growth.

KEYWORDS:

Green infrastructure; Ecosystem service, Global change, Infrastructure, Urbanization

Алемиту Ворку Бейи*

Центр развития лесного хозяйства Эфиопии в Мекеле, Отдел исследований в области производственного и городского лесоводства
Эфиопия

Автор для переписки:
alemituworku13@gmail.com

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Обзор возможностей и проблем выращивания уличных деревьев в условиях мощеных городских территорий

РЕЗЮМЕ

Уличные деревья давно признаны фактором, способствующим повышению стоимости жилой недвижимости, и предлагают многочисленные экологические, экономические и социальные преимущества как в жилых, так и в коммерческих районах. Цель данной обзорной статьи — изучить возможности и проблемы, связанные с посадкой деревьев в городских условиях. Однако быстрые темпы урбанизации привели к значительному увеличению непроницаемых поверхностей, что может усилить экологическое давление на деревья. Уличные деревья играют решающую роль в городской жизни, предоставляя широкий спектр преимуществ в жилых и коммерческих зонах, и способствуют благополучию сообществ, предлагая экологические, экономические и социальные выгоды. Тем не менее, расширение непроницаемых поверхностей может усугубить нагрузку на городские экосистемы и городские леса. Эта нагрузка часто заставляет корни деревьев разрастаться в местах, обеспечивающих более благоприятные условия для роста, но, к сожалению, эти места также наносят ущерб инфраструктуре и поднимают дорожное покрытие. Этот ущерб влечет за собой значительные затраты, что побуждает к изучению различных профилактических мер, направленных на сохранение здоровья деревьев и минимизацию повреждений дорожного покрытия. В данной статье представлен всесторонний обзор преимуществ, предоставляемых уличными деревьями, их ценности в сообществах, расходов, связанных с неконтролируемым ростом корней и повреждением дорожного покрытия, и, что наиболее важно, путем внедрения этих профилактических мер городские территории могут сохранить многочисленные преимущества, предоставляемые деревьями, одновременно смягчая негативные последствия, связанные с их ростом. Представлены последние исследования проверенных мер по предотвращению повреждения дорожного покрытия и стимулированию роста деревьев.

КЛЮЧЕВЫЕ СЛОВА:

Зеленая инфраструктура, Экосистемные услуги, Инфраструктура, Урбанизация, Глобальные изменения

1. Introduction

Urbanization is the main elements of global change that dramatically influences biological and environmental patterns, affecting human well-being at all spatial scales [1]. Decreased vegetation cover is a hallmark of urbanization, and urban environments are on the cusp of having greater impervious surface than tree cover worldwide [2]. This trend toward increasing imperviousness has dramatic consequences for the environmental conditions experienced by urban populations locally and at regional-to-global scales. Tree canopy is related to better air quality and correspondingly lower cardiovascular and respiratory disease [3,4]. Areas with more tree canopy cover may have lower rates of violent crime [5,6]. Additionally, there is a correlation between a higher presence of trees and positive mental health outcomes [7], as well as improved perceptions of the environment by residents [8]. From a physical standpoint, the shade provided by trees effectively cools urban areas with low reflectivity [9], resulting in lower perceived temperatures [10] and a decrease in heat-related deaths [11,12]. Furthermore, trees serve as important habitats for urban wildlife [13] and help mitigate flooding and water quality issues by intercepting rainwater.

As climate change drives rising summer temperatures in cities worldwide, the value of urban trees will only increase, and it is particularly important to understand nuances between different types of urban trees to best support and manage equitable urban environments. Urban parks and the planting of trees along streets contribute to the development of engaging and lively public areas in cities. However, the growth of trees in these locations can be constrained if the design of tree plots does not effectively address the issue of water stress. In the past three decades, the main objective of street trees has shifted from a focus solely on aesthetics, aimed at enhancing the visual appeal and decorative aspects, to a broader purpose that encompasses providing various services. These services include reducing stormwater runoff, conserving energy, and enhancing the quality of air [14]. However, the advantages mentioned above are not fully experienced due to significant landscape design challenges that restrict the access of tree roots to vital resources such as water, air, and nutrients. The growth of trees is influenced by various non-living factors, including soil moisture, soil volume, soil permeability, soil composition, amount of sunlight reaching the canopy, and air quality [15]. Changes in soil moisture and nutrient availability in urban environments can lead to expensive infrastructure damage. For instance, tree roots tend to flourish beneath impermeable sidewalks and roads, where they can find sufficient water and nutrients for survival and growth [16].

Recent studies have focused on the use of permeable surfaces, which allow water to penetrate through the pavement and reach the soil [17,18]. According to various international literature, there are several factors related to the environment, economy, maintenance, and aesthetics that form the basis for selecting species and can influence the process of planting and selecting street trees [19,20] have proposed dividing the criteria for species selection into three categories that define the essential characteristics of urban trees: (i) "basic features" (such as adaptability to climate, tolerance to diseases and pests) [21]; (ii) "urban stress tolerance"[22]; and (iii) "amenity and functional features" (such as high aesthetic value, sturdy branches, autumn leaf color, dense foliage)[23]. This review provides an overview of the advantages of street trees, the difficulties encountered in cultivating trees in urban settings, and potential approaches to enhance the health of street trees and mitigate pavement damage. The main emphasis of the review is on the interactions between tree roots and pavements, although it acknowledges that other parts of the trees, such as trunks and branches, can also pose challenges to urban infrastructure. While the majority of the literature examined in the review originates from temperate regions like the United States and Europe, it also includes studies conducted in tropical areas.

2. The Importance of Street Tree in Urban

Cities can be seen as intricate settings influenced by various factors that can either contribute to their success or lead to their failure. These factors encompass the local economy, social cohesion and safety, city identity, infrastructure, and the overall health and well-being of the residents. While economic, environmental, and social influences are significant, the level of involvement and commitment demonstrated by city leaders plays a crucial role in shaping the outcomes. This becomes especially evident when examining the historical development of municipal policies and political engagement in relation to the physical structure and design of a city [24]. Urban street trees offer a wide range of advantages to cities and their inhabitants, contributing to the overall quality of urban environments and providing both measurable economic and environmental value. Extensive research has shown that these trees enhance local and regional air quality, raise property values, mitigate the urban heat island effect, reduce energy consumption for heating and cooling, and contribute to the visual appeal and distinctiveness of urban spaces [4]. Moreover, street trees play a crucial role in fostering healthy urban communities and have significant social impacts. They promote human well-being by improving public health [25], lowering crime rates, facilitating social interactions within communities [26], and increasing property values [27]. While these benefits are typically classified as environmental, economic, or social, it is important to note that some benefits overlap multiple categories.

2.1. Environmental importance of street tree in Urban

Street trees enhance the livability of towns and cities by offer-

ing several benefits. They reduce stormwater runoff, enhance air quality, store carbon, provide shade, and mitigate the urban heat island effect. Additionally, street trees promote biodiversity by serving as a food source, habitat, and landscape connectivity for urban wildlife [28]. Urban trees cool the environment through shading and transpiration. However, the extent of this cooling effect depends on the amount of canopy cover in the vicinity [29,10]. While some studies have found a linear relationship between canopy cover and cooling [30], emerging evidence suggests that the relationship is often nonlinear. It indicates that limited cooling occurs until canopy cover reaches 25%–50%, after which the cooling effect becomes more significant [30]. Nevertheless, further research is necessary to comprehend the underlying reasons for this nonlinearity and its applicability across different climate zones. Moreover, the strength of the correlation between canopy cover and cooling depends on the scale of observation [10]. The exact extent of the influence zone of street trees is not well-defined and is likely to vary with the time of day.

Increases in impervious surface area and soil compaction, due to urbanization, reduce water infiltration into soil and increase storm water runoff and peak flow rates. For example, urban runoff from summer rainfall is much higher from asphalt (62%) than from surfaces with tree pits (20%) or turf (<1%), highlighting the effect that trees can have on storm water reduction [31]. Leaves and branches intercept, absorb and temporarily store water before it evaporates from tree surfaces or gradually infiltrates into the soil. Mature deciduous trees, such as sweetgum, intercept between 1.89 and 2.65 kiloliter (kL) of water per year [32], while evergreen trees including pines can intercept more than 15.41 kiloliter (kL) per year [33]. Emissions and noise from road traffic can be a serious health issue but trees are particularly effective at diminishing noise and capturing airborne pollutants including ozone, nitrogen oxides, sulphur oxides, sulphur dioxides, carbon monoxide, carbon dioxide (CO2) and particles less than 10μm in size [34]. Large healthy trees can remove between 60 and 70 times more air pollution than smaller trees [35]. Trees remove CO2 from the atmosphere through photosynthesis, and they decrease the consumption of fuel for heating and cooling by providing shade and insulation [36]. The inner-city tree population of Melbourne, Australia (~100,000 trees) is estimated to have sequestered one million tons of carbon [37]. The cooling effect provided by trees is directly related to tree size, canopy cover, tree location, and planting density. As much as 80% of the cooling effect of trees results directly from shading [38]. Street trees can reduce daytime temperatures by between 5°C and 20°C, making everyday activities more pleasurable and healthier [39].

2.2. Social Importance of Street Tree in Urban

The presence of green spaces in urban areas has numerous positive effects on the community. It fosters interaction among residents, promotes physical activity, reduces stress, and enhances social cohesion [40]. Research suggests that urban areas with abundant street trees tend to experience lower crime rates and increased public safety. Studies have shown that building areas with a high amount of vegetation can lead to around 50% lower crime levels compared to areas with low vegetation, and a 10% increase in tree cover is associated with a 12% decrease in crime [6]. Moreover, larger street trees have been linked to a decrease in both the occurrence and fear of crime [40] The reduced crime rates in well-maintained vegetation areas are often attributed to a stronger sense of community care among residents. Another social benefit of street trees is their ability to serve as a visual and physical barrier between pedestrians and motorists. By creating a vertical wall between the sidewalk and the road, street trees provide a clear boundary that helps guide motorists' movements and allows them to assess their speed, ultimately enhancing community safety [40]. Additionally, trees act as a physical defense for pedestrians, offering protection against vehicle-related injuries.

The economic advantages of urban street trees are not as straightforward to measure as those of traditional forestry or fruit trees, primarily because street trees typically lack a direct market value [27]. However, it is possible to estimate the economic benefits associated with street trees, which can provide a measurable basis for supporting municipal tree care programs and promoting tree planting initiatives. Expressing these benefits in monetary terms allows policymakers and decision-makers to easily comprehend and evaluate them. Unfortunately, there is often a tendency to remove trees without replacing them, as they are sometimes perceived as liabilities rather than assets due to misconceptions [42]. Street trees have the potential to provide various economic benefits, including reducing energy costs and increasing business income and property values. Extensive research has demonstrated the significant energy savings that can be achieved by planting street trees [27]. Moreover, the benefits of energy savings, carbon sequestration, stormwater management, and improved air quality can be estimated directly and evaluated in economic terms. The functional advantages of trees, such as their ability to remove air pollution through leaf absorption and their capacity to reduce stormwater runoff through root uptake and canopy interception, become more pronounced as the tree canopy cover increases.

3. Challenges of Growing Street Trees in Urban Environments

Street trees offer numerous advantages to the environment, society, and economy. However, they can also lead to disruptive

and expensive damage to pavement infrastructure. To mitigate these issues and minimize costs associated with pavement and tree replacement, researchers have explored preventive measures aimed at reducing damage and enhancing tree health.

3.1. Impact of Street Tree in urban environment

Despite their numerous benefits, street trees can also cause certain negative impacts on ecosystems [43]. One significant issue is the physical damage caused by tree roots to surrounding surfaces and underground structures, commonly referred to as root damage [44]. In urban areas, some street trees pose a gradual threat to public properties by compromising the structural integrity of sidewalks, curbs, and underground pipes. Above ground, root damage leads to sidewalk protrusions, and pedestrians may trip over buttress roots [45]. The scale of infrastructural problems caused by roots is evident in the annual expenditures allocated from government budgets for urban forestry or greening purposes. For example, a study conducted in Beijing estimated that the total value of ecosystem disservices, including root damage, was around 10.54 billion renminbi (RMB) in 2019, placing a financial burden on local governments. Additionally, both regional and national costs are incurred due to tree maintenance, infrastructure repairs, and compensatory payments to injured pedestrians. Older and larger tree species in urban areas are often responsible for footpath uplift and cracking [46].

4. Selection and Management of Street Tree in Urban Area

Street trees play a crucial role in urban landscapes and offer psychological, social, and economic benefits [47]. However, there are several challenges associated with the planting and selection of street trees. Firstly, the roots of street trees often damage sidewalk infrastructure, posing safety concerns for pedestrians. The extent of sidewalk damage depends on various factors such as tree characteristics, height, diameter at breast height, and the size of the planting hole [19]. Secondly, common issues in street tree management and maintenance include inadequate water supply, nutrient deficiencies, vandalism, soil compaction, mechanical injuries, pruning, and fertilization [48]. Thirdly, certain tree characteristics can contribute to environmental health problems, including the accumulation of fallen flowers, leaves, fruits, and an increase in insect populations [19]. Consequently, the selection of suitable street trees becomes crucial in order to avoid these problems. Several studies have identified criteria for street tree selection based on expert opinions or the input of managers. For example,[49], suggested considering visual, spatial, physical, biological, and functional factors when selecting tree species. [50], highlighted climatic adaptation, disease resistance, phenotypic plasticity, aesthetic factors, growth form, growth potential, and resistance to limb breakage as key considerations. [51], emphasized the importance of factors such as resistance to urban environments, landscape effects, ecological impacts, and economic considerations in the process of street tree selection.

Street trees play a crucial role in urban green infrastructure as they provide various ecosystem services, including air purification [52], microclimate regulation, and noise reduction, which contribute to improving human well-being [53]. However, street trees can also present certain challenges such as obstructing views and dropping litter. These negative impacts can be mitigated through the implementation of effective management plans that involve careful tree variety selection, establishment and care programs, and the support of the local municipality in terms of finances and expertise [52]. Currently, there is limited knowledge about street trees in sub-Saharan Africa, with most studies focusing on larger green spaces such as parks [54]. Previous studies conducted in northern cities have revealed that street trees were often uniform and comprised of a single species, with specialized public services responsible for their planting, maintenance, and protection [55-57]. While similar public services exist in many African cities, additional financial support and human resources are necessary. As a result, the few street trees that do exist are typically protected and maintained by local residents rather than formal institutions [58].

Uncontrolled Street tree harvesting has led to an increased interest among local populations in exploiting and diversifying their use, as noted by [59]. It has been observed that preferred tree species are being introduced into these plantations by the local communities resulting in changes to the composition of the plantations and posing challenges to tree viability and management approaches [60] discovered that urban street trees are susceptible to various stresses, such as pollution, as well as accidents caused by trampling, grazing, and vandalism. These factors hinder the growth and development of the trees. To mitigate these issues, protective equipment is sometimes installed around street trees during their growth. However, in many developing countries, including the cities of the Democratic Republic of the Congo (DR Congo), the condition of tree equipment is often not assessed before installation. In summary, uncontrolled access to street tree harvesting has heightened local interest in their abusive use and diversification. Local populations introduce preferred species into the plantations, leading to changes in floristic composition and management approaches. Urban street trees face stress and accidents, which impede their growth, and the assessment of tree equipment condition is often overlooked in developing countries like the DR Congo.

When selecting street trees, it is crucial to take maintenance and management into account [61]. A global study highlighted the importance of choosing trees that are easy to maintain, require minimal watering, need less frequent maintenance, align with availability and requirements, and have lower maintenance costs [61]. Local studies

Table 1. Roadside tree species selection [65]:

Site	Characteristics to consider
Social factor	Purpose of the trees: beauty, fruit, shade, serving as windbreaks, a filter of pollutants Functional utility: medicinal, nutritional, economic
Economic factors	Establishment costs Maintenance and management costs
Tree characteristic factors/ Resistance to urban environments	Flowering, adaptability, diversity, tolerance, structure, wind tolerance; resistance to termites, drought, poor soil, cold, high temperatures, diseases and pests, and mechanical damage; crown, height, and canopy density Selected trees should have a good canopy, providing Shade to cool the area along the road, making it more comfortable for the pedestrians
Educational factor	Knowledge, skills, experience, expertise
Environmental Constraints	Climatic conditions (heat, drought, and waterlogging tolerance), soil conditions The selected trees should be adaptable to various Conditions such as drought.
Cultural constraints	Utilities such as structures (buildings) and power lines (The selected trees should not grow tall enough to disrupt power lines, but if that is the case there must be a pollarding strategy
Limitation constraints	Space and planting location

have also emphasized the significance of engineering, budget, and human resources in street tree management [51]. To effectively manage street trees in the long term, it is essential to gather data on their distribution, including species composition, size and age structure, and spatial inventories. This information is valuable for urban managers who aim to maximize the environmental benefits provided by street trees, as factors such as species composition; size, canopy, and age structure significantly influence the environmental functions of these trees [62].

5. Tree species most suitable for urban growth

This part outlines particular criteria to consider when choosing appropriate tree species for planting alongside roads and details the methodology for assessing the suitability of streets for such planting. Additionally, this section highlights general factors in tree selection that reflect the needs and preferences of the community. The fundamental concept in street tree planting is selecting the correct tree for the appropriate location [50]. Due to the tough conditions along roadsides, planting requires special consideration. To maximize the advantages of street trees, it is crucial to choose tree species based on the characteristics of the site, the resilience of the trees, a thorough analysis of both the above and below ground conditions, and the potential of the tree species to enhance drainage, capture dust, and minimize surface runoff. The criteria for selection are grounded in the medicinal, nutritional, economic, and ecological importance of the trees, along with their adaptability, the cultural significance tied to particular species, and their capacity to absorb carbon dioxide [63]. The selected trees should be evergreen in order to capture dust year-round, particularly during the dry season when dust becomes problematic for farms and homes near the road [64]. Certain trees serve as a food source, notably those that yield fruit for nearby communities and passersby, including school children. Providing shade is also crucial for travelers who walk long distances under the relentless sun on their way home. Table 1 details the factors to consider when selecting trees.

6. Conclusions and Recommendations

In conclusion, street trees and vegetation in urban areas offer valuable ecosystem services and contribute to the overall well-being of communities. They provide numerous environmental, social, and economic benefits, including shade, storm water reduction, improved air quality, habitat creation, and enhanced aesthetic appeal. While some costs associated with tree damage exist, the positive impacts of street trees are generally perceived as outweighing the negatives by city residents. However, the economic value of street trees is often underestimated. Therefore, it is important to quantify the environmental benefits of street trees in monetary terms to facilitate better understanding and decision-making by policymakers. To ensure the effective management of street trees, it is crucial to follow planting guidelines that promote appropriate tree selection and suitable spacing. This proactive approach can prevent future problems and minimize any potential harm to residents. Furthermore, fostering communication, coordination, and cooperation between urban forest managers and users is essential. This collaborative effort improves understanding and cultivates a more productive working relationship, ultimately enhancing the quality and reliability of the urban forest as a valuable resource.

It is worth noting that the literature available on street trees is geographically limited, which restricts the scope and generalizability of the conclusions drawn. Thus, further research on street trees, particularly in tropical regions, is necessary. Additional studies focusing on street tree benefits, infrastructure damage prevention, and strategies for managing urban trees would be highly valuable in guiding effective tree management practices in urban environments. Overall, increasing knowledge and awareness of the benefits and potential challenges associated with street trees will contribute to their successful integration and management within urban landscapes.

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About the Author:

Alemitu Worku Beyi – Researcher, https://orcid.org/0009-0006-8825-6933 , Corresponding Author, alemituworku13@gmail.com

Об авторе:

Алемиту Ворку Бейи – исследователь, https://orcid.org/0009-0006-8825-6933, автор для переписки, alemituworku13@gmail.com