URBAN STREET TREE PLANNING AND MANAGEMENT FOR RESILIENT ECOSYSTEM SERVICE PROVISION IN ADDIS ABABA, ETHIOPIA

A Master's Thesis submitted to the school of graduate studies of Addis Ababa University in partial fulfillment of the requirements for a Master of Science Degree (M.Sc.) in Environmental Planning and Landscape Design

BY

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Title of Thesis: **Urban street tree planning and management for resilient ecosystem service provision in Addis Ababa, Ethiopia**

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Declaration

I, the undersigned, declare that this thesis titled: "Urban Street Tree Planning and management for Resilient Ecosystem Service Provision in Addis Ababa, Ethiopia" is my original work and has not been presented for a degree in any other university and that all sources of material used for the thesis have been duly acknowledged, following the scientific guidelines of the Institute.

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The thesis can be submitted for examination with my approval as an Institute's advisor.

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Abstract

Unplanned urbanization threatens environmental sustainability, and Addis Ababa is straining its ecosystem, causing a mismatch between ecosystem service (ES) supply and demand. In essence, this study investigates Addis Ababa's urban street tree planning and management practice from a resilience perspective while focusing on their ecosystem service supply and demand, disservice, as well as challenges. The research is a descriptive and exploratory study that employs quantitative and qualitative methods. Site observation, key-informant interviews, and questionnaire surveys were employed for data collection. Using ES Cascade model as a framework, the research performed thematic, descriptive, correlation, and apparent urgency analysis based on expert and user perception. The resilience assessment of street trees indicated a lack of functional redundancy and species richness with Churchill Road having the relatively highest Shannon diversity (1.89) and equitability (0.29), while Meskel Square to Lancha showed the lowest values (0.26 and 0.04, respectively). Besides, connectivity concerns with trees in various street corridors, concerns with stakeholder participation, and limited adaptive capacity were found. Regarding zone-based ES supply and demand quantification, species diversity (2.67 periphery, 2.29 intermediate), followed by aesthetics (2.09 periphery, 1.72 intermediate), stormwater management (1.93 intermediate, 1.72 periphery), and local climate regulation (1.34 intermediate) revealed a gap that requires apparent urgency. Results also highlight a high incidence of ecosystem disservices associated with, littering, infrastructural damage, and obstructing use of space. Besides, species selection and space allocation were identified as high-priority planning and design concerns. The prevalence of Grevillea robusta and Phoenix canariensis, species with 51% and 15% respective dominance indicates uniformity in tree species selection, implying the necessity for adaptable solutions that consider urban dynamics. Prioritizing ecosystem services than mere aesthetics, selection of climate-resilient and locally adaptable species, and integrating them with surrounding UGI components were among the recommendations forwarded.

Keywords*: Ecosystem Service (ES), ES supply and demand, ES cascade model, Resilience, Street Tree, Addis Ababa*

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TABLE OF CONTENTS

List of Figures

List of Tables

Acronyms

ES	Ecosystem Service
SDGs	Sustainable Development Goals
GI	Green Infrastructure
UGI	Urban Green Infrastructure
UHI	Urban Heat Island
NGOs	Non-Governmental Organizations
PAS	Principal Arterial Streets
SAS	Sub Arterial Streets
CS	Collector Streets
LS	Local Streets
SES	Socio Ecological Systems
A.A	Addis Ababa
LRT	Light Rail Transit
AAPDC	Addis Ababa City Planning and Development Commission
AACRA	Addis Ababa City Road Authority
EFDI	Ethiopian Forest Development Institute
FDRE PSI	Policy Studies Institute (PSI)
AACAUBGDB	Addis Ababa City Administration Urban Beautification and Green Development Bureau
AAWSA	Addis Ababa Water and Sewerage Authority
EEP	Ethiopian Electric Power
EEU	Ethiopian Electric Utility
H	Shannon diversity index
Hmax	Maximum Shannon Diversity Index
H/Hmax	Equitability Shannon Index
CBD	Inner City
Inter	Intermediate zone
Peri	Periphery zone

Chapter 1: INTRODUCTION

1.1 Background to the Study

Unplanned and unmanaged urbanization represents a threat to environmental sustainability, whereas, planned urbanization leads to positive development outcomes and can be leveraged for improved quality of life and overall prosperity (Knudsen et al., 2020). However, Africa's current urbanization process is leading to an urban fabric that is lacking accessible, efficient, inclusive, and well-designed public spaces that combine to produce attractive built environments, provide public amenities, and enable a satisfactory urban lifestyle, with a low-quality public space (UN-Habitat, 2017).

Sub-Saharan Africa is the fastest urbanizing region globally with a 4.1 percent annual rate of urbanization compared to the global 2.0 percent rate (Saghir and Santoro, 2018), and many parts of the region endure urbanization with unwise utilization of natural resources, facing one of the biggest challenges in the world (Güneralp et al., 2017). Likewise, Addis Ababa, Ethiopia's primal city is experiencing extensive population growth and migration, placing a significant strain on the city's ecosystem (Kasa et al., 2011).

Ethiopian environmental policy was devised aiming at improving human well-being by promoting sustainable social and economic development through the sound management and use of natural, human-made, and cultural resources and the environment as a whole (Federal Democratic Republic of Ethiopia, 1997). The policy also reflects ensuring the restriction of exotic plant species plantation and promoting sustainable forest management to achieve social acceptability, economic viability and balanced service from urban forests.

Considering urban street trees as part of the urban forest (Escobedo et al., 2011; Pataki et al., 2021), their balanced ecosystem service (ES) provision could help in realizing several sustainable development goals (SDGs). Particularly, SDGs 11.2, 11.7, 12.2, and 13.1 are the ones to be addressed in this research. While, the major consideration lies in SDG 11, intending to make cities inclusive, safe, resilient, and sustainable. Hence, protecting and restoring ecology through the integration of urbanism and nature should be encouraged (Williams, 2000), and it requires planning and management of urban street trees for long-term benefits (Marjan van den Belt, 2016).

Urban street trees, being an integral component of the urban ecosystem (Yao et al., 2022), provide a range of ES that spurs the path of resilient and sustainable development (Burden, 2006; Monteiro and Doick, 2021). Managing stormwater, protecting biodiversity, carbon sequestration, cooling city streets, filtering particle pollutants, enhancing aesthetics, increasing land value, food provision, and improving public health are among the many benefits of urban street trees (Borelli, 2016; Monteiro et al., 2019).

Although greening streets is effective in increasing ES capacities (McPhearson et al., 2014), the ability of street trees is dependent on the social, ecological/biophysical, and technological factors all contributing to their specific context (Marjan van den Belt, 2016). Therefore, context-sensitive species selection helps to ensure the attainment of an ideal outcome from urban street trees (Durfee, 2021). In other words, the better suited a tree is to the site, the greater chance it will have of surviving, growing faster, and maximizing benefits (Sousa-Silva et al., 2021).

Moreover, integrating a social-ecological perspective (community involvement, promoting public health, and adaptation to local climate) with the concept of resilience contributes to the achievement of better urban sustainability (Elmqvist, et al., 2013). Besides, societies gain social benefits through ecological and environmental services, and ecological and environmental services are preserved through optimum management practices, and the study by Abunnasr, 2013, proves more to the point.

Therefore, street tree planning should identify the benefits or services which are being delivered by urban street trees. The value being given by the street users along with the actual demands of ES is also crucial when contemplating their relationship with the city and its green infrastructure elements.

In summary, as cities face escalating environmental challenges and rapid urbanization, understanding and enhancing the resilience of street tree planning and management is essential to securing the long-term provision of critical ecosystem services. By evaluating current practices and resilience strategies, this research aims to assess ES supply and demand with the aim of balancing and enhancing ES provision from urban street trees in Addis Ababa.

1.2 Statement of the Problem

Urban Green Infrastructure, particularly urban street tree planning, is a form of nature-based solution to the contemporary urban and environmental challenges that help to promote climate resilience and ensure ecosystem efficiency (Escobedo et al., 2011; Hopton and Berland, 2014). Given that urban environments are impacted and constrained by heavy constructions and stresses from urbanization, the planning and management of green infrastructure are facing a unique set of challenges (Tan et al., 2021); generating serious concerns about species and ecosystems' ability to adapt and survive for long-term service provision (Ecosystem Resilience).

In developing countries, more is being learned about the profound negative environmental effects of treeless urban streets as they face a larger risk of failing to sustain service delivery over time (Walker and Salt, 2006). However, urban tree planting efforts are hampered by the relatively limited space for tree planting in dense cities (Pataki et al., 2021) and by factors such as air pollution, soil compaction, wide pH ranges, heat, and general abuse (Sæbø et al., 2003), which makes it difficult to establish new trees and maintain existing ones.

Likewise, Addis Ababa, an exemplar of Ethiopia's fast urbanization and transformation (Tegenu, 2010), achieves only 1.5m^2 green area coverage per capita and is challenged while dealing with the hazards and stresses that lead to increased urban heat island (UHI), and loss of natural ecosystems and their services (Addis Ababa Resilient Project Office, 2020). Furthermore, despite the abundance of native tree and shrub species that grow under different climatic conditions in Ethiopia (1100 species, Teketay, 2001), knowledge gap of species selection is evidenced by exotic tree species dominating urban streets. Exotic species selection are not adapted to the local climatic conditions, affects environmental resilience and sustainable provision of ES, and that, directly and indirectly affect human wellbeing.

According to Buffam et al., (2022), urban street trees in Addis Ababa are being challenged by biophysical, societal, and management barriers. Challenges in the biophysical domain include the limited use of street palettes, the introduction of invasive and non-native species, inadequate provision of shade, and low density of street trees with a high mortality rate. In terms of society, there is a lack of clear methods for communicating perceptions, values and demands of the public to decision makers.

Regarding governance and management barriers, a limited number of professionals along with a lack of standards, monitoring, and follow-up to ensure tree survival and function is argued as the major challenge. As per AACPDC, (2017) structure plan of Addis Ababa, the availability of street plantations in connection with pedestrian roads and medians is quite limited, and those that are available are unsustainable due to improper site management and lack of post-plantation follow-up.

In Addis Ababa, rapid redevelopment, densification, and demographic shifts are transforming the urban environment, impacting the provision of ecosystem services (ES). Urban infrastructure expansion often damages tree roots, while extensive use of sealed surfaces limits soil moisture, affecting tree health and resilience (Hale et al., 2015). To adapt to these challenges and mitigate climate impacts(Seok et al., 2022), enhancing the urban tree canopy with climate-resilient, locally suited species is a key strategy (Durfee, 2021). However, elevated urban temperatures, dry soils, and high radiative loads increase evapotranspiration, reducing street trees' ability to survive and provide cooling benefits in densely built areas (Salmond et al., 2016).

In Addis Ababa, the interconnected impacts of urban climate risks and the essential benefits provided by street trees demand a systems-thinking approach for effective ES management (Gómez Martín et al., 2020). Therefore, it is crucial to ensure that today's urban trees are selected and managed to sustain long-term resilience, supporting both current and future urban needs (Sousa-Silva et al., 2021).

However, a mismatch between the scales at which street trees are supplied, demanded, and managed is evident (McPhearson et al., 2014). Unless we balance the gap between ES supply and demand from urban street trees, their long-term ES provision may be affected, thus hindering the realization of enhanced urban sustainability, ecosystem resilience, and human wellbeing.

In light of the aforementioned problems, this research aims to fill the conceptual and knowledge gaps pertaining to urban street trees in Addis Ababa (see details in section 1.3). In doing so, the existing situational analysis of urban streets on the selected street corridors is performed along with their ES supply and demand identification, ecosystem disservice, and challenge assessment; thereby developing planning solutions and strategies for the resilient and long-term provision of ES.

1.3 Research Gaps

Aiming to fill some conceptual and knowledge gaps described hereunder, this study incorporated urban forestry and green infrastructure development concepts, in particular to the assessment of urban street tree planning and management practice from ecosystem service and resilience perspectives.

A. Conceptual Gaps

Although it's hardly implemented, Addis Ababa's ongoing development considers a 30% increment towards green development intending to change the low priority given to urban forestry and green infrastructure planning in developing sub-Saharan countries (Eshetu et al., 2021). Particularly on street trees, a study by (Adem, 2020; Buffam et al., 2022) highlighted the benefits that street trees bring to improve human wellbeing, while also indicating problems related to space allocation for street greenery in Addis Ababa.

According to Buffam et al., (2022), future researchers should focus on improving the lack of studies on UGI planning and management for improved ES provisioning. Unfortunately, there seems to be a missing piece of literature that assesses the supply and demand of ecosystem services from urban street trees in Addis Ababa.

Moreover, a study by Addis et al., (2022) suggested the incorporation of climate governance in the UGI study. Besides, the complexity required to manage challenges in an era of budget constraints makes it ever more important to maximize the benefits provided by each tree and to build a more resilient urban green infrastructure overall (Hale et al., 2015; Roy et al., 2012).

There is a lack of comprehensive frameworks that integrate resilience principles, such as redundancy, diversity, connectivity, and adaptive capacity, within UGI planning. This limits the ability of cities like Addis Ababa to create green infrastructure that can withstand the unique environmental and urban pressures specific to sub-Saharan climates.

By incorporating resilience principles like redundancy and diversity, a range of tree species that improve ecosystem are introduced. Ecological networks are facilitated by the connectivity principle, which connects green spaces for the benefit of humans and wildlife. While adaptive capacity principle enables adaptable responses to climate change, participation promotes community involvement in tree planting and maintenance, providing long-term urban resilience and sustainability.

The absence of tailored guidelines for selecting resilient, native tree species means that many urban planting efforts may fail to address long-term environmental and social needs. Including indigenous species in UGI could enhance biodiversity and increase resilience against climate and soil-related challenges unique to Addis Ababa.

A study by Maru et al., (2021) Bekele et al. (2020) highlight the need for increased species diversity and improved management practices in urban forestry to build resilience. The study highlights the need for a more deliberate integration of resilience principles by noting that the existing approach to UGI is inadequate for addressing emerging climate problems. Unfortunately, the lack of literature that mainstream resilience principles with street tree planning and management in sub-Saharan countries is evident.

B. Knowledge Gap

The planting of an appropriate tree species that considers particularly targeted ecosystem services along a specific street corridor is challenged by a knowledge gap among the stakeholders. According to AACPDC, (2017), the selection of tree species has been merely based on aesthetic considerations rather than temperature regulation. It is common practice to see trees planted along medians creating visibility problems for vehicular movements, thereby hindering smooth traffic. Trees on the sidewalk are not even providing proper shade for pedestrians.

The study by Workneh, (2021) also reported that a lack of knowledge regarding species selections that are suited for planting street trees is among the significant barriers to street greening practices in Ethiopia.

1.4 Objectives of the Study

1.4.1 General Objectives

The general objective of this study is to assess Addis Ababa’s urban street tree planning and management practice from a resilience perspective while focusing on their ecosystem service supply and demand, disservice, as well as challenges.

1.4.2 Specific Objectives

i. To assess Addis Ababa's street tree planning and management practice from a resilience perspective
ii. To quantify the supply and demand of ecosystem service from urban street trees in Addis Ababa
iii. To assess Ecosystem disservices and challenges of urban street tree planning and management in Addis Ababa

1.5 Research Questions

The research questions are ordered according to the specific objectives listed above.

i. What characterizes the resilience of street tree planning and management in Addis Ababa?
ii. Which ecosystem services are being provided and what ecosystem services are the most demanded from urban street trees in Addis Ababa?
iii. What are the Ecosystem disservices and street tree planning and management challenges in Addis Ababa?

1.6 Scope of the Study

The scope of this study incorporates both spatial as well as thematic. The spatial scope shows the physical extent of the study in terms of geographical location and physical elements of the street considered in the study, while the thematic scope frames the themes to be discussed in this study.

1.6.1 Spatial scope

Geographically, the project sites are located in the capital city of Ethiopia, Addis Ababa, on which sample street corridors are selected using a range of site selection criteria (see details in section 3.2 and Table 3.1). Regarding streetscape elements, the study considers sapling and mature trees planted on pedestrian walkways and median parts of a street, two vital spaces for street greenery on a typical street.

1.6.2 Thematic Scope

The thematic scope of this research highlights the main topics that are addressed while achieving the objectives specified regarding urban street tree planning and management practices in Addis Ababa. The major themes on which this study has focused are listed below:

- Urban forestry and green infrastructure planning related to ecosystem service and urban street tree
- Resilience in urban ecosystem from the perspective of diversity, redundancy, connectivity, participation, and adaptive capacity principles
- Ecosystem service supply and demand particularly related to local climate and air quality regulation, stormwater regulation, recreational, aesthetics, and human health benefits, as well as supporting biodiversity from urban street trees
- Ecosystem disservices, urban street tree development and management practices and challenges from environmental, social, governance, and institutional themes

1.7 Significance of the study

Considering Addis Ababa is a complex and dynamic urban environment with a range of environmental problems, ensuring the long-term and resilient ES provision from urban street trees supports building a green and multifunctional city with improved human well-being. For that matter, assessing the existing planned urban street trees and their ES supply and demand guides the path to delivering those ES that are demanded in Addis Ababa.

This research will provide insights into how the selection, management, and expansion of the urban tree canopy can enhance these critical climate-regulating functions in the context of a rapidly urbanizing city like Addis Ababa. This study will also offer evidence-based recommendations for urban policymakers to design and implement green infrastructure policies that align with climate adaptation and sustainable development goals.

The findings of this research benefit the government (city administration and sub-cities) by providing the required information and expertise on how to cope with environmental concerns related to street tree planning and management. Moreover, it provides information for authorities to act using effective and up-to-date street tree plantation schemes for a resilient environment and balanced ES provision.

1.8 Limitations of the study

Resource limitations: as the study area has a broad spatial extent, it was not easy to collect user-based data freely and investigate through the selected sites. Given the work schedule and character of government offices in Addis Ababa, Finding sufficient and organized data that are relevant to the study from experts was also challenging.

Time constraints: Because this thesis study must normally be finished in a specific period, the researcher's time for study was constrained. Hence, to complete the project within the allotted time, the scope had to be reduced.

Methodological constraints: the assessment and quantification of ecosystem service using commonly used software on the field (e.g. InVEST) was not ideal for the scope of this study (urban street trees) as it may not provide the level of detail needed for such assessments, especially at the local scale of individual street trees.

This study faced methodological limitations in quantifying the biophysical domain (the supply side of ecosystem services), as it relied solely on respondents' perceptions rather than direct measurement of biophysical indicators. Limited resources and the complexity of assessing urban ecosystem services at a granular level further constrained the research. Hence, extensive and detailed data on street user perception was necessary to identify the supply of and demand for ecosystem services, thereby making the whole research process somehow challenging and time-consuming.

1.9 Research Outline

The study is organized into five chapters. Each chapter begins with an introductory section to elaborate on the content of the chapter.

The first chapter of the study focuses on introductory remarks by stating the background of the study, research gaps, problem statement, general and specific objectives with research questions, defining the spatial and thematic scopes, along with limitations and research outline.

In the second chapter, a literature review containing a theoretical and conceptual review of the relevant topics pertaining to urban street trees and their ecosystem services, as well as resilience principles that are given due consideration in this study.

In the third chapter, the general overview of the study area in terms of spatial location, site selection criteria, and detailed description of sample sites are presented. Besides, this chapter mainly focused on the methods and materials related to research design, sampling techniques, data collection, analysis, and interpretation.

In the fourth chapter, the findings from collected data are presented in the result section and consistently discussed through converging and diverging literature on the subject matter. Moreover, chapter four provides planning implications of the results obtained in the study.

Lastly, chapter five presents the conclusion and recommendations of the study with resilience-based strategies and approaches to enhance and balance the provision of ecosystem service from urban street trees.

Chapter 2: LITERATURE REVIEW

This part of the study is founded on relevant literature to highlight important aspects of the study's subject matter. The key terms and conceptual premises under the principal theme of street trees and ES provision, as well as the notion of using the ecosystem cascade model as a framework, are discussed in the first section of the literature review. As part of the theoretical review, ecosystem services, and disservices from urban street trees, ecosystem service supply and demand, the relationship between street tree planting, long-term ecosystem service provision and resilience, along with the resilience principles and their relevant links between socio-ecological systems is reviewed. Besides, developmental plans, strategies, and standards related to street tree development and management are discussed. Finally, a summary of the whole chapter concludes the literature review.

2.1 Definition of terms and concepts

2.1.1 Definition of Terms

Ecosystem Services (ES): are defined as "the benefits people obtain from ecosystems" (MEA, 2005). They are classified into four categories, provisioning, regulating, cultural, and supporting.

Provisional ES: these are the products obtained from ecosystems, including food and fiber, fuel, freshwater, ornamental resources, and biochemical and natural resources.

Regulating ES: the benefits obtained from the regulation of ecosystem processes, including air quality maintenance, climate regulation, water regulation, erosion control, water purification, and waste treatment.

Cultural ES: the nonmaterial benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences.

Supporting ES: are those that are necessary for the production of all other ecosystem services. For example; soil formation, nutrient cycling, and habitat provision.

Urban Ecosystem Services: these are services and benefits provided by urban ecosystems, in which urban ecosystems are often portrayed as embedding both the built infrastructure and the ecological infrastructure (Elmqvist, Fragkias et al., 2013).

ES Disservice: ecosystem-generated functions, behaviors, and characteristics that have adverse impacts on people's quality of life, either actually or as perceived by street users (Shackleton et al., 2016).

ES Supply: is the total amount of ES that may be obtained in a given area (Marjan van den Belt, 2016), as well as the capacity of an ecosystem's ecological processes or biophysical components to generate ES (Martínez-Harms and Balvanera, 2012).

ES Demand: is the sum of all ecosystem goods and services currently consumed or utilized in a particular area over a given time (Wolff et al., 2015).

Resilience: Regarding the environment, resilience thinking has become a lens of inquiry that provides a forum for multidisciplinary discussion and cooperation. “Resilience is about cultivating the capacity to sustain development in the face of expected and surprising change and diverse pathways of development and potential thresholds between them” (Folke, 2016). In this study, the term resilience is applied under consideration of stresses faced by urban street trees from urbanization.

Socio-Ecological Systems: Socioecological systems emphasize the integrated idea of the "humans-in-nature" approach and are systems where social, economic, ecological, cultural, political, technical, and other components are intimately intertwined. Across geographical and temporal dimensions, socioecological systems (SESs) are quite integrated and coevolving, with the ecological component supplying vital services to society such as the provision of food, fiber, energy, and drinking water.

2.1.2 Conceptual Premise

Ecosystem Service Assessment, Supply and Demand

Ecosystem services assessments are important tools that highlight benefits and trade-offs between different options, ideally by integrating biophysical and socioeconomic methods (MEA, 2005). When considering ES, the current level of service provision may not be an accurate reflection of the level at which the service can be sustained over the long term (Paetzold et al., 2010), and its value is dependent on specific management context (land use, population density, local climate).

According to Marjan van den Belt (2016), supply and demand are dynamically interconnected and a "gap" between them suggests either scarcity or abundance, affecting also any value attributed to ES.

Conceptually, the **Ecosystem Cascade Model** (Andersson-Sköld et al., 2018) tries to describe the supply side by relating the biophysical domain with function or performance of the ecosystem to provide services. Whereas the demand side is represented with the societal domain and it's highly associated with how they value the service being provided and the actual benefit lured from the ecosystem. The balanced point of ES provision, on the other hand, is placed at the middle of these two domains, indicating little or no gap between supply of and demand for ES.

Buffam et al., (2022) also reported that the Cascade model of ES provision to be a useful framework for identifying city-specific resources and barriers around ES provision. Ecosystem Service Cascade model representing the natural ES supply side (green box) and the societal ES demand side (pink box), along with the governance framework of ES assessment is presented in Figure 2.1 below.

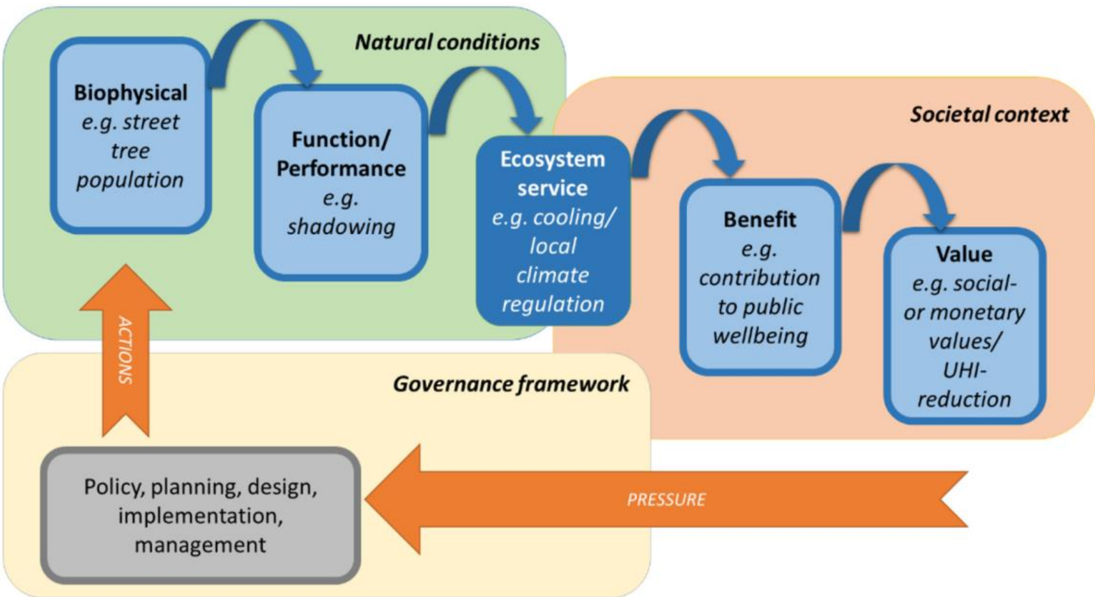


Figure 2.1 Ecosystem Service Cascade Model (Conceptual framework of the study)

Source: Buffam et al., (2022)

2.2 Theoretical Review

2.2.1 Ecosystem Services from Urban Street Trees

Street trees in cities are an important part of the urban environment and offer a variety of ecosystem services. Nowadays, understanding the ecosystem services that urban street trees offer has attracted more attention. This section lists and describes the ecosystem services urban street trees provide in four categories: regulating, provisional, cultural, and supporting ecosystem services.

A. Regulating Ecosystem Services

Local climate regulation: It is well known that asphalt and concrete parking lots and roadways raise the temperature of cities by 3 to 7 degrees compared to green and permeable surfaces. The cost of energy for customers and homes is considerably impacted by these temperature rises. A properly shaded area, mostly from urban street trees, may lower a household's energy costs by 15% to 35% (Burden, 2006).

By evapotranspiration, providing shade, and reflecting sunlight, trees can reduce air temperature. By combining transpiration with the evaporation of water from the soil and other surfaces, the process of evapotranspiration absorbs heat energy from solar radiation and cools the air around it. Trees reflect sunlight and offer shade. As a result, shaded structures and other man-made surfaces absorb and store less energy, which reduces their ability to release heat at night. Since trees and green areas tend to be lighter in color than built surfaces, they also absorb and store less energy than built surfaces (Coutts et al., 2016; Monteiro et al., 2019).

Air quality regulation: Reduced air quality in cities is turning into a major problem for worldwide health. Urban road traffic is the main source of emissions for dangerous particulate matter (Tallis et al., 2011). Urban tree stands modify the city's climatic characteristics and air quality by the sequestration of carbon dioxide and the removal of various air pollutants (Chang Zhao, Heather A. Sander, 2015; Kiss et al., 2015).

Vailshery et al., (2013) found that road segments with tree cover have lower ambient air temperature, road surface temperature humidity, and air pollution. In urbanized areas with significant public traffic, such as streets and market places, where most trees have actually been cut down rather than grown in recent years, street tree planting can have a bigger influence on microclimatic improvement and air pollution reduction.

Stormwater management: Urbanization has a substantial impact on an area's hydrology because it decreases the quantity of water that penetrates into the soil and accelerates surface runoff, elevating peak discharge rates. Engineers typically expand the number and size of sewage and drainage channels to address these phenomena. Trees, on the other hand, use rainwater absorption to speed up infiltration and slow down surface runoff (Berland et al., 2017).

Through their leaf system, trees absorb the first 30% of the majority of precipitation, enabling evaporation to return to the atmosphere. Never does this moisture reach the ground. Up to 30% of precipitation is also absorbed back into the ground, taken up by the root system, kept there, absorbed, and then transpired back into the atmosphere. Additionally, some of this water naturally seeps into the aquifer and groundwater (Burden, 2006).

Particularly in urban areas, “Surfaces such as asphalt respond quickly to rainfall and can shed 90% of received rainfall to drain pushing the limits of drainage systems in heavy rainfall events. Many studies have shown that significant amounts of rainwater can be held and evaporated from tree canopies, reducing and delaying the response of an area to rainfall events. However, the gross interception rate varies greatly with species, tree size, planting density and previous canopy wetness, resulting in a large spread of gross interception values” (Armson et al., 2013).

B. Cultural Ecosystem Services

Aesthetic Value and Recreation: Urban street trees have the potential to make the environment more green and beautiful, increasing the aesthetic quality of the street and overall corridor. Trees create more pleasant walking environments, bringing about increased walking, talking, pride, care of the place, association, and therefore actual ownership of homes, blocks, neighborhoods plazas, businesses, and other civic spaces (Burden, 2006).

Reduced and more appropriate urban traffic speeds: Urban street trees create vertical walls framing streets, and a defined edge, helping motorists guide their movement and assess their speed (leading to overall speed reductions). Street safety comparisons show a reduction of run-off-the-road crashes and overall crash severity when street tree sections are compared with equivalent treeless streets (Burden, 2006).

Human health (Reduced blood pressure, improved overall emotional and psychological health): Small-scale spatial maintenance of urban tree populations appears to have a major impact on human health. Exposure to urban street trees has been associated with improved respiratory health outcomes, such as decreased incidence of asthma and other respiratory disorders, as well as improved mental health outcomes, such as decreased stress, anxiety, and depression (Kardan et al., 2015).

Even in congested cities with little room to grow urban forests, the health benefits of trees may be a very essential element of the advantages of urban forests. This is due to the strong possibility that exposure to urban forests, parks, and minor plants may improve people's health (Pataki et al., 2021).

Improved business: Businesses on treescape streets show 20% higher income streams, which is often the essential competitive edge needed for main street store success, versus competition from plaza discount store prices (Burden, 2006).

Reduced Infrastructure cost: the shade provided by urban street trees can extend the lifespan of expensive asphalt by 40–60% (Burden, 2006). This factor is based on the asphalt's decreased daily heating and cooling, or expansion and contraction. Roadway overlays will represent a substantial cost saving for sustaining a more economical road infrastructure as peak oil prices rise. In addition, when the risk of flooding in urban areas and stormwater runoff is reduced, so is the expense of building stormwater infrastructure.

C. Provisioning Ecosystem Services

Edible fruit provision: despite having a conflicting street user perception towards having edible trees in urban streets, urban forests provide food for people (Colinas et al., 2019).

D. Supporting Ecosystem Services

Biodiversity: urban street trees can be a home for wildlife, where they can contribute to increased biodiversity by serving as important habitats for birds and other animals (Sandström et al., 2006).

2.2.2 Ecosystem Disservices from Urban Street Trees

In the development of their functions, if not managed in an adequate and integrated way, urban street trees sometimes can negatively affect the quality of the environment or the life of urban residents, producing some of the so-called ecosystem disservices (Lyytimäki and Sipilä, 2009).

Lack of attention to these ecosystem disservices (e.g. aesthetic issues, the likelihood of tree failure, the risk to human safety, health issues like respiratory problem due to allergy, and infrastructure damage from root growth (Drew-Smythe et al., 2023b; Masini et al., 2023)) may seriously hamper environmental management in general and urban green management in particular.

A balanced and comprehensive assessment of ecosystem services and disservices provided by urban street trees is needed for green development and management (Lyytimäki, 2017). Moreover, Roman et al., (2021) suggest that researchers who study urban trees should think about looking into qualitative studies of ecosystem disservices as experienced by professionals, street users, and other stakeholders. Therefore, Table 2.1 below shows examples of ecosystem disservices from street trees.

Table 2-1 Examples of ecosystem disservices from urban trees

Type of Disservices	Example
Aesthetic issues	- Trees perceived as ugly - Trees growing in unsuitable places - Indirect effects of tree growth decreasing the aesthetic value of built structures - Trees hosting species producing aesthetic discomfort
Safety and security issues	- Direct physical risks related to trees and tree growth - Safety and security issues related to other natural or semi-natural species - Urban parks as places of fear related to human misconduct
Health issues	- Trees causing direct health effects - Trees producing air pollutants or precursors of air pollutants affecting health - Trees provide habitats for other species causing health effects

Economic issues	- Direct costs caused by planting, maintaining, and removing plant coverage. - Direct costs caused by attempts to remove unwanted species - Indirect costs caused by land use restrictions
Mobility and infrastructure issues	- Urban trees forestalling fast and comfortable transportation and movement, especially the use of motorized transportation or the movement of people with disabilities or elderly people. - Roots causing blockages of sewer pipes, and branches causing electric and other wires to short circuit.
Environmental and Energy issues	- Biogenic volatile organic compounds and secondary aerosol emissions from trees, carbon, and methane emissions from decomposition affecting air quality and climate change. - Displacement of native species and introduction of invasive ones. - Decreased possibilities for utilization of direct sunlight - Energy consumption, resource use, and pollution from maintenance activities.

Source: (Lyytimäki, 2017)

2.2.3 Ecosystem Service Supply and Demand

Street trees provide a range of ES where they act as catalysts of UGI interconnectedness and multifunctionality. With proper planning and implementation, balancing the gap between supply and demand would be easier. Unfortunately, a study by (Adem, 2020; Buffam et al., 2022) highlighted the benefits that street trees bring to improve human wellbeing, while also indicating problems related to space allocation for street greenery in Addis Ababa.

According to Buffam et al., (2022), future researchers should focus on improving the lack of studies on urban green infrastructure (UGI) planning and management for improved ES provisioning. This section highlights the supply, demand, supply, and demand assessment. Unfortunately, there seems to be a limited piece of literature that assesses the supply and demand of ecosystem services from urban street trees in Addis

Hereunder are reviewed the supply and demand of ES from urban street trees and the potential gaps assessed by researchers.

Supply of Ecosystem Services: Addis Ababa's ecosystem service supply from urban street trees (section 2.3.1) is affected by a range of factors that exacerbate the gap between anticipated demand.

Limited Green Coverage: As a result of inadequate tree planting and poor maintenance of existing trees, the recommended standards of green coverage are below standard (Eshetu et al., 2021), indicating a huge factor in the unbalanced supply of ecosystem services from urban green infrastructure components like urban street trees

Species Diversity: Imported species being the new normal, their effectiveness towards adapting to local climatic conditions and provision of full benefits is compromised (Biggs et al., 2012). This indicated the lack of diverse and native tree species furthered the gap between the anticipated demand and provided supply.

Urban Expansion: Unplanned and unmanaged urbanization represents a threat to environmental sustainability, whereas, planned urbanization leads to positive development outcomes and can be leveraged for improved quality of life and overall prosperity (Kasa et al., 2011; Knudsen et al., 2020). In addition, the prioritization of gray infrastructure development aggravated the neglect of street trees in urban areas.

Demand for Ecosystem Services: The demand for the ecosystem services provided by urban street trees is increasing. Given the increasing temperature and urban density, street users tend to look for shaded areas and street trees are the major ones (Buchel and Frantzeskaki, 2015). Moreover, Addis Ababa is the major center and capital of the country, increased population, and vehicular emissions is witnessed over the years. Likewise, the increased demand for air purification services by street trees is heightened. Besides, urban residents increasingly seek green spaces for recreation, placing further demand on the limited green infrastructure (Burden, 2006).

Supply and Demand: Additionally, there is a growing disparity in Addis Ababa between the supply and demand for ecological services. Urban development frequently fails to incorporate green infrastructure, which results in an imbalance between the availability and demand for ecosystem services. Furthermore, the growth and appropriate upkeep of urban street trees are hampered by a lack of technical and financial resources. The mismatch between supply and demand is further exacerbated by poor enforcement of laws pertaining to urban greening and the lack of precise rules for incorporating street trees into urban development.

2.2.4 Street Tree Planting for Enhanced Ecosystem Service Provision

According to Pauleit, (2003) and Monteiro et al., (2019), enabling trees to function at their maximum capacity has to consider the characteristics of tree species and the condition of the planting site throughout the planning process.

Tree species characteristics:

- Canopy size and crown density – a wider canopy and high density of leaves and branches in the crown of the tree will provide more shade.
- Leaf type and color – the ability to reflect solar radiation is normally increased in trees with lighter leaves or leaves with certain characteristics, including hairs or waxy surfaces.
- Evapotranspiration rate – the higher the rate, the more cooling a tree will provide.
- Drought tolerance – higher tolerance to drought ensures that evapotranspiration will occur for longer.

Site conditions:

- Water supply – an adequate water supply is crucial to ensure evapotranspiration and the long-term health and growth of trees and shrubs. Design strategies such as using sustainable drainage systems can help achieve this.
- Ground cover – the use of vegetated groundcover and permeable pavements will allow rainwater to infiltrate the soil.
- Soil quality – techniques such as soil profiling, mulching, and the incorporation of green waste composts will improve the quality and water-holding capacity of soils, improving water retention and accelerate plant establishment and growth.
- Tree planting pits – the pits that are dug when the tree is planted should match species requirements and be proportional to the canopy projection.

- Landscaping – the aim should be to offer a microclimate favorable to plants, which seeks to minimize barriers to growth such as restricted access to light

2.2.5 Long-term Ecosystem Service provision and Ecosystem resilience

Urban street tree and their ES provision take into consideration of stability both from the perspective of balancing ES supply and demand and securing resilient ecosystem. To that end, it is crucial to understand the relationship between resilience and ecosystem service provision. When contemplating the long-term sustainability of all ecosystem services, the extent to which ecosystems are transformed to provide services, coupled with management interventions, becomes critical.

Recent developments have increased the frequency and severity of shocks and stresses, generating serious concerns about species and ecosystems' ability to adapt and survive. Ecosystem resilience is thought to be a product of the diversity of ecosystem functional groups, their species, and diversity within species and populations (Folke et al., 2004). Most ecosystems contain some degree of built-in resilience to environmental disturbances, including the ability to adjust to changes in the environment over time (Falk, 2017). Ecological dynamics and disturbance responses, on the other hand, need a resilience-based paradigm as a necessary development of environmental management in a fast-changing world (Falk and Millar, 2016).

Ecologically, modified ecosystems are often simpler, and as a result, they are less resilient to external influences (drought, fire, overgrazing, disease, and invasive species) than complex ecosystems. Therefore, they face a higher risk of failure to maintain service delivery over time (Walker and Salt, 2006). Conserving remaining biodiversity, enhancing connectivity, and recovering degraded ecosystems are all effective methods for improving long-term resilience and assuring the continued provision of ecosystem services (Department of the Environment, Water, Heritage, and the Arts, 2009).

In order to satisfy present and future societal requirements, it is essential to increase the resilience of ecosystem services (ES), which support human well-being. This requires specific governance and management strategies (Biggs et al., 2012). Besides, the integration of resilience principles into the planning and management of our ecosystems, street trees, can help to enhance ES supply, thereby securing long-term ES provision.

2.2.6 Principles for Building Resilience in socio-ecological systems (SES)

Resilience principles are specific tools that make a city resilient or help policies translate it to practice for better improvement of resilience practice. These principles are applied to evaluate proposed options and plans, again also applied in a wider process of resilience assessment to the urban systems and components. A report by Biggs et al., (2012) provided seven principles for building resilience in social-ecological systems, from which this study focused on five of them described hereafter.

- **Diversity:** Diversity in SES encompasses biodiversity, spatial heterogeneity, livelihood strategies, and institutional diversity (Biggs et al., 2012). On urban streets, population stability depends on species adaptation to the diversity of street side conditions in a community over time, rather than on species diversity. Good age diversity, to provide adequate successful replacements, is essential for population stability (Richards, 1983).
- **Redundancy:** is closely related to diversity and is a system property that describes the replication of particular elements or pathways in a system. Particularly, the spacing of tree plantations can indicate how street trees are arranged along the street repeatedly. Besides, the planting schemes being redundant along other street corridors in a city can show the application of the redundancy principle. Managing diversity and redundancy is necessary to sustain ecosystem service (ES) output over the long run in the face of disturbance and change (Biggs et al., 2012).
- **Connectivity:** to provide resilience to the supply of ecosystem services in response to disturbances, connectivity between social and ecological components might be important. In SES, connectivity often makes it easier to move the energy, materials, or information required for the ecosystem services' resilience. The strength and structure of connection, in particular, may protect ecosystem services from a disturbance by promoting recovery or by limiting the spread of a disturbance locally.
- **Participation / Integration:** The term "participation" refers to the key stakeholders' active involvement in the management and governance process. Participation might range from simple information sharing to full power transfer. It might happen at any or all stages of the management process, from issue identification and goal setting to policy implementation, outcome monitoring, and evaluation (Biggs et al., 2012).

  Transparency, knowledge sharing, trust-building, decision-making legitimacy, and learning may all be supported through the participation or integration of a range of stakeholders, including the public. The ability of a management system to recognize and analyze shocks and disturbances may be improved with the help of these processes, which is essential for enabling the teamwork needed to adapt to change in social-ecological systems (Sharifi and Yamagata, 2018).

- **Adaptive capacity:** is the capacity to develop and put into action effective strategies to respond to changing risks and pressures to minimize the likelihood of occurrence and/or the severity of unfavorable consequences.

  The capacity and depth of a system's coping can both be improved by actions that result in adaptation. The set of resources (natural, financial, institutional, or human) available for adaptation, as well as the capability or capacity of that system to employ those resources successfully in the pursuit of adaptation, constitute the adaptive capacity inherent in a system (Brooks and Adger, 2005).

Table 2-2 Considered resilience principles and their respective parameters towards the socio-ecological system

Resilience principles	Parameters
Diversity	Species diversity
	Age diversity
Redundancy	Repetition and harmonization of street tree plantation on the specified segment
	Functional redundancy (species with the same function)
	Spacing of street tree plantation
Connectivity	Urban street trees with each other along street corridors
	Urban street trees with other GI components of the city
Participation / Integration	Integration among institutions and social groups
	Public participation
Adaptive Capacity	Protective structures against street user pressure
	Less water-demanding, pest-resistant, and fast growth rate species selection
	Provision of adequate maintenance
	Wider planting pits that consider street tiles

Source: collected from (Biggs et al., 2012; Richards, 1983; Folke et al., 2004; (Brooks and Adger, 2005; Sharifi and Yamagata, 2018)

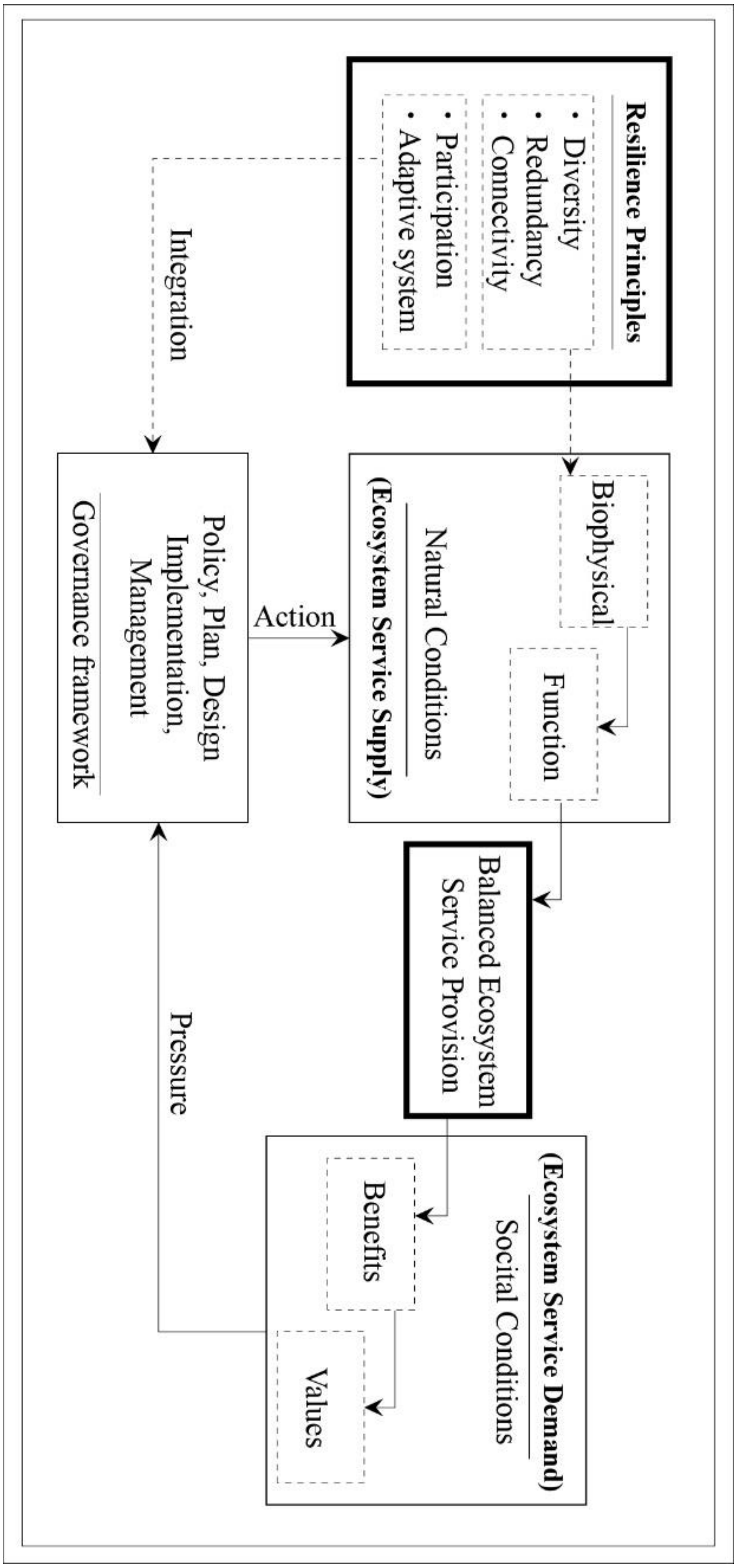


Figure 2.2 Modified conceptual framework of the study

Source: (Own modification, 2022)

2.2.7 Review of national and local development strategies and plans

The research's underlying issue, the development and management of street trees, is crucial to the urban environment. To establish a portion of the essential theoretical framework for the research, this section reviews a number of legal and technical documents of Ethiopia in general and those of Addis Ababa in particular. This review also includes pertinent technical standards that provide precise technical advice and direction for the development of street greenery.

Climate Change Resilient Urban Green Development Strategy

The Ethiopian Ministry of Urban Development, Housing and Construction (MUDHC) developed the Climate Change Resilient Green Development Strategy, which was published in 2014. The strategy identifies the absence of green development standards as the primary obstacle to the implementation of urban green infrastructure. The quick development of such a national standard to provide practical direction and a legal framework for the implementation of UGI in Ethiopia's metropolitan centers was suggested as a solution to this problem. This is the first strategic and practical step to be taken by the Ethiopian government to the later preparation of the National Urban Green Infrastructure Standard (NUGIS).

The strategy defined 17 elements of urban green infrastructure, from which, 'Road dividers, Roadsides, and Roundabouts' is one of the 17 UGI components that is most related to the topic of this study. In this section of the strategy, a basic overview of advances in roadside vegetation is provided; beginning with the problem of global warming that has drawn attention to street vegetation. Street tree development and management is no longer planted primarily for aesthetic purposes; instead, it is a necessary component of urban growth.

The strategy concludes by noting that, despite the significant and varied benefits of street greenery, selection, planting, and maintenance of street greenery are not routinely carried out in Ethiopian cities.

Structure Plan of Addis Ababa

Addis Ababa's Plan and Development Commission prepared the structure plan of Addis Ababa in 2017. Environment is one of the major components of the Structure Plan which comprises green infrastructure and defined the term as a physical green environment within Addis Ababa city proper. It is a network of multifunctional open spaces, including formal parks, gardens, woodlands, green corridors, waterways, street plantations, and open courtyards.

As per the long-term vision of Ethiopia for growth and transformation, the Structure Plan for environmental protection and development contributes to the livability of Addis Ababa by ensuring a clean environment; providing adequate, accessible, networked, and functional green spaces; ensuring sustainable natural resource utilization and management; and reducing exposure to natural disasters (AACPDC, 2017).

Among these goals, bringing networked multifunctional green spaces that could contribute to environmental protection, economic development, and social equity will result in increased per capita accessible green space, and increased total coverage of green areas providing multiple ecosystem services. In particular, the structure plan report states: that all pedestrian walkways should be planted with shade trees; road medians should be planted with shade-providing plants; street corridors should be planted with ornamental and shade-providing plants.

2.3 Summary of Literature Reviews

Urban street trees are an important part of the urban environment and offer a variety of ecosystem services ranging from regulating (air quality, local temperature, stormwater), cultural (aesthetics, recreation, health, economic), supporting biodiversity, or provision of edible fruits. Unfortunately, in the development of their functions, if not managed in an adequate and integrated way, urban street trees sometimes can also negatively affect the aesthetic, safety and security, health, economy, mobility and infrastructure, and environmental quality of the life of urban residents.

Hence, urban street trees and their ES provision should take into consideration of stability both from the perspective of balancing ES supply and demand and securing a resilient ecosystem. When contemplating the long-term sustainability of all ecosystem services, the extent to which ecosystems are transformed to provide services, coupled with particular management interventions, becomes critical. In that sense; diversity and redundancy, connectivity, participation and integration, and adaptive capacity are among the resilience principles this study has mainstreamed in the planning and management assessment of urban street trees.

Chapter 3: RESEARCH METHODS AND MATERIALS

The methodology section of this scientific research provides the methods and techniques for approaching the research, allowing readers to understand it and evaluate its reliability and validity. The description of the site with a detailed selection criteria highlights the research area's particular spatial scope. The research design, data types and sources, sampling design, data collection, analysis, and presentation methods are also presented to introduce the study's methods and materials.

3.1 Description of the Study Area

3.1.1 Spatial Location of the study area

Addis Ababa, Ethiopia's capital and diplomatic center of Africa, had a population of 2,112,737 in 1994 (Tigabu and Semu, 2008), and the World Population review (2022) estimates that it now has a population of 5.22 million. Spanning over 54,000 hectares, Addis Ababa is located at the heart of Ethiopia, between 8^{o} 51' 0'' and 9^{o} 6' 0'' N and 38^{o} 39' 0'' and 38^{o} 54' 0'' E. The city's dominance over other Ethiopian cities may be shown in terms of politics, market, population, service, and infrastructure.

Addis Ababa is an exemplar of Ethiopia's fast urbanization and transformation, in which, its expansion is characterized by inefficient resource management. Particularly, with the expense of urban forestry and related natural resources (AACPDC, 2017). The current structure plan of Addis Ababa considers the delineation of main city center along Churchill corridor depending on the level of activity, development potential, and current development trends. In terms of land use zoning, the rind road is used to delineate the intermediate zone, which is mainly made up of high and mixed-density housing. Extending to the city boundary is the peripheral zone dominated by low density mixed-density housing.

Urban streets are found to be distributed over the spatial extent of the city with more density on the intermediate and inner city zones rather than the periphery. To make the site selection more representative of the whole city, this study focuses on main urban street trees, eight different street corridors distributed over the spatial extent of Addis Ababa, on which the site selection made use of a range of criteria listed below.

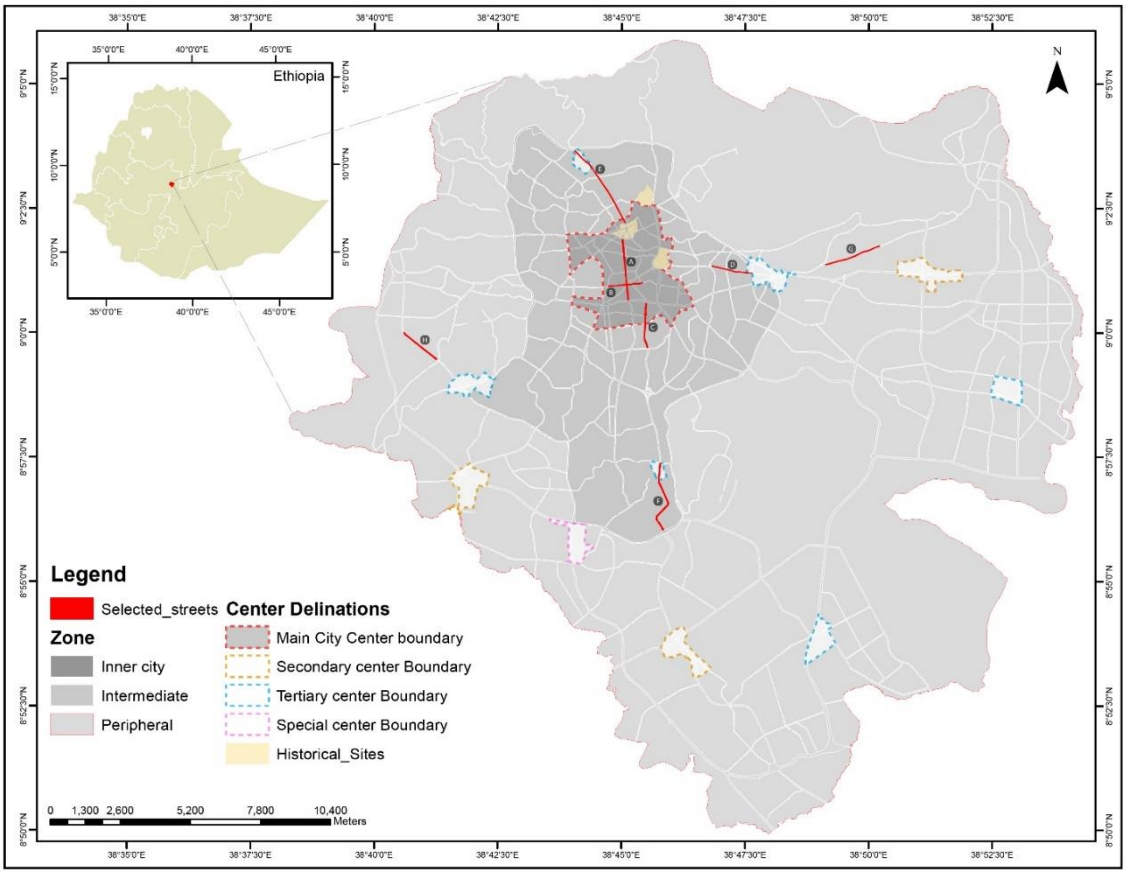


Figure 3.1 Location map of the study area

Source: Adopted from (AACPDC, 2017)

3.1.2 Site selection criteria used on this study

- **Street hierarchy**: Considering the street hierarchy proposed by the (AACPDC, 2017), streets in Addis Ababa are classified into four categories;
  - Principal Arterial Streets (PAS) are large, generally interconnecting roads that handle heavy traffic and long-distance transit.
  - Sub Arterial Streets (SAS): roads that link the smaller regions of a city by distributing traffic from key arterials to minor streets.
  - Collector Streets (CS) are routes that combine traffic from neighborhood roads with arterial traffic, so achieving a balance between accessibility and flow of traffic.
  - Local Streets (LS) are neighborhood roads with low traffic volumes that offer direct access to homes and businesses.

Considering the availability of street trees and the practice of planning and managing urban street trees in Addis Ababa, this study only selects main streets, PAS, and SAS hierarchy.

- **Availability of street trees**: the number of trees on that specific street corridor can determine the total tree population, which is used on the first objective, thereby affecting the selection of a representative sample. Hence, the availability of street trees is also used as one of the site selection criteria.
- **Zoning and type of surrounding land use**: According to the structure plan of Addis Ababa, the city is classified into three zones (Inner city or Main city center, Intermediate zone, and Periphery zone) comprised of a range of land uses including residential, commercial, mixed, green and open space, industrial, service and alike. The use and function of a land can shape the type of activities, type of street users and associated provision of services, including ecosystem service from nature. Thus, having these land uses as a selection criteria was founded to be crucial.
- **Spatial Distribution**: taking into consideration of level of activity and potential for future development, the structure plan of Addis Ababa delineated main, secondary, tertiary, special, and woreda level city centers. Since these centers are distributed across the spatial boundary of the city, the street corridor selection considers streets radiating from or within the close distance of primary, secondary, and tertiary city centers.
- **Level of activity and traffic flow**: As the study is focusing on urban street trees, the level of activity and traffic flow on a street corridor can dictate the way street users interact with the environment and street trees, which is useful while assessing the development and management challenges of street trees.

Based on the above criteria; street corridors from Legahare to Piassa (Churchil Road), Sengatera/Goma kuteba to Filweha, Meskel Square to Lancha, Megenagna to Signal / Waryt square, Piassa Giorgis to Addisu gebeya, Saris Adeyabeba to Kality Maseltegna, Lamberet to Wesen, and Ayertena Kidanemihret to Alembank have been selected.

3.1.3 Description of selected street corridors

i. **A street corridor from Legahare to Piassa (Churchill Road)**

The first case study area involves a 50-meter-wide PAS segment with a length of 2.3km located at the Main City Center (Inner city of Addis Ababa). This particular street corridor is an exemplary one with modified and newly constructed green spaces, street trees, bike lanes, parking spaces, and wider spaces for other street-side public activities. Commercial and administrative buildings and parcels dominate the surrounding area. Four different green strips (part of the road dedicated for street tree planting) of urban street trees are planted: two on the right side of the street, one on the left, and one in the median. It's the most active street with plenty of street user on it day and night.

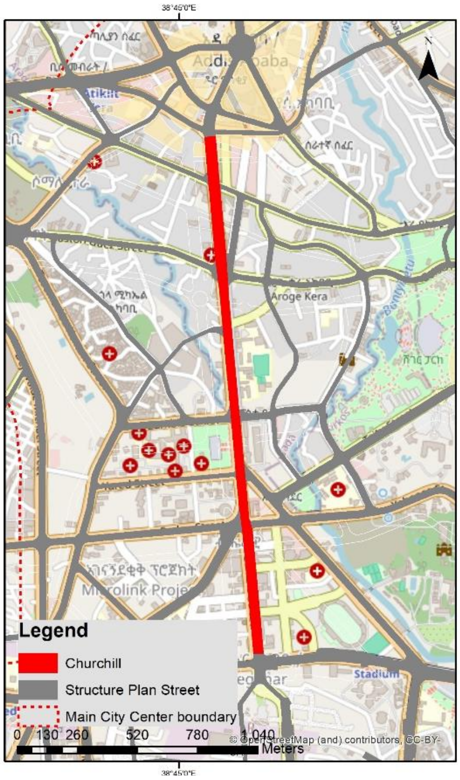


Figure 3.2 street corridor from Legahare to Piassa (Churchil Road)
Source: Adopted from (AACPDC, 2017; Open Street Map)

ii. **A street corridor from Sengatera/Goma Kuteba to Filweha**

The second case study area involves a 30-meter-wide SAS segment with a length of 1.4 km located at the Main City Center (Inner city of Addis Ababa). The site is characterized by lower traffic flow (both vehicular and pedestrian), and the domination of administrative and service land uses. As for the availability of street trees, there is smaller number of trees on both sides of the street, while the median is densely populated with large urban street trees.

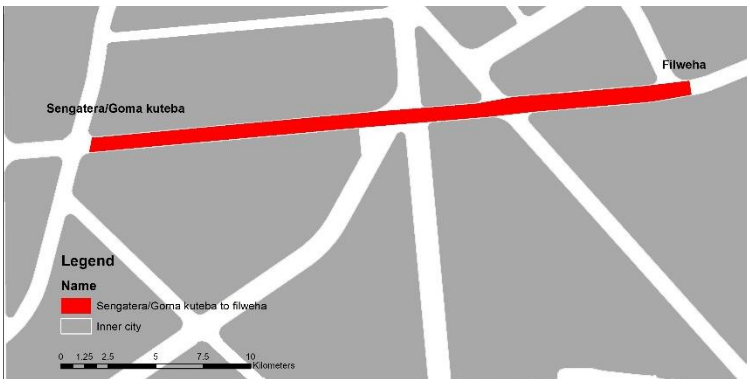


Figure 3.3 Street corridor from Sengatera/Goma kuteba to Filweha

Source: Adopted from (AACPDC, 2017)

iii. A street corridor from Meskel Square to Lancha

The third case study area involves a 40-meter-wide PAS segment with a length of 1.74 km stretching from the inner city to the intermediate zone. The site is characterized by the domination of mixed commercial land uses with high level of activity. Street trees with relatively higher abundance exist on both sides of the street corridor and the median is occupied by the light rail transit (LRT).

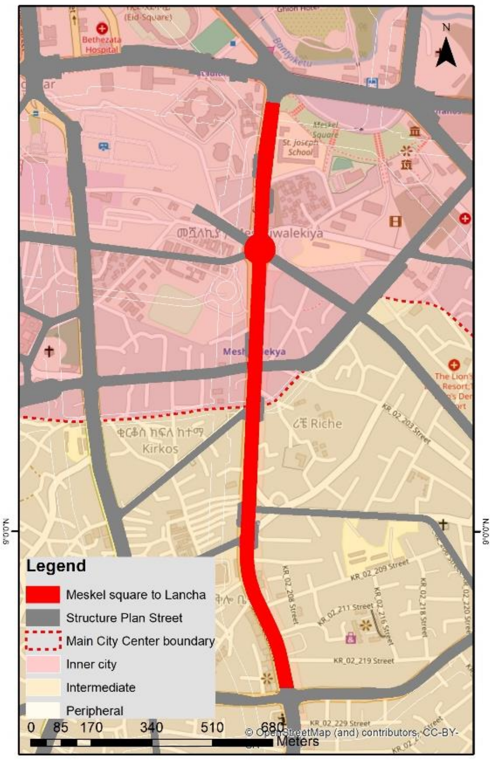


Figure 3.4 Street corridor from Meskel square to Lancha

Source: Adopted from (AACPDC, 2017; Open Street Map)

iv. A Street corridor from Megenagna to Signal / Waryt square

The fourth case study area involves a 25-meter wide and 2.25 km long SAS segment characterized by mixed commerce, service, and pure residential land use domination. Being located on the intermediate zone, the street is highly active in the daytime with vehicular movement, while a medium level of activity and pedestrian movement is seen during the field observation. Moreover, the site has a higher availability of street trees on both sides of the street near Signal condominium, while a relatively medium number of street trees are available on the rest sections of the street corridor.

Figure 3.5 Street corridor from Megenagna to Signal / Waryt square

Source: Adopted from (AACPDC, 2017; Open Street Map)

v. A Street corridor from Piassa Giorgis to Addisu Gebeya

The fifth case study area involves a 30-meter wide and 3.32 km long PAS segment in the intermediate zone, characterized by mixed commerce and pure residential land use domination. Having the locational advantage of being situated in the highland areas of Addis Ababa, the site has regulated air temperature and the existence of Sheger Park plays its role in that matter. Moreover, the site is highly active and it has a relatively higher availability of street trees with species diversity.

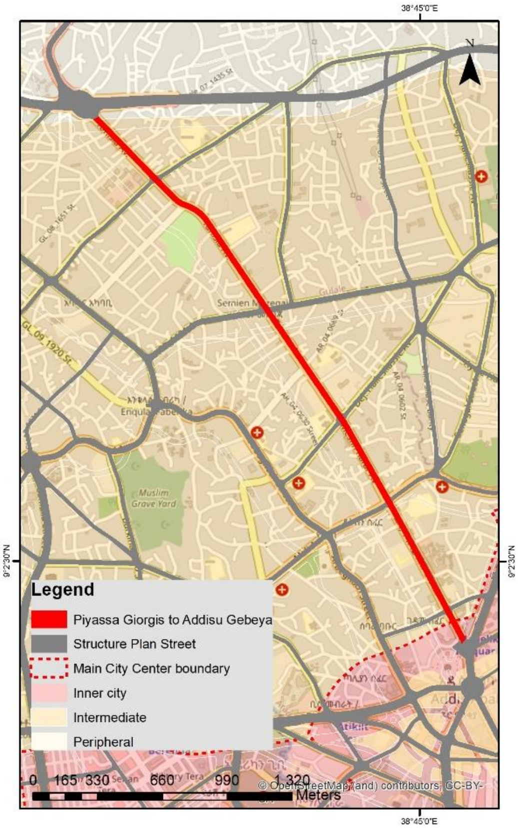


Figure 3.6 Street corridor from Piassa Giorgis to Addisu Gebeya

Source: Adopted from (AACPDC, 2017; Open Street Map)

vi. A Street corridor from Saris AdeyAbeba to Kality Maseltegna

The sixth case study area involves a 30-meter wide and 2.8 km long PAS segment situated on the intermediate zone, the southern parts of Addis Ababa. Manufacturing land use dominates the site. Moreover, commercial activity is high around Saris and there is high level of vehicular and pedestrian movement. According to the 2017 structural plan of AA, the site is proposed to be tertiary zone.

Figure 3.7 Street corridor from Saris AdeyAbeba to Kality Maseltegna

Source: Adopted from (AACPDC, 2017; Open Street Map)

vii. A Street corridor from Lamberet to Wesen

The seventh case study area involves a 30-meter wide and 2.27 km long SAS segment in the periphery zone, located 1 km away from Megenagna tertiary center and CMC secondary center. It is characterized by pure residential land use on the left side, while the right side is dominated administration, service, and manufacturing. Both sides of the street are rich in urban trees, and there is a medium level of vehicular and pedestrian movement.

Figure 3.8 Street corridor from Lamberet to Wesen

Source: Adopted from (AACPDC, 2017; Open Street Map)

viii. A Street corridor from Ayertena Kidanemihret to Alembank

The last and eights case study area involves a 35-meter wide and 1.6 km long PAS segment located 900 meters far from the newly proposed secondary center at Ayertena. Being in the peripheral zone of A.A, pure residential land use dominated the surrounding area. Both sides of street are rich in street trees.

Figure 3.9 Street corridor from Ayertena Kidanemihret to Alembank
Source: Adopted from (AACPDC, 2017; Open Street Map)

Table 3-1 Summarized characteristics of selected street corridors

Selected street corridors	Hierarchy	Width (m)	Length (Km)	Zoning	Dominating land use
Churchill	PAS	50	2.3	Inner City	Commercial and Administrative
Sengatera/Goma kuteba to filweha	SAS	30	1.4	Inner city	Administration and Service
Meskel square to Lancha	PAS	40	1.74	Inner city/ Intermediate	Mixed Commerce
Megenagna to Signal	SAS	25	2.25	Intermediate	Mixed Commerce, Service, and Residence
Piassa Giorgis to Addisu gebeya	PAS	30	3.32	Intermediate	Mixed Commerce and Pure residence
Saris Adeyabeba to Kality Maseltegna	PAS	40	2.8	Intermediate	Manufacturing and Industry
Lamberet to Wesen	SAS	30	2.27	Periphery	Pure residence, Manufacturing, and Service
Ayertena Kidanemihret to Alembank	PAS	35	1.6	Periphery	Pure residence,

Source: (AACPDC, 2017), Google earth pro, (2022)

3.2 Research Design

This is descriptive and exploratory research that examines the existing situation of the site and proposes a solution using a combination of quantitative and qualitative approaches.

- **The Descriptive Design** is used to explain the current state of a situation. Hence, this method is used to characterize the current spatial state of planned street trees.
- **The Exploratory Design** is used to identify tree species along the selected street corridors, and determine what services are being supplied by the urban street trees and what ES is demanded by the street users. Additionally, this method helps to identify what challenges do the urban street trees faces in terms of resisting natural and human-induced problems.

3.3 Data Types

Primary data: identification of tree species, planting situation, surrounding land uses, disservices, and developmental and management challenges are performed using primary data from the site (Both from the trees and people).

Furthermore, ES being supplied along with the current and future demand are collected from a range of street users and experts on the subject matter.

Secondary data: the ecosystem service assessment of urban street trees involved using secondary data from previously organized workshops on challenge identification and prioritization of highly demanded ecosystem services. Professors and researchers from Addis Ababa University (EiABC) and Swedish University of Agricultural Science (SLU) organized the workshop in 2022 in Addis Ababa, Ethiopia. Stakeholders from the local municipalities' different administrational units (e.g. urban planning, green space management), regional experts, and representatives from relevant academic institutions were incorporated to represent different perspectives on urban street trees.

3.4 Sources of Data

Both primary and secondary data were collected from different sources. As for the primary data, the site itself is a source for data collection. Data is also collected from street users on the selected street corridors. On the other hand, secondary data; pieces of literature that are relevant to the study are referred from governmental offices and the internet. This includes reports performed for the planning and management of street trees in the city, other published and unpublished articles, magazines, and related documents.

The resilience assessment of urban street trees diversity and redundancy, connectivity, participation and integration, and adaptive capacity is performed with primary data from the street corridors (street tree species types and number of trees planted per species, spacing of tree plantation, and street users participation activities). On special cases, identification of scientific names, family and species are supported by using information gathered from experts and the internet. The assessment also considers functional redundancy where tree species with similar function exist.

To assess the current supply of ES from urban street trees, primary data (ES supply perception) from both the users and experts were collected. Experts from a range of organizations involved on the subject matter (Addis Ababa City Administration Urban Beautification and Green Development Bureau) were interviewed. Users of street trees on specific case study areas were also other sources for ES supply assessment.

Regarding data about the identification of ES demand, secondary data (highly prioritized/demanded ecosystem services from urban street trees) is collected from researchers who participated in a workshop on challenge identification and prioritization of highly demanded ecosystem services in Addis Ababa, organized by professors and researchers from Addis Ababa University (EiABC) and the Swedish University of Agricultural Sciences (SLU). Later on, users of street trees on specific case study areas were the major sources for ES demand assessment.

To assess Ecosystem Disservices and challenges of street tree development and management, socio-spatial challenges, Ecosystem disservices, and adaptation mechanisms were collected from the street corridors. Additionally, street users on the site, and experts from responsible bodies for the planning and management of street trees were contacted as sources of data.

3.5 Sampling Design

Being cautious when taking a sample, and generating in-depth information from the perceptions of street users and experts required the incorporation of a range of sampling techniques. The sampling design section presents how the total population is defined, and the selection of representative samples.

3.5.1 Defining the Population

The tree population for this study is site-specific. The total population is defined by counting the number of trees found on both sides of the selected street corridors, and when median trees are available, the median as well. As for the number of street users in Addis Ababa, the total population is unknown. Hence, a mathematical formula (described on section 3.6.2) is used to select samples.

Regarding expert population, the number of professionals with the required qualification, working on the selected organizations, were defined to be the total population. Experts in the public institutions that are in charge of developing and overseeing UGI, notably urban street trees in Addis Ababa are considered. Moreover, this study takes additional respondents responsible for street design and construction, as well as policy and strategy devising institutes.

i. Addis Ababa City Administration Urban Beautification and Green Development Bureau (AACAUBGDB)
ii. The Addis Ababa City Planning and Development Commission (AAPDC), a regulatory body
iii. Addis Ababa City Road Authority (AACRA)
iv. Ethiopian Forest Development Institute (EFDI)
v. FDRE Policy Studies Institute (PSI)

3.5.2 Selecting Representative Sample

Sampling respondents for Expert population

Experts from the aforementioned institutions were chosen using **purposive or judgmental sampling, a non-probability sampling method**. The selection of experts takes into consideration of their profession and position on that organization.

Sampling for Street user Population

In addition, **cluster random sampling from the probability sampling technique** was utilized to choose a group of people who were determined to be the users of street trees. Clustering of street users were dependent upon their interaction with the streets (**pedestrians, street vendors, car users, and street fronts).**

The number of samples size was specified following a review of published literature and statistical methods (Bartlett et al., 2001; Tehrani et al., 2015; Uakarn et al., 2021). Sample size determination by calculation formula of Krejcie and Morgan, (1970) stated eq.(1), when the population size and the population proportion is unknown.

$$\text{(1)} \qquad n = \frac{z^2}{4e^2}$$

Where n = sample size, z = value for specific confidence/reliability level, and e = accepted error margin. In this study, 95% confidence interval is considered, which brings us to the z value of 1.96, and the error margin of 5% (0.05).

$$n = \frac{(1.96)^2}{4(0.05)^2} = \mathbf{384.16}$$

Using the aforementioned confidence and marginal error values, a minimum sample size of 384 was determined to be necessary. To provide more accurate findings, Bartlett et al., (2001) recommended adjusting the sample size calculation to the projected response rate from prior research (e.g., 81% in Addis Ababa, (Buffam et al., 2022)). As a result, eq. (2) is used to estimate a total street user sample size of 474 to be picked from selected street corridors.

(2) N = sample size/response rate

N = 384/0.81 **= 474 (where N is the adjusted sample size)**

Sampling for Tree population

As for the tree population, **using line sampling of systemic sampling**, approximately 10% of street trees on each street corridor were sampled by picking 1 (one) tree among 10 (ten) trees for observational assessment of ES disservices and challenges. The selection of street trees considered the species types, and species diversity assessment was performed by counting every street tree planted per the identified species type on each sides of the selected street corridors.

3.6 Method of Data Collection

The resilience assessment, along with the ES disservices and challenges of developing and managing urban street trees involves field observation and physical survey methods to collect data regarding the current status of street trees, while structured questionnaire surveys were used to collect data from street users.

- **Field Observation**: this method was used at the earlier stage of the study which involved going to the actual study area and identifying tree species, observing the current status of street trees along with the major challenges encountered onsite. Moreover, the site’s existing situation was captured by photographs.
- **Physical Survey**: physical surveys were basically performed for actions that involve the spatial aspects of the study area; measuring planting spacing distance, and exploring the connectivity of street trees with surrounding UGI elements. The site’s guide map, Arial pictures, and environmental checklists (Annex III) accompany the circulation pattern on the site.

The assessment of ES supply and demand from urban street trees, on the other hand, involved extensive data collection from both experts and users of street trees. The method made use of key informant interviews and structured questionnaire surveys. Obtained information from the site were supplemented by secondary data from the workshop that ranked and prioritized a wide range of ES based on the method used by Buchel and Frantzeskaki, (2015) for assessing the future ecosystem service demands.

During the data collection, a sample size of 417 street user respondents were surveyed, while 19 experts were interviewed from a range of institutions. In this study, identification of the perceptions of street users and experts towards current and future demand of ES from urban street trees was performed using **Likert Scale**.

On a scale of one (1) to five (5), with one denoting the least perceived or demanded ES and five denoting the most perceived or demanded ES, each street users were tasked to complete a survey questionnaire regarding their perceptions of ecosystem service supply and demand. With a range of 0.8 mean value from a total value of 5, each ES list was described to highlight the level of ES supplied and demanded in Addis Ababa.

- **Key Informant Interview**: city experts in planning and design sectors were identified as a key informant, and collection of relevant information regarding the ES being supplied by street trees and current planning and governance challenges were performed using guiding interview questionnaire (Annex II).

  Given the multidisciplinary character of the study, collecting the opinions of experts from a range of educational and professional qualification was necessary. In the process, 5 environmentalists working as green development experts, 8 urban planners and architects working as a spatial plan-making and implementation experts and landscape designers, 2 civil engineers, 1 project manager on the task of monitoring and evaluation of projects, and 3 researchers were interviewed (*Table 3-2*).

Table 3-2 Experts mixes of key informants interviewed

No.	Qualification	Position of the expert	Number of respondents
1	Environmentalists	Green Development Experts	5
2	Urban Planners and Designers	Spatial plan making officers, Landscape Designers	8
3	Civil Engineer	Civil Engineers	2
4	Project Manager	Project Monitoring and Evaluation	1
5	Urban Study Researchers	Research officers	3
		Total	19

Source: (Own computation, 2023)

- **Structured Questionnaires**: after specifying specific benefits provided from each ES category, questionnaires were developed in Kobo Toolbox and distributed to street users to identify the level of demand for prioritized ES from urban street trees. The questionnaire survey used guiding documents with a list of organized and structured questions. The questions incorporated general information about the street users, their interaction with the street, and their perception of ES supply and demand from urban street trees. The questionnaires were filled by selected street user samples along the street.

3.7 Method of Data Analysis

Using the cascade model (Andersson-Sköld et al., 2018) as a framework, this research tried to fill the gap between the demand and supply sides, while also identifying challenges that hinder the optimal provision of ES from urban street trees. Hence, it follows a mix of qualitative and quantitative data analysis. Statistical analytic software like IBM SPSS 27, Microsoft Power BI desktop, and Microsoft Excel 2016 are used to manage and analyze collected field data regarding street user's and expert's profiles, their perception towards the current practice of street tree development, perceived supply and future demands, and the challenges of and from urban street trees.

Thematic analysis Data collected both from key informant interviews with experts, and street user data were categorized by theme and the narration is performed accordingly**. Correlation analysis** was also performed to highlight the relationship between respondents' profiles and obtained data.

Descriptive method: is used to address the existing situational assessment of street trees through field visits and physical surveys. The number of trees and their respective species type, their planting location and spacing, and further information were described quantitatively.

Structured questionnaires and site surveys were collectively being the building blocks of the **descriptive statistics** in a setting where they address the ES supply and demand assessment. Responses from Likert scale data were summarized using central tendency frequency statistics (mean and mode).

The gap assessment is then performed using **apparent-urgency analysis,** as utilized by Buffam et al., (2022). A normalized disparity between expected future demand and perceived current supply of ES is estimated to identify urgent ES for each zone. Higher values of ES indicate the most urgent, interpreted as those with a potential to address urban challenges with further planning and management of urban street trees.

3.8 Method of Data Presentation

This study applied aforementioned data collecting and analysis methods to come up with findings that leads to the solutions and recommendations for the identified research gap. After the finalization of data collection and analysis, findings were mainly presented verbally. Additionally, result presentations were supported with tables, charts and pictures obtained during the overall research process.

3.9 Ethical Consideration

The researcher solely conducts the study and did not plagiarize the works of others, thereby taking full responsibility in attesting the validity and reliability of the claims expressed on this thesis. Furthermore, this study adhered to ethical considerations by first getting an official support letter from Addis Ababa University (EiABC), addressed to the concerned bodies. As for the respondent's consent, the letter included information about the objectives of the study and the researcher informed the respondents voluntary participation upon meeting. The study keeps a 100% permission, anonymity and confidentiality of data collected from individuals and documents.

Table 3-3 Summary of Research methodology

	Specific Objective 1	Specific Objective 2	Specific Objective 3
	To assess Addis Ababa's Street tree planning and management practice from a resilience perspective	***To quantify the supply and demand of ecosystem service from urban street trees in Addis Ababa***	***To assess Ecosystem disservices and challenges of urban street tree planning and management in Addis Ababa***
Research Design	Descriptive and Exploratory	Exploratory	Descriptive and Exploratory
Research Approach	Quantitative	Quantitative	Qualitative
Collected Data	• Street tree species • Number of trees planted • Spacing of plantation • Connectivity with surrounding environment	• List of ES being supplied/demanded by/from urban street trees • Street users perception towards the level of ES service supply and demand	• Socio-spatial challenges • Ecosystem dis-services • Adaptation mechanisms
Source of Data	• Street corridors	• Street tree users • Experts from A.A municipal office • Experts from A.A green and beautification office	• Street corridors • Street tree users • Surrounding environment along the streets
Method of Sampling	None	• Cluster random sampling for users • Purposive sampling for experts	• Line sampling / systemic sampling of one tree every 10 tree • Cluster random sampling for user
Method of data collection	• Field observation • Physical survey	• Key informant interview • Structured questionnaire	• Field observation • Structured questionnaires
Method of data analysis	• Descriptive statistics • Correlation Analysis	• Descriptive statistics • Apparent-Urgency Analysis	• Thematic analysis
Instruments Used	• Meter • Camera	• Questionnaire • Voice recorder	• Observation checklist • Questionnaire

Source: Own source, (2023)

Chapter 4: RESULT AND DISCUSSION

4.1 Results

4.1.1 Profile of Sample Respondents

The research made use of data from both street users and experts, where their profiles range from the perspective of demography, educational and occupational status, type of respondents, and the frequency of their visit, along with the reason for accessing that street. Hereunder are described their profile respectively.

4.1.1.1 Profile of Street user Population

A. Demography

The demographic pattern of sample populations is presented from gender and age perspectives. From the total sample of 417 respondents, male respondents make up the majority (64%) of the street user population surveyed from each street corridor, while female respondents make up 36% of the total population.

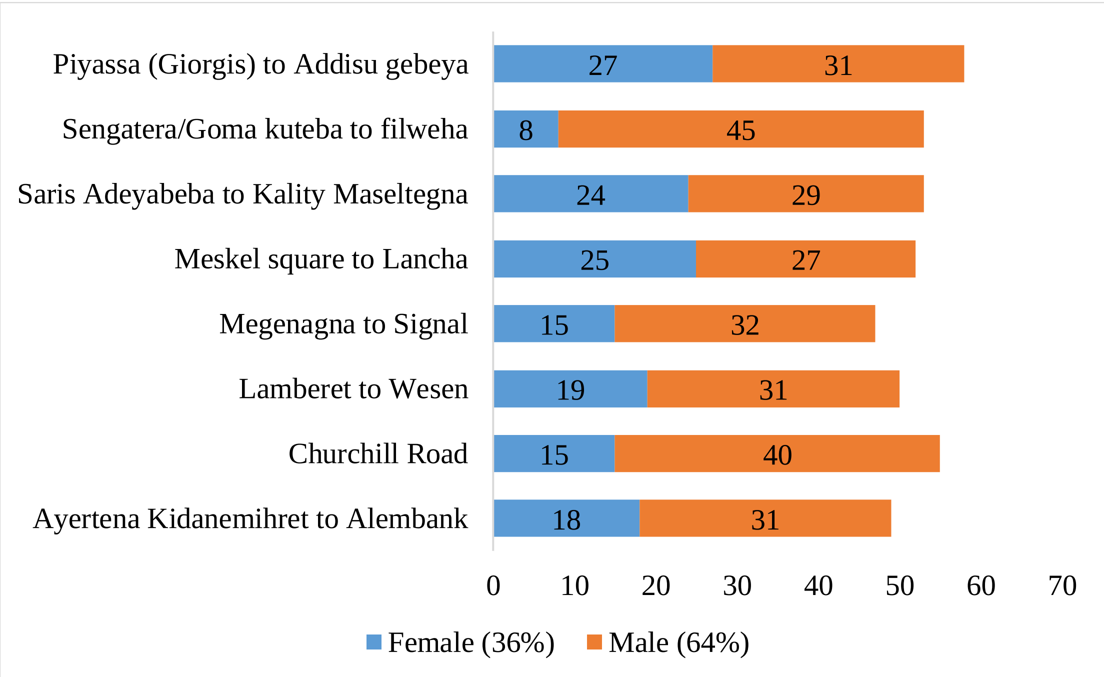


Figure 4.1 Gender of the street user population

In terms of the sample population's age structure, 50% of respondents were between the ages of 18 and 30 while 36% were between the ages of 31 and 64, meaning that 86% of the population fell within the range that is productive. Those over 65 (5%), and those under 18 (9%) make up the remaining 14%.

Table 4-1 Age classification of street users per each street corridors

Street corridors Inventoried	Age				Total
	Below 18	18 - 30	31 - 64	65 and Above	
Ayertena Kidanemihret to Alembank	10	26	10	3	49
Churchill Road	4	23	25	3	55
Lamberet to Wesen	5	26	14	5	50
Megenagna to Signal	1	28	17	1	47
Meskel square to Lancha	1	25	26	0	52
Saris Adeyabeba to Kality Maseltegna	5	26	21	1	53
Sengatera/Goma kuteba to filweha	1	27	24	1	53
Piassa (Giorgis) to Addisu gebeya	12	27	14	5	58
Total	39	208	151	19	417

B. Educational Status

Street users with educational levels below the 10th grade and those with certificates and diplomas make up the majority of responders in terms of street user populations, accounting for 41% and 27% of the overall population, respectively. The remaining 22% and 10% are made up of highly educated street user groups with a degree and master's status, respectively.

Table 4-2 Educational status of street user population per each street corridors

Street corridors Inventoried	Educational Status				Total
	Read and Write	Certificate (Diploma)	Degree	Masters and above	
Ayertena Kidanemihret to Alembank	18	18	7	6	49
Churchill Road	17	15	15	8	55
Lamberet to Wesen	25	13	9	3	50
Megenagna to Signal	14	15	13	5	47
Meskel square to Lancha	28	4	12	8	52
Saris Adeyabeba to Kality Maseltegna	29	13	10	1	53
Sengatera/Goma kuteba to filweha	15	15	17	6	53
Piassa (Giorgis) to Addisu gebeya	27	21	7	3	58
Total	173	114	90	40	417

C. Occupational Status

The occupational status of street users was classified to be Unemployed, Student, Private Business, and Employed. Street users who are employed either in governmental or private institutions, and those with their own private businesses take the majority's share of 43% and 38% respectively. While, the remaining 16% and 3% share is accompanied by students and unemployed individuals. Despite the availability of immense movement flow on streets along the inner city and intermediate zones of the city, three out of eight street corridors (Saris, Meskel Square, and Megenagna) did not register unemployed street users. Besides, the Sengatera street corridor was the one with the highest number of employed street users (28), and Meskel square street corridor registered the highest number of street users with private businesses (31).

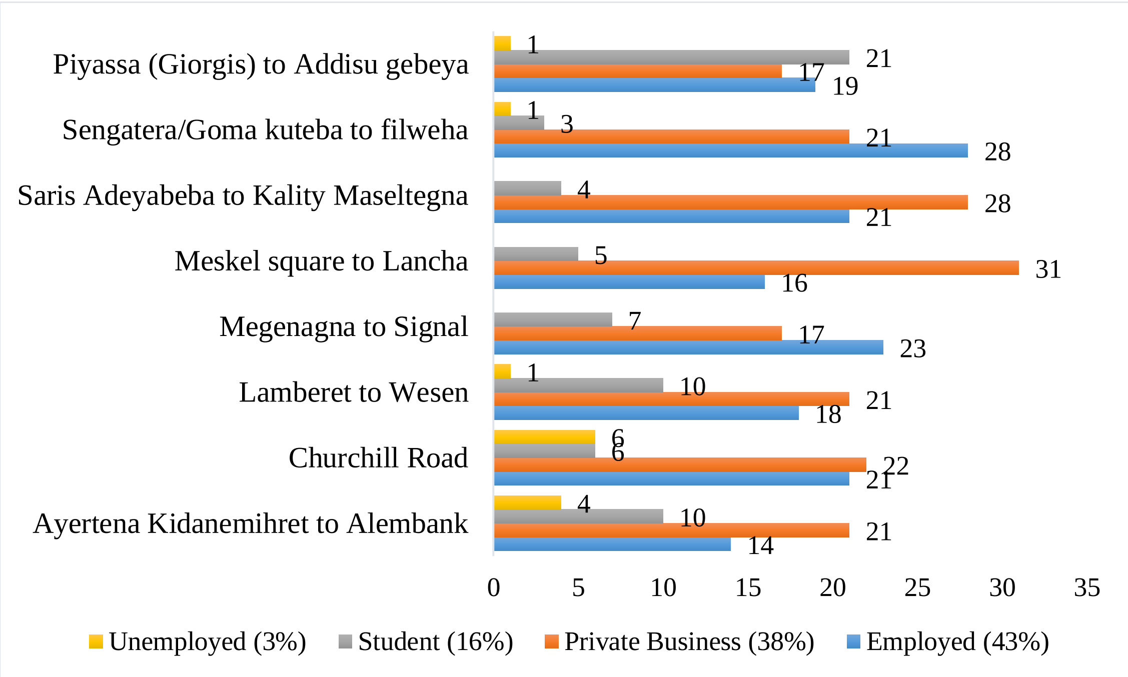
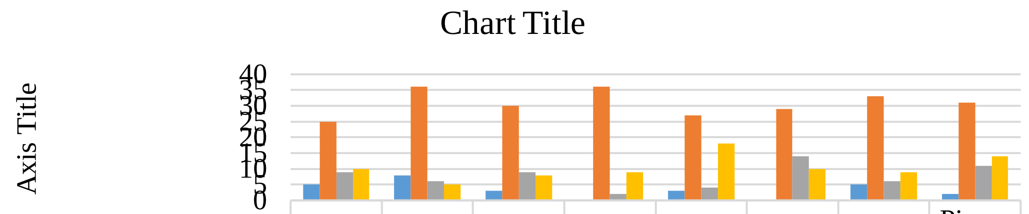


Figure 4.2 Occupational status of street user population per each street corridors

D. Type of Street Users

Regarding the type of street users, this study identified pedestrians, street vendors, street fronts, and car users. Pedestrian street users dominated the survey across all street corridors with 59% of overall percentage. Moreover, street users with businesses on the street make up of 35% of total street users inventoried with 20% being street vendors, and 15% street fronts. Taking the least share of 6%, car users were also incorporated in this study.



	Ayertena Kidanemihret to Alembank	Churchill Road	Lamberet to Wesen	Megenagna to Signal	Meskel square to Lancha	Saris Adeyabeba to Kality Maseltegna	Sengatera/Gomakuteba to filweha	Piyassa (Giorgis) to Addisu gebeya
Car user (6%)	5	8	3	0	3	0	5	2
Pedestrian (59%)	25	36	30	36	27	29	33	31
Street fronts (15%)	9	6	9	2	4	14	6	11
Street Vendor (20%)	10	5	8	9	18	10	9	14

Figure 4.3 Type of street users per each street corridors

E. Purpose and Frequency of Street Usage

Street users access the streets for different purposes. Walking (11.9%), shopping (5.3%), heading to school (8.8%), work or business (52%), recreation and visiting purposes (6%), for appointment (6%), waiting for public transportation (7.6%), and other (2.5%) purposes related with family have been identified during the survey assessment. Since the survey was multiple selection based, street users were allowed to select more than one purpose for accessing the street. The results obtained show 75.3% of largest share to do business on the street, followed by walking, education, and to wait public transportation with 17.3%, 12.7%, and 11% respectively (Table 4.3).

Table 4-3 Street user's purpose to access the street

Purpose of using this Street	**Responses**		**Percent of Cases (Total sample case = 417)**
	Number of responses	Percent	
Walking	72	11.9%	17.3%
Shopping	32	5.3%	7.7%
Education	53	8.8%	12.7%
Work/business	314	52.0%	75.3%
Recreation / Visiting	36	6.0%	8.6%
Appointment	36	6.0%	8.6%
Waiting for public transportation	46	7.6%	11.0%
Other	15	2.5%	3.6%
Total	604	100.0%	144.8%

Regarding the frequency of street usage, 52.5% of users access the street on a daily basis, which is the majority's share of the other options. Street users also tend to use the street once, twice, or three times per week and the collected data shows 10.3%, 22.05%, and 4.55% access frequency respectively.

Besides, 8.2% of street users access the street once a month for different purposes. Finally, 2.4% of street users selected other labeled option, which is to mean once per three or six months. Moreover, Megenagna street corridor is the most accessed street on a daily basis (85%), while Churchill and Sengatera street corridors have shown relatively higher number of street users that intend to come once a month or less (Table 4.4).

Table 4-4 Frequency of street usage by user population per each street corridor

Street corridors Inventoried	**How often do you use this street?**						**Total**
	Daily	Once a week	Twice per Week	Three times per Week	Once a month	Other	
Ayertena Kidanemihret to Alembank	25	10	12	0	1	1	49
Churchill Road	23	8	7	2	11	4	55
Lamberet to Wesen	27	3	14	5	1	0	50
Megenagna to Signal	40	1	0	2	4	0	47
Meskel square to Lancha	28	3	19	0	1	1	52
Saris Adeyabeba to Kality Maseltegna	28	2	16	5	2	0	53
Sengatera/Goma kuteba to filweha	32	11	0	0	6	4	53
Piassa (Giorgis) to Addisu gebeya	16	5	24	5	8	0	58
Total	219	43	92	19	34	10	417
	52.5 %	10.3%	22.05%	4.55%	8.2%	2.4 %	100%

4.1.1.2 Profile of respondent's Expert population

A total of 19 experts were interviewed from different institutions that have enormous impact on the green development and management of Addis Ababa City (Table 4.5). The Addis Ababa Plan and Development Commission and the Addis Ababa City Administration Urban Beautification and Green Development Bureau took the higher percentage of interviewed experts.

Table 4-5 Number of experts interviewed per each institution/organization

Name of Institution / Organization	Number of Experts
Addis Ababa City Administration Urban Beautification and Green Development Bureau (AACAUBGDB)	5
Addis Ababa City Road Authority (AACRA)	3
Addis Ababa Plan and Development Commission (AAPDC)	8
Ethiopian Forest Development Institute (EFDI)	1
FDRE Policy Studies Institute (PSI)	2

The level of their professional career varied from team leader to junior level experts, which helps to grasp different perspectives. In line with this, 4 team leaders, 8 senior level experts, 5 mid-senior level experts, and 2 junior level experts were interviewed.

Table 4-6 Experience level of interviewed experts

Level	Year of Experience	Number of Experts
Junior	0 to 2	2
Mid-Senior	3 to 5	5
Senior	More than 5	8
Team Leader	More than 10	4

4.1.2 Resilience Assessment of Existing Urban Street Tree Planning and Management

4.1.2.1 Species Recorded

The list of tree species recorded on each street corridor are presented below.

- **Churchill Road**

Table 4-7 Species identification on Churchill street corridor

No	Scientific Name	Family Name	Local / Common Name	Tree Count			
				Left Side	Median	Right Side	Total (n)
1	*Grevillea robusta*	Proteaceae	Grevillea	17	3	5	25
2	*Phoenix canariensis*	Arecaceae	Zenbaba	1	97	18	117
3	*Jacaranda mimosifolia*	Bignoniaceae	Yetemenja zaf	13	39	68	120
4	*Araucaria biramulata*	Araucariaceae	Araucaria	93	16	141	250
5	*Nerium oleander*	Apocynaceae	Oleander	1	6	-	7
6	*Hibiscus Sp*	Malvaceae		1	1	1	3
7	*Acacia mearnsii*	Fabaceae		10	-	1	11
8	*Ficus sycomorus*	Moraceae	Shola	6	1	7	14
9	*Olea europaea*	Oleaceae	Weyira	56	-	82	138
10	*Cupressus sempervirens*	Cupressaceae	Cypress tree	-	7	-	7
11	*Hagenia abyssinica*	Rosaceae	Kousso	-	1	-	1
12	*Bougainvillea spectabilis*	Nyctaginaceae		-	2	-	2
13	*Ficus benjamina*	Moraceae		-	-	2	2
14	*Dracaena steudnerii*	Dracaenaceaee	Etsepatos	-	-	2	2
15	*Callistemon citrinus*	Myrtaceae	Red Bottle Brush	-	-	1	1
16	*Pinus patula*	Pinaceae	Paynus	-	-	1	1
17	*Casuarina cunninghamiana*	Casuarinaceae	Shewshewe	-	-	1	1
18	*Juniperus procera*	Cupressaceae	Yehabesha Tid	-	-	15	15
19	*Vernonia amygdalina*	Asteraceae	Girawa	-	-	1	1
20	*Azadirachta indica*	Meliaceae	Kinin (Neem Tree)	-	-	1	1
21	*Cordia africana*	Boraginaceae	Wanza	-	-	5	5
22	*Podocarpus falcatus*	Podocarpaceae	Zigba	-	-	2	2
23	*Acacia abyssinica*	Fabaceae	Yehabesha Girar	-	-	2	2

- **Sengatera to Filweha**

Table 4-8 Species identification on Sengatera to Filweha street corridor

No	Scientific Name	Family Name	Local / Common Name	Species Count			
				Left Side	Median	Right Side	Total (n)
1	*Grevillea robusta*	Proteaceae	Grevillea	26	56	27	109
2	*Phoenix canariensis*	Arecaceae	Zenbaba	-	93	-	93
3	*Jacaranda mimosifolia*	Bignoniaceae	Yetemenja zaf	-	30	6	36
4	*Araucaria biramulata*	Araucariaceae	Araucaria	-	5	-	5
5	*Nerium Oleander*	Apocynaceae	Oleander	-	3	-	3
6	*Cupressus sempervirens*	Cupressaceae	Cypress tree	-	5	-	5
7	*Callistemon citrinus*	Myrtaceae	Red Bottle Brush	-	2	1	3
8	*Pinus patula*	Pinaceae		-	1	-	1
9	*Casuarina cunninghamiana*	Casuarinaceae	Shewshewe	-	1	1	2
10	*Juniperus procera*	Cupressaceae	Yehabesha Tid	-	1	-	1
11	*vernonia amygdalina*	Asteraceae	Girawa	-	2	-	2
12	*Acacia abyssinica*	Fabaceae	Girar		8		8
13	*Schinus molle*	Anacardiaceae	Qundo berbere	-	5	-	5

- **Lancha to Meskel Square**

Table 4-9 Species identification on Lancha to Meskel Square street corridor

No	Scientific Name	Family Name	Local / Common Name	Species Count		
				Left Side	Right Side	Total (n)
1	*Grevillea robusta*	Proteaceae	Grevillea	214	197	411
2	*Phoenix canariensis*	Arecaceae	Zenbaba	4	-	4
3	*Jacaranda mimosifolia*	Bignoniaceae	Yetemenja zaf	2	1	3
4	*Ficus sycomorus*	Moraceae	Shola	1	-	1
5	*Cupressus sempervirens*	Cupressaceae	Cypress tree	-	2	2
6	*Callistemon citrinus*	Myrtaceae	Red Bottle Brush	2	-	2
7	*Pinus patula*	Pinaceae				
8	*Casuarina cunninghamiana*	Casuarinaceae	Shewshewe	1	-	1
9	*Persea americana*	Lauraceae	Avocado	5	-	5
10	*Mangifera indica*	Anacardiaceae	Mango	1	-	1

- **Megenagna to Signal**

Table 4-10 Species identification on Megenagna to Signal street corridor

No	Scientific Name	Family Name	Local / Common Name	Species Count		
				Left Side	Right Side	Total (n)
1	*Grevillea robusta*	Proteaceae	Grevillea	127	107	234
2	*Phoenix canariensis*	Arecaceae	Zenbaba	-	3	3
3	*Jacaranda mimosifolia*	Bignoniaceae	Yetemenja zaf	7	4	11
4	*Callistemon salignus*	Myrtaceae	White Bottle Brush	-	1	1
5	*Callistemon citrinus*	Myrtaceae	Red Bottle Brush	-	8	8
6	*Azadirachta indica*	Meliaceae	Kinin (Neem Tree)	1	-	1
7	*Acacia abyssinica*	Fabaceae	Girar	-	3	3
8	*Acacia melanoxylon*	Fabaceae	Omedla	-	5	5
9	*Schinus molle*	Anacardiaceae	Qundo berbere	1	-	1

- **Addisu Gebeya to Piassa**

Table 4-11 Species identification on Addisu Gebeya to Piassa street corridor

No	Scientific Name	Family Name	Local / Common Name	Species Count			
				Left Side	Median	Right Side	Total (n)
1	*Grevillea robusta*	Proteaceae	Grevillea	36	50	73	159
2	*Phoenix canariensis*	Arecaceae	Zenbaba	-	14	-	14
3	*Jacaranda mimosifolia*	Bignoniaceae	Yetemenja zaf	2	10	5	17
4	*Nerium Oleander*	Apocynaceae	Oleander	1	-	-	1
5	*Acacia mearnsii*	Fabaceae		-	1	-	1
6	*Cupressus sempervirens*	Cupressaceae	Cypress tree	-	15	-	15
7	*Callistemon citrinus*	Myrtaceae	Red Bottle Brush	1	1	1	3
8	*Casuarina cunninghamiana*	Casuarinaceae	Shewshewe	-	12	-	12
9	*Juniperus procera*	Cupressaceae	Yehabesha Tid	-	-	4	4
10	*vernonia amygdalina*	Asteraceae	Girawa	-	1	1	2
11	*Acacia melanoxylon*	Fabaceae		42	124	23	189
12	*Arbutus unedo*	Ericaceae	Enjori	-	1	-	1

- **Lamberet to Wesen**

Table 4-12 Species identification on Lamberet to Wesen street corridor

No	Scientific Name	Family Name	Local / Common Name	Species Count			
				Left Side	Median	Right Side	Total (n)
1	*Grevillea robusta*	Proteaceae	Grevillea	108	3	125	236
2	*Phoenix canariensis*	Arecaceae	Zenbaba	2	-	3	5
3	*Jacaranda mimosifolia*	Bignoniaceae	Yetemenja zaf	13	-	5	18
4	*Acacia mearnsii*	Fabaceae		-	-	4	4
5	*Cupressus sempervirens*	Cupressaceae	Cypress tree	-	55	1	56
6	*Callistemon citrinus*	Myrtaceae	Red Bottle Brush	1	-	-	1
7	*Pinus patula*	Pinaceae		-	44	-	44
8	*Juniperus procera*	Cupressaceae	Yehabesha Tid	-	-	1	1
9	*Cordia Africana*	Boraginaceae	Wanza	-	-	2	2
10	*Acacia melanoxylon*	Fabaceae		-	-	1	1
11	*Spathodea campanulata*	Bignoniaceae	African tulip tree	2	-	-	2

- **Alembank to Kidanemihret**

Table 4-13 Species identification on Alembank to Ayertena Kidanemihret street corridor

No	Scientific Name	Family Name	Local / Common Name	Species Count		
				Left Side	Right Side	Total (n)
1	*Grevillea robusta*	Proteaceae	Grevillea	233	148	381
2	*Jacaranda mimosifolia*	Bignoniaceae	Yetemenja zaf	8	7	15
3	*Ficus sycomorus*	Moraceae	Shola	-	1	1
4	*Callistemon citrinus*	Myrtaceae	Red Bottle Brush	2	1	3
5	*Pinus patula*	Pinaceae		-	2	2
6	*Casuarina cunninghamiana*	Casuarinaceae	Shewshewe	1	-	1
7	*Azadirachta indica*	Meliaceae	Kinin (Neem)	1	-	1
8	*Schinus molle*	Anacardiaceae	Qundo berbere	-	2	2

- **Maseltegna to Saris**

Table 4-14 Species identification on Maseltegna to Saris street corridor

No	Scientific Name	Family Name	Local / Common Name	Species Count		
				Left Side	Right Side	Total (n)
1	*Grevillea robusta*	Proteaceae	Grevillea	163	150	313
2	*Phoenix canariensis*	Arecaceae	Zenbaba	178	150	328
3	*Jacaranda mimosifolia*	Bignoniaceae	Yetemenja zaf	8	31	39
4	*Callistemon citrinus*	Myrtaceae	Red Bottle Brush	12	1	13
5	*Azadirachta indica*	Meliaceae	Kinin (Neem Tree)	16	-	16
6	*Acacia melanoxylon*	Fabaceae	Omedla	-	2	2
7	*Nerium Oleander*	Apocynaceae	Oleander	15	-	15
8	*Pinus patula*	Pinaceae		3	-	3
9	*Spathodea campanulata*	Bignoniaceae	African tulip tree	11	-	11
10	*Ficus benjamina*	Moraceae		12	-	12
11	*Cupressus sempervirens*	Cupressaceae	Cypress tree	18	-	18
12	*Araucaria biramulata*	Araucariaceae	Araucaria	4	-	4
13	*Casuarina equisetifolia*	Casuarinaceae	Shewshewe	6	-	6
14	*Juniperus procera*	Cupressaceae	Yehabesha Tid	-	3	3
15	*Arbutus unedo*	Ericaceae	Enjori	-	9	9
16	*Casimiroa edulis*	Rutaceae	Kazmir, Kazamora	-	1	1

Regarding species identification, street trees were recorded by scientific, family, and local name, and their count on either the left, median, or right side of each street corridors. As per the results, Churchil, Sengatera, Saris, and Addisu Gebeya street corridors recorded the highest species richness respectively.

Given their central locational advantage, Churchil street corridor recorded the highest number of tree species types, among which, *Grevillea robusta*, *Phoenix canariensis,* and *Jacaranda mimosifolia* were the major ones with the most species count. The rest species identified along Churchil segment accounts very small proportion from the total population.

Likewise, Sengatera, Saris Adeyabeba, and Addisu Gebeya street corridors recorded numerously high species richness, again, with *Grevillea robusta, Phoenix canariensis,* and *Jacaranda mimosifolia* species abundance.

Table 4-15 Prevalence of identified species in Addis Ababa

No	Scientific Name	Family Name	Local / Common Name	Prevalence
1	Grevillea robusta	Proteaceae	Grevillea	**1868 (51%)**
2	Phoenix canariensis	Arecaceae	Zenbaba	**564 (15%)**
3	Jacaranda mimosifolia	Bignoniaceae	Yetemenja zaf	**259 (7%)**

Source: Own computation, (2023)

4.1.2.2 Diversity and Redundancy

Being the first resilience principle selected to assess the current practice of Addis Ababa's street tree planning and management, diversity and redundancy principle resulted in clear and specific data for each street corridors. By counting the number of tree species in each street corridors, the richness result is obtained. From that, Addis Ababa's streets were founded to be rich in species, with a maximum of 23 species identified in Churchill road, while a minimum of 8 (eight) species was identified in Alembank street corridor.

Using Shannon diversity index (H), the study assessed the diversity of street tree species in each street corridors. The higher the value of H, the higher the diversity of species in a particular community. The lower the value of H, the lower the diversity. A value of H = 0 indicates a community that only has one species.

Table 4-16 Diversity assessment of mature urban street trees in Addis Ababa

No	Street corridor Inventoried	Number of Tree Species (Richness)	Total Number of Trees	Shannon Diversity Index (H)	Maximum Shannon Diversity Index (Hmax)	Equitability (H/Hmax)
1	Ayertena Kidanemihret to Alembank	8	406	0.31	6	0.05
2	Churchill Road	23	728	1.89	6.59	0.29
3	Lamberet to Wesen	10	326	0.93	5.78	0.16
4	Megenagna to Signal	9	267	0.59	5.58	0.1
5	Meskel square to Lancha	10	430	0.26	6.06	0.04
6	Saris Adeyabeba to Kality Maseltegna	16	793	1.5	6.67	0.22
7	Sengatera/Goma kuteba to filweha	13	273	1.69	5.61	0.30
8	Piassa (Giorgis) to Addisu gebeya	12	421	1.37	6.04	0.22

Source: Own computation, (2023)

As the result calculated from onsite species identification data indicates, Churchill road registered the relatively higher Shannon diversity index value of 1.89, followed by Sengatera, Saris to Kality, and Piassa to Addisu Gebeya streets each with 1.69, 1.5, and 1.37 shannon diversity index. Meanwhile, Meskel square to Lancha and Alembank to Kidanemihret streets show the least Shannon diversity index value of 0.26 and 0.31 respectively.

Moreover, the Shannon Equitability Index (H/Hmax) is a way to measure the evenness of species in a community. The term “evenness” simply refers to how similar the abundances of different species are in the community.

The highest Shannon equitability index was calculated on Sengatera and Churchill streets with a value respective value of 0.3 and 0.29. Meskel Square to Lancha, Alembank to Kidanemihret, and Megenagna to Signal streets show a very low Shannon equitability index value of 0.04, 0.05, and 0.1 respectively. Table 4.15 summarizes details of each result per street corridor.

Result from Expert Interview

Regarding the integration of diversity and redundancy resilience principles on the current street tree development and management practice, experts were tasked to reflect their personal professional knowledge and experience.

As the street tree species diversity variable is concerned, 36.84% of experts selected medium integration, and 31.58% of experts reflected on low integration, while high and none integration options were both selected by 15.79% of the total 19 experts. Likewise, the integration of Age diversity variable shows the highest selection for low (36.84%), medium (31.58%), and high (26.32%).

Regarding redundancy, 36.84% of experts indicated medium integration of tree species with similar functions (functional redundancy), while 5.26 % of them believed very high integration. The repetition of street tree plantation schemes in Addis Ababa is chosen to be very high by 15.79% of experts, and 36.84% as highly repeated on other city streets. The density of street trees is considered to be low and medium by 63.16% of experts (each 31.58%).

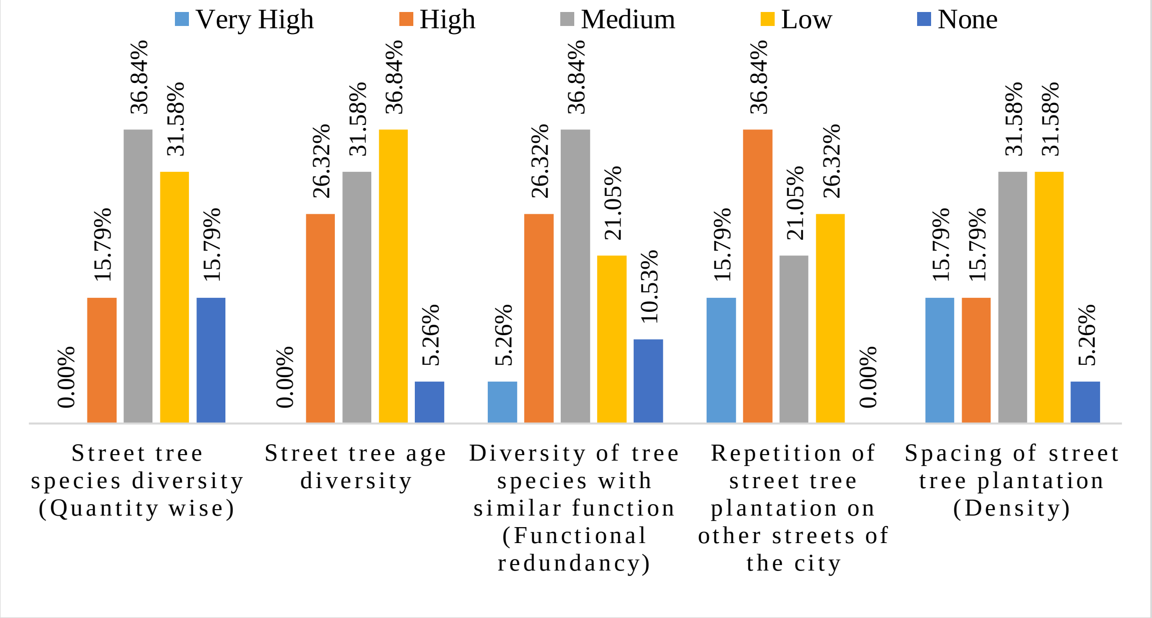


Figure 4.4 Integration of diversity and redundancy resilience principles on the current street tree development and management practice

4.1.2.3 Connectivity

When assessing the resilience of street trees in Addis Ababa, connectivity is another key factor to consider. While it was essential to analyze the layout and orientation of urban streets to ensure connectivity, the study's scope and the number of street corridors inventoried made it difficult to include a spatial evaluation of each tree's connection to nearby green infrastructure and other trees. However, expert insights were still taken into account.

This particular section of the study resulted from an expert interview. Based on their professional and experiential knowledge, experts were presented with two variables to indicate the connectivity of street tree development in Addis Ababa. First, the connectivity of urban street trees with each other along street corridors, and secondly the connectivity of urban street trees with other green infrastructure components of the city.

Based on a Likert-scale assessment of 19 expert data, 52.63% of experts believed that there is low connectivity of street trees with each other, while 36.84% selected medium connectivity as their choice. Regarding the connectivity of street trees with surrounding green components, 63.16% of experts indicate low connectivity, while the remaining 31.58% rest on medium connectivity.

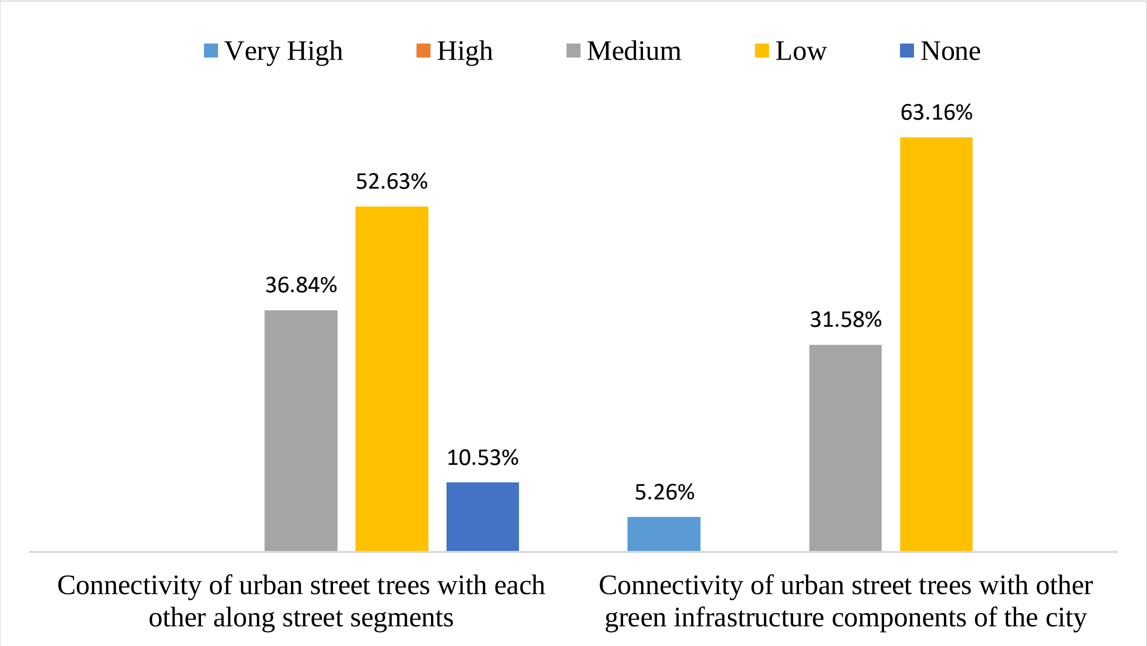


Figure 4.5 Integration of connectivity resilience principles on the current street tree development and management practice

4.1.2.4 Participation

Regarding the participation resilience principle, the amount of public involvement in street tree planting, maintenance (watering, pruning, mulching, and fencing), and provisioning (sapling and financial support) activities was assessed. Based on information from 417 street users, 29.7% (124 street users) have participated in street tree development or management activities, compared to 70.3% (293 street users) who have never done so.

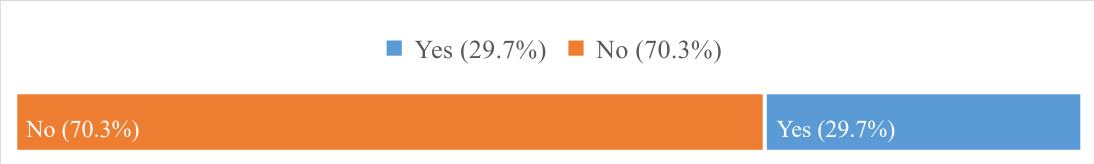


Figure 4.6 Public participation in street tree development and management practice

Given the multi-selection option of the survey question, 124 distinct street users responded to a range of street development and management activities (count of 204). Considering a distinct count of street users, plantation activities took the majority of 39.8% participation, followed by watering (22.9%) and financial support 10%, respectively. Table 4.16 detailed the number of responses and percentage share of each activities in terms of both distinct street user count and multiple selection cases.

Table 4-17 Distinct and Multiple response share of public participation activities

Participation Activities		**Distinct Responses**		**Percent of Cases**
		Number of responses	Percent	
Provisioning	Street tree (Sapling) provision	16	6.4%	12.9%
	Financial support	25	10.0%	20.2%
Plantation	Street tree plantation	99	39.8%	79.8%
Management	Watering	57	22.9%	46.0%
	Mulching	20	8.0%	16.1%
	Pruning	17	6.8%	13.7%
	Fencing	10	4.0%	8.1%
Other	Other	5	2.0%	4.0%
Total		249	100.0%	200.8%

Education pattern and Participation Crosstabulation

The prevalence of "Don't Know" responses across all groups suggests a widespread lack of awareness regarding opportunities for public participation in street tree planning and management activities. This trend is particularly notable among respondents with "Read and Write Only" and "Certificate/Diploma" education levels, which may indicate the need for targeted outreach to these groups.

Positive evaluations ("High" and "Very High") were scarce, with only 35 combined responses across all educational levels. This indicates that public participation in street tree planning is either underdeveloped or not effectively communicated to the public. Respondents with higher educational levels (e.g., "Masters and Above") were slightly more likely to rate participation positively, but the numbers remain low overall. Conversely, respondents with lower educational levels ("Read and Write Only") were more likely to indicate "Don't Know" or "Very Low" participation, reflecting a significant lack of engagement.

Table 4-18 Educational pattern and participation crosstabulation

Educational Status		Don't Know	High	Low	Very High	Very Low	Total
Certificate/ Diploma	76	7	10	3	17	1	114
Degree	48	4	13	3	21	1	90
Master's and above	14	4	6	1	15	0	40
Read and Write	114	12	27	1	18	1	173
Total	252	27	56	8	71	3	417

Considering the total number of case responses (204), a correlation of public participation was made with gender for each street corridor. Street users participated in Sengatera, Saris, and Megenagna street corridors participated a lot with 20.59%, 17.16%, and 16.67% respectively. Meanwhile, male street users recorded 77.9% of responses, and only 22.1% of female participation is noted. In terms of activities, plantation (48.5%) was dominant among the given responses, and the remaining management and provisioning activities come next with a respective value of 30.9% and 18.1%. Figure 4.7 illustrates the level of gender-based public participation per each street corridor and grouped participation activities.

Although it only contributes 2.5%, some street users responded with other participation activities. Landscape designing, preparation of the planting space, cleaning the area, and provision of continuous consultation were among the specified additional activities in Lamberet and Churchill street corridors.

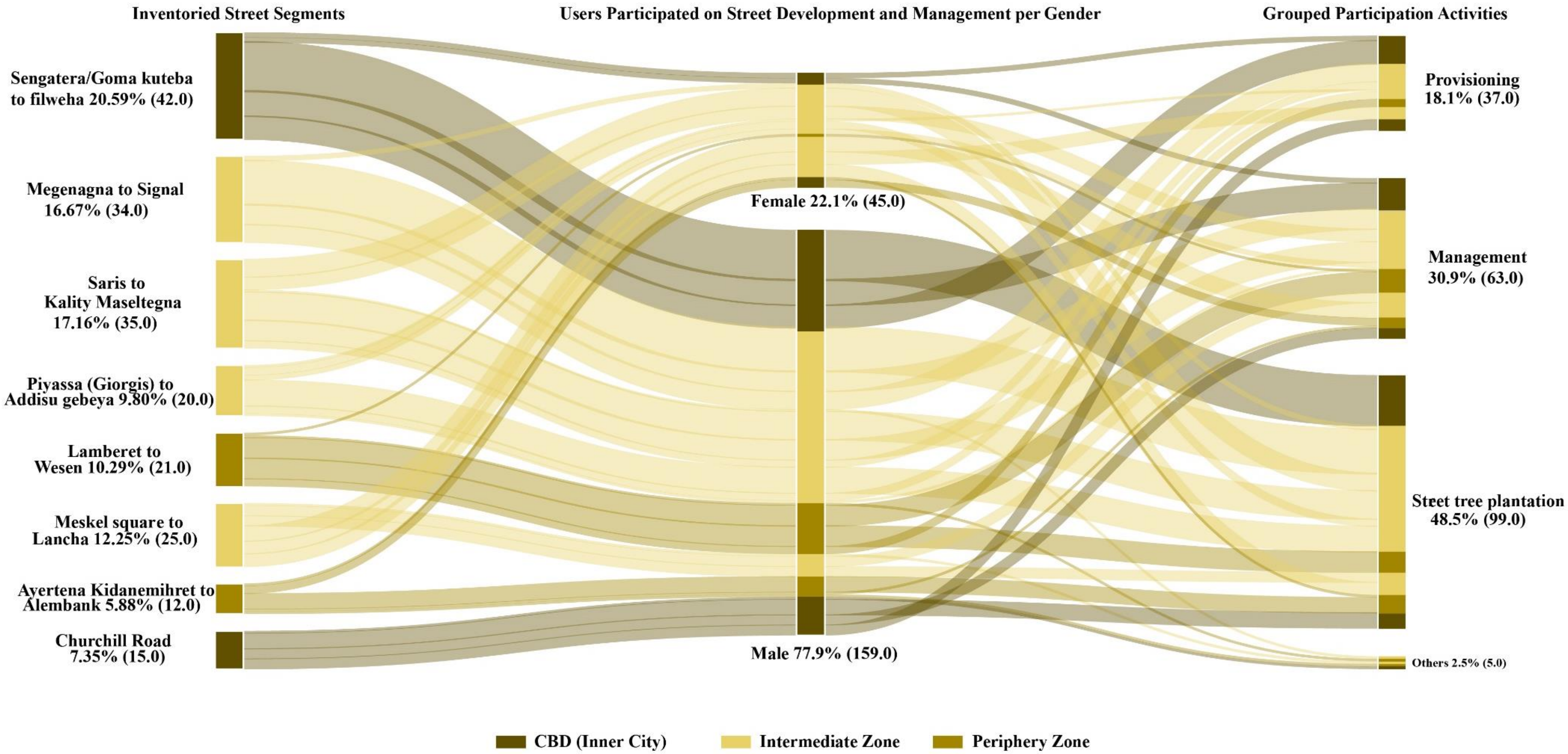


Figure 4.7 A Sankey diagram showing the cross-relation of gender with street tree development and management of public participation activities per each street corridor. The flow shows how much male and female street users participated in which activities from each street corridor.

4.1.2.5 Adaptive Capacity

The capacity of urban street trees to adapt to changes from stresses and hazards is referred to as Adaptive Capacity. Hereunder are six identified variables that help to assess the adaptive capacity of current street trees in Addis Ababa. Under each variable is shown the resulting value from Likert-scale expert data.

Wider planting pits that consider pavement life: 36.84% of experts gave their opinion as medium level to how street tree plantation uses widened pits that consider pavement life. The remaining 63.16% of experts select low and very low consideration of wider planting pits from longer pavement life, 31.58% for each.

Provision of Adequate maintenance: given the importance of adequate maintenance for the increased ability to withstand change, experts were tasked to put their understanding of this matter from very high to none. As a result, 10.53% of experts show a high level of maintenance is being undertaken, while 47.37% believed medium maintenance is provided. On the other hand, 31.58% indicate a shortage of maintenance activities, while 10.53% of experts show no maintenance whatsoever is provided.

Protective structures against street users pressure: fence structure for the protection of sapling and seedlings from unresponsive street users is considered as one variable that enhance adaptive capacity of street trees. On the subject, 42.11% of experts sided for medium provision of protective structures, while 36.68% reflected their perspective of low provision of protective structures for street trees.

Pest resistance species selection: only 5.26% of experts selected very high consideration of pest resistance as a species selection criterion for street tree development. The majority's share is taken by medium consideration for pest resistance, which is 47.37%. The rest 36.84% and 10.53% of experts believed there is low and no consideration for pest resistance.

Less water-demanding species selection: 10.53% of interviewed experts believed that there is a very high incorporation of less water-demanding species selection criteria while planting street trees in Addis Ababa. The majority of 52.63% of experts think that medium consideration is given towards selecting tree species with low water demand.

Fast growth rate species selection: the highest percentage (21.05) of experts show that Addis Ababa's street tree species selection considered fast growth as a basic requirement. Moreover, 31.58% of experts selected a high value for this variable. Followed by 36.84% for medium consideration of growth rate as a species selection criteria.

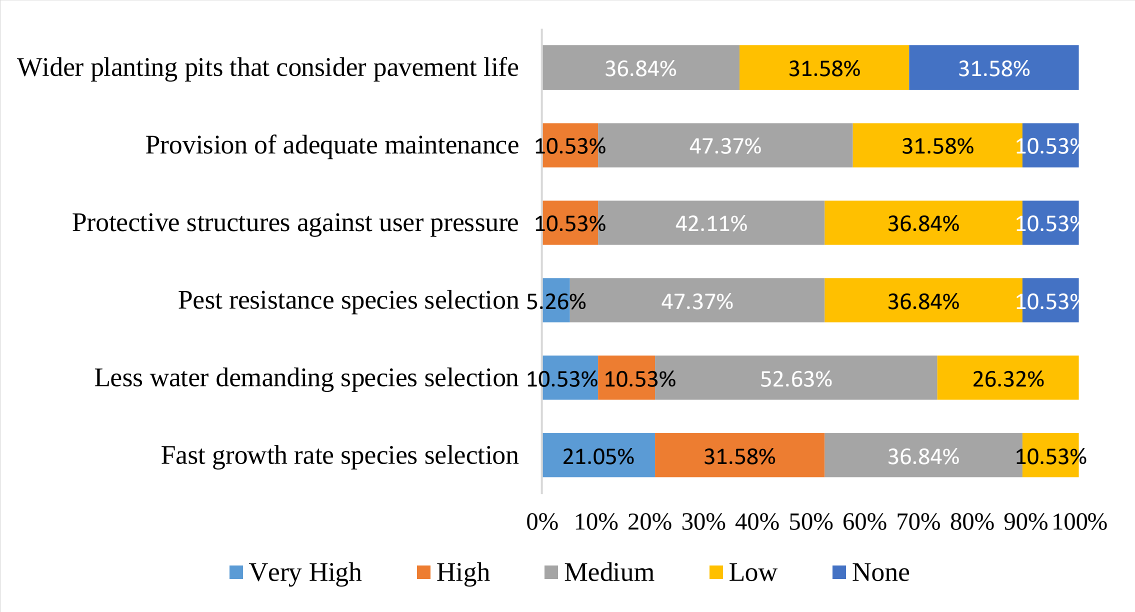


Figure 4.8 Integration of Adaptive capacity resilience principle on street tree development and management practice

Figure 4.9 Adaptive measures taken - protective structure

4.1.3 Urban Street Tree Ecosystem Service Supply and Demand Assessment

The overall calculated values of ES supply, demand, and apparent urgency is described below as per the defined zones of Addis Ababa; commercial business district, intermediate zone, and periphery zone (Table 3.1). Moreover, Annex V presented detailed computed mean values for each street corridor.

4.1.3.1 Ecosystem Service Supply Assessment

Commercial business district (CBD) zone:

As the inner city zone of Addis Ababa, CBD exhibits a higher supply of all regulating, cultural, and supporting services in comparison to the peripheral and intermediate areas. With a mean value of 3.87, the cultural ecosystem services stand out as having a sufficient supply along the inner city. Besides, the regulating and supporting services show 3.13 and 2.99 mean values of ES supply respectively (Figure 4.9).

In particular to the individual ecosystem services and indicators; street beautification, comfort for use, inspiration and motivation (inspiring creativity, encouraging outdoor activities, and promoting a sense of well-being), as well as space for socializing, were the highest supplied cultural ES with a mean value of 4.4, 4.09, 4.03, and 3.85 respectively. The lowest mean results from a total value of five (5) were calculated for noise reduction, stormwater management, and habitat for wildlife, with respective values of 2.45, 2.66, and 2.69.

Local climate regulation, air quality regulation, recreation, and species diversity shows relatively intermediate mean values on the inner city of Addis Ababa. Although they share similar least supplied ES, Sengatera to Filweha street corridor has substantially lower mean values when compared to Churchill street corridor (Annex V).

Intermediate Zone:

Located between the inner city and periphery zone of Addis Ababa, the intermediate zone resulted in a lower mean value of ES supply, especially the supporting services. Computed as per the ES categories, the regulating and cultural services ranked first and second with lower intermediate values of 2.65 and 2.59 respectively. Besides, with a mean score of 1.95, supporting ES services were found to be the least supplied. The highest value for local climate regulation (3.13) and the lowest for habitat for wildlife (1.85), respectively, demonstrate the magnitude of the lack of ES supply in this zone.

Among the four street corridors grouped under the intermediate zone, Saris to Kality and Piassa to Addisu Gebeya street corridors show relatively higher mean values of ES supply. On the contrary, Megenagna to Signal and Meskel Square to Lancha street corridors indicate the lowest mean values of ES supply respectively.

Among the least offered ES in the street corridors of Megenagna and Meskel Square are aesthetic quality, species diversity, storm water management, and noise reduction. Local climate regulation, recreation and human health ES are among the highly supplied services along Saris and Addisu Gebeya street corridors (Annex V).

Periphery Zone:

Like the intermediate zone, lower mean values of ES supply are witnessed from the periphery zone of Addis Ababa. The mean values of ES supply for regulating, cultural, and supportive ES were 2.79, 2.59, and 1.75 respectively, ranking from highest to lowest. Air quality regulation, in particular, dust removal and noise reduction are the least provided regulating ES with typical values of 2.22 and 2.21. Regarding cultural ES, physical exercise, social setting, and human health resulted in 2.03, 2.06, and 2.35 mean values. Local climate regulation, when compared to other factors, received the highest intermediate score of 3.31 mean ES supply.

Supporting longer pavement life (1.76) and physical exercise (1.68) are two of the least ES supplied in Lamberet to Wesen street corridor, while species diversity and habitat for wildlife are the lowest of all in Alembank to Ayertena street corridor with 1.65 and 1.55 mean values respectively (Annex V).

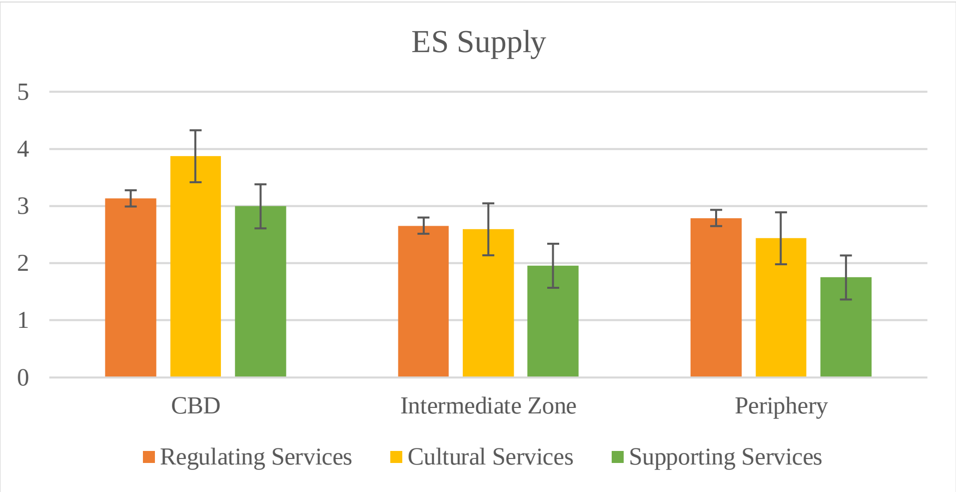


Figure 4.10 Ecosystem service supply assessment

4.1.3.2 Ecosystem Service Demand Assessment

Commercial business district (CBD) zone:

Demands for regulating ES exhibit the highest cumulative value of 4.3, from which Local climate regulation ES shows a significantly higher individual rating of 4.63 from overall list of regulating ES. Cultural ES demand ranked second with a 4.17 cumulative mean value. Further articulated from individual ES and indicators perspective, comfort for use, street beautification, and social setting obtained the highest values of 4.46, 4.42, and 4.37 respectively. On the other hand, creating a sense of space and physical exercise were among the least scoring 3.77 and 3.8 values respectively.

Besides, low scoring demand for supporting ES was computed to be 3.95, from which, habitat for wildlife (3.69) scored the lowest individual mean value. Being the least demanded of all, edible fruit provision service scored a 3.46 mean value in CBD.

Intermediate Zone:

Cultural, regulating, and supporting ES all show higher demand from street users with respective mean values of 4.29, 4.22, and 4.14. Regarding each individual ES and indicators, physical exercise (3.96), habitat for wildlife (3.93), and food provision (3.24) are the only ES with a score of lower than 4. Aesthetics, comfort for use, and thermal comfort scored top three demanded ES in the intermediate zone of Addis Ababa with individual mean values of 4.64, 4.61, and 4.42 respectively.

ES demand on a street corridor from Piassa to Addisu Gebeya indicates the highest among other streets with emphasis on local climate regulation, carbon sequestration, street beautification, and human health; all scoring higher than 4.72, which is very highly demanded.

Periphery Zone:

The periphery zone of Addis Ababa shows the highest cultural (4.4) and regulating (4.32) ES demand from the rest zones. Likewise, supporting service (4.1) is highly demanded. To be specific, local climate regulation and stormwater management scored 4.47 and 4.35 respective mean values from a list of regulating ES. While comfort for use, street beautification, and social setting ranked the top among cultural ES with mean values of 4.71, 4.68, and 4.57 respectively. Moreover, tree species diversity shows highest demand of 4.42 while habitat for wildlife scored the lower 3.78 mean value from list of supporting ES.

In particular to specific street corridors, Lamberet to Wesen street corridor shows high demand for cultural ES, all scoring higher than 4.5, except for human health (4.48) and physical exercise (4.28). Refer Figure 4.10 for graphical illustration of Ecosystem Service demand assessment in the inner city, intermediate, and peripheral zones of Addis Ababa.

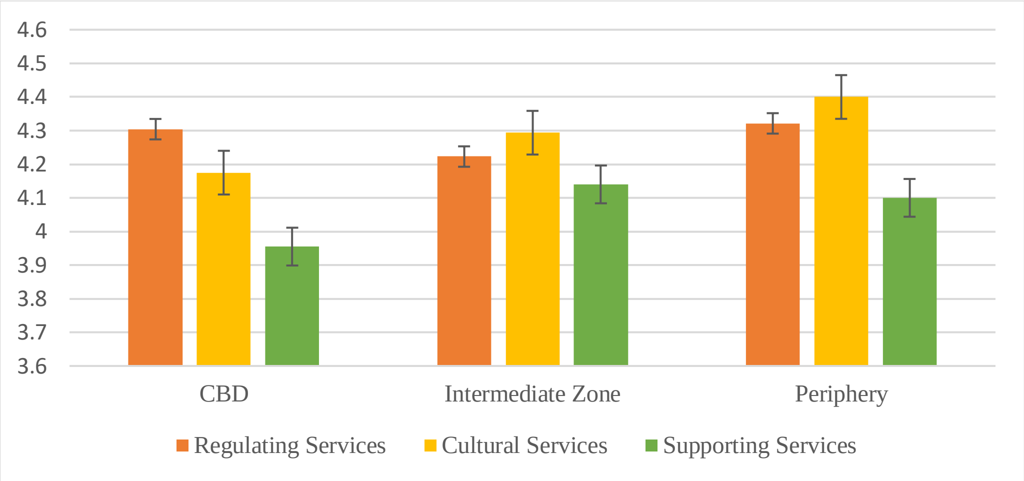


Figure 4.11 Ecosystem service demand assessment.

4.1.3.3 Results from Apparent-Urgency Analysis (Supply vs. Demand)

Commercial business district (CBD) zone:

Cultural ES shows the highest sufficiency with the lowest difference value of 0.36 in contrast to regulating (1.17) and supporting (0.96) ES in the inner city. Overall, the CBD of Addis Ababa recorded the smallest urgency for ES when compared with the intermediate and periphery zones (Figure 4.11).

Regarding regulating ES in CBD, noise reduction, rainwater trapping, and flood/runoff control noted intermediate urgency values of 1.61 1.45, and 1.42 mean differences respectively. All ecosystem services and their indicators scoring less than 0.65, the CBD zone of Addis Ababa does not show urgency for cultural ES. Likewise, supporting ES scored less than one.

Intermediate Zone:

Supporting ES show 2.19 normalized mean difference, which is the most urgent in the intermediate zone. With an individual men difference computation, tree species diversity shows higher urgency of 2.29, while habitat for wildlife shows 2.08. Both the regulating (1.56) and cultural (1.73) ES show medium to high urgency when compared with CBD.

Among others, street beautification, social setting, and physical exercise are the highest cultural ES that shows urgency values of 2.04, 1.97, and 1.9 respectively. Regarding regulating services, noise reduction, rainwater trapping, and flood control services indicate relatively highest urgency values of 1.95, 1.93, and 1.85 respectively. Megenagna to Signal and Meskel Square to Lancha street corridors indicate the highest urgency for street beautification with a mean difference of 2.96 and 2.70 respectively. Again, species diversity is demanded in urgency with respective values of 2.19 and 2.89 in both streets.

Periphery Zone:

The periphery zone is the one with the highest urgency values in relation to the remaining two zones of Addis Ababa. Regulating ES recorded a 1.53 intermediate urgency mean value, while cultural and supporting ES showed the highest 2.03 and 2.35 urgency values respectively.

Considering the individual regulating ES list, dust reduction (2.03) and noise reduction (2.01) are the only regulating ES with a difference value of greater than two. However, five of seven cultural ES show the highest urgency mean values of greater than two. To name a few, social setting and comfort for use were recorded at 2.51 and 2.12 respectively. Meanwhile, both supporting ES; species diversity, and habitat for wildlife show high urgency with 2.67 and 2.03 values.

Lamberet to Wesen street corridor indicated the highest urgency for cultural ES, in particular, longer pavement life, comfort for use, social setting, and physical exercise with respective vales of 2.94, 2.80, 2.76, and 2.60. Meanwhile, species diversity (2.70) is the only highest ES demanded in urgency along the Alembank to Ayertena street corridor.

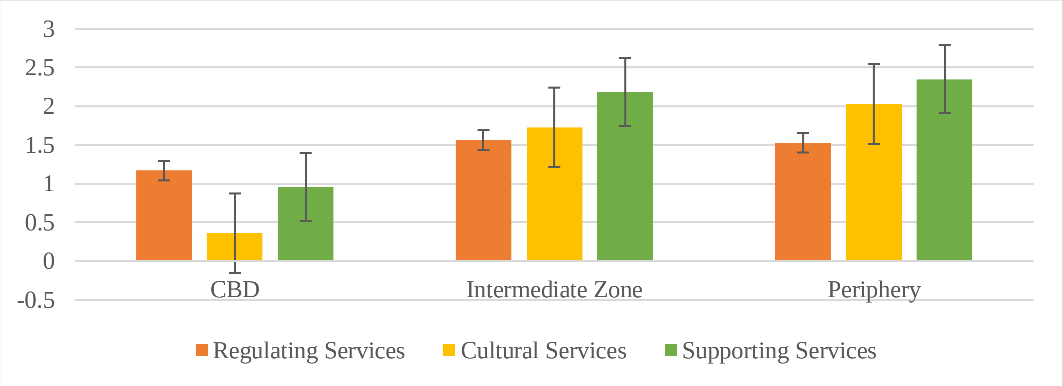


Figure 4.12 Ecosystem service apparent urgency assessment (Supply vs Demand)

Table 4-19 Summarized street user-based mean assessment of ecosystem service supply, demand, and apparent urgency from urban street trees in the inner city (CBD), Intermediate zone (Inter), and Periphery zone (Peri) of Addis Ababa, Ethiopia.

Ecosystem Services	Ecosystem Sub-services (Indicators)	Perceived Supply			Future Demand			Apparent Urgency		
Regulating Services		**CBD**	**Inter**	**Peri**	**CBD**	**Inter**	**Peri**	**CBD**	**Inter**	**Peri**
Local Climate Regulation	Thermal comfort	3.7	3.08	3.26	4.6	4.42	4.45	0.9	1.34	1.19
	Shade provision	3.69	3.19	3.36	4.65	4.25	4.49	0.96	1.06	1.13
Air Quality Regulation	Dust reduction / removal	3.43	2.65	2.22	4.28	4.05	4.25	0.85	1.4	2.03
	Carbon sequestration	3.34	2.83	2.99	4.34	4.26	4.14	1	1.43	1.15
	Noise reduction	2.45	2.08	2.21	4.06	4.03	4.22	1.61	1.95	2.01
Storm water Management	Flood/runoff control	2.69	2.43	2.81	4.11	4.28	4.29	1.42	1.85	1.48
	Trapping Rainwater	2.64	2.34	2.69	4.09	4.27	4.41	1.45	1.93	1.72
Cultural Services		**CBD**	**Inter**	**Peri**	**CBD**	**Inter**	**Peri**	**CBD**	**Inter**	**Peri**
Aesthetic Value	Inspiration / Motivation	4.03	3.06	2.87	4.19	4.31	4.46	0.16	1.25	1.59
	Street beautification	4.4	2.6	2.59	4.42	4.64	4.68	0.02	2.04	2.09
	Supporting longer pavement life	3.58	2.74	2.56	4.07	4.26	4.37	0.49	1.52	1.81
	Creating sense of Place				3.77	4.1	3.94			
Recreation and Human Health	Physical exercise	3.47	2.06	2.03	3.8	3.96	4.07	0.33	1.9	2.04
	Emotional and psychological health	3.68	2.46	2.35	4.32	4.2	4.4	0.64	1.74	2.05
	Social setting	3.85	2.3	2.06	4.37	4.27	4.57	0.52	1.97	2.51
	Comfort for use	4.09	2.93	2.59	4.46	4.61	4.71	0.37	1.68	2.12
Supporting Services		**CBD**	**Inter**	**Peri**	**CBD**	**Inter**	**Peri**	**CBD**	**Inter**	**Peri**
Biodiversity	Tree species diversity	3.3	2.06	1.75	4.22	4.35	4.42	0.92	2.29	2.67
	Habitat for wildlife	2.69	1.85	1.75	3.69	3.93	3.78	1	2.08	2.03
Provisioning Services		**CBD**	**Inter**	**Peri**	**CBD**	**Inter**	**Peri**	**CBD**	**Inter**	**Peri**
Food provision	Edible Fruit Provision				3.46	3.24	3.31			

Legend: Lacking or Urgent — Intermediate — Present or Sufficient

Correlation between Type of Street Users and Ecosystem Services with Apparent Urgency

In this study, apparent urgency for ES is shown towards local climate regulation, stormwater management, and aesthetics and recreation. Local climate regulation, particularly shade provision and thermal comfort is identified as the urgently demanded ES by pedestrians and street vendors with a 1.21 mean value, while car users show only a 0.04 difference from the supply and demand assessment.

When it comes to stormwater management, in particular, runoff reduction and rainwater trapping; street vendor's and car user's responses show great urgency with respective mean values of 2.1 and 1.88 difference from supply and demand assessment. Aesthetics and recreation, on the other hand, is urgently demanded by pedestrians, street vendors, and street fronts with 1.54, 1.47, and 1.24 mean values respectively.

Table 4-20 Correlation between Type of Street Users and Ecosystem Services with Apparent Urgency

Type of Street Users	Apparent Urgency		
	Local Climate Regulation	**Storm Water Management**	**Aesthetics and Recreation**
Pedestrians	1.21	0.66	1.54
Street Vendors	1.01	2.1	1.47
Street Fronts	0.71	1.23	1.24
Car Users	0.04	1.88	0.38

Legend: Lacking or Urgent — Intermediate — Present or Sufficient

In general, the correlation shows how pedestrians tend to demand local climate regulation and aesthetics rather than stormwater management. Whereas Street vendors and car users show great interest in stormwater management.

Figure 4.13 Correlation between Type of Street Users and Ecosystem Services with Apparent Urgency

4.1.4 Ecosystem Disservices from Urban Street Trees in Addis Ababa

Ecosystem disservice assessment was performed with a list of predefined potential ecosystem disservices from urban street trees. The results show that 60.9% of 417 street users encountered one or more ecosystem disservices from urban street trees in Addis Ababa. Whereas the remaining 39.1% of respondents never encountered any ecosystem disservice.

In particular to each street corridor, Churchill and Alembank to Ayertena Kidanemihret street corridors were the ones with minimum ecosystem disservice encountered. Figure 4.12 below show the number of responses recorded for yes or no question on whether street users have encountered any of listed ecosystem disservices on their preferred street corridor.

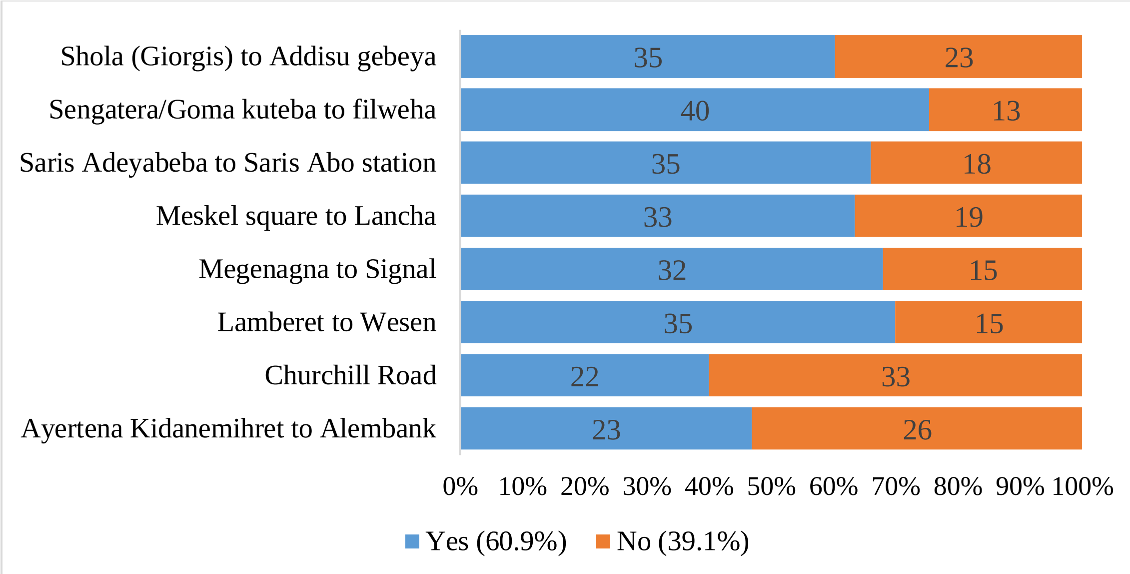


Figure 4.14 Street user's Ecosystem Disservice encounter

Given the possibility of selecting multiple options, 417 street users gave a total of 601 responses regarding ecosystem disservices. From this, 126 respondents (21%) encountered littering and poor aesthetic quality of the surrounding environment because of urban street trees. The second and third largest share of ecosystem disservices encountered in the inventoried streets is damage to property and cars, tree branches falling, and obstructing use of space, accounting 17%, 16.1%, and 14.8% respectively. Table 4.18 shows the number of respondents, their percentage for a total number of responses, and the percentage from multiple response cases.

Table 4-21 Distinct and multiple response count of Ecosystem disservices encountered by street users

Ecosystem Disservices	**Responses**		**Percent of Cases**
	N	Percent	
Tree branch falling	97	16.1%	38.0%
Dear or dried trees	62	10.3%	24.3%
Littering and Poor aesthetic quality	126	21.0%	49.4%
Blocking view	54	9.0%	21.2%
Causing drainage problems	28	4.7%	11.0%
Damage to cars, property, and buildings	102	17.0%	40.0%
Obstructing use of space	89	14.8%	34.9%
Hiding traffic signs and lighting	35	5.8%	13.7%
Other	8	1.3%	3.1%
Total	601	100.0%	235.7%

As we can see from the stacked bar chart (Figure 4.13), ecosystem disservices identified on the study are assessed per each street corridor. The results show that tree branch falling and littering disservices are more common in Alembank street corridor. Obstructing use of space by street trees is selected by 21 respondents in Lamberet to Wesen street, and 22 respondents on Meskel Square to Lancha street. Tree branch falling and dear or dry trees are mostly recognized disservices on Churchil, Megenagna, Sengatera, and Piassa street corridors. Damage to property, cars, and buildings is the most common ecosystem disservice on Meskel Square and Sengatera streets.

Figure 4.15 Ecosystem Disservices encountered on site

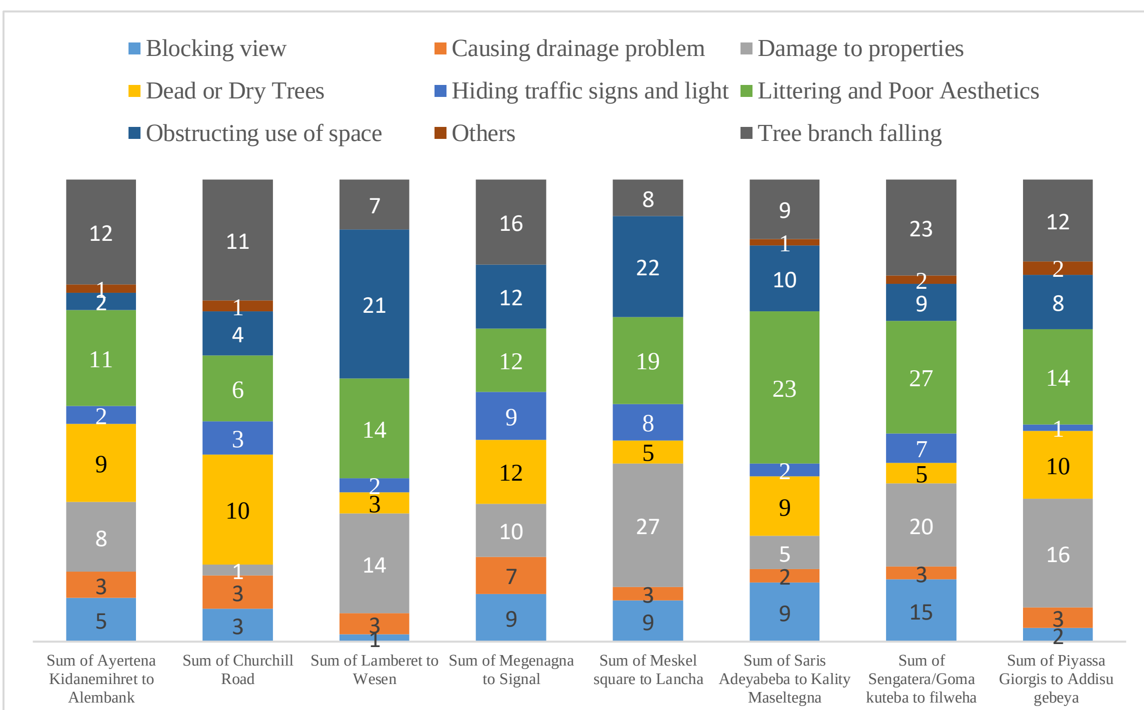


Figure 4.16 Ecosystem disservices identified per each street corridor

Correlation of Ecosystem Disservice Encounter with the Overall Assessment of Street Tree Planning and Management Practice

The correlation assessment shows the impact of ecosystem disservice encounters negatively influences public perceptions of urban street tree planning and management practice. 35.29% of street users who encountered Ecosystem Disservice from urban street trees perceived poor planning and management practice, while 27.65% of street users perceived medium practice. On the other hand, 26.04% and 24.75% of street users who never encountered Ecosystem Disservice perceived poor and medium planning and management practices respectively.

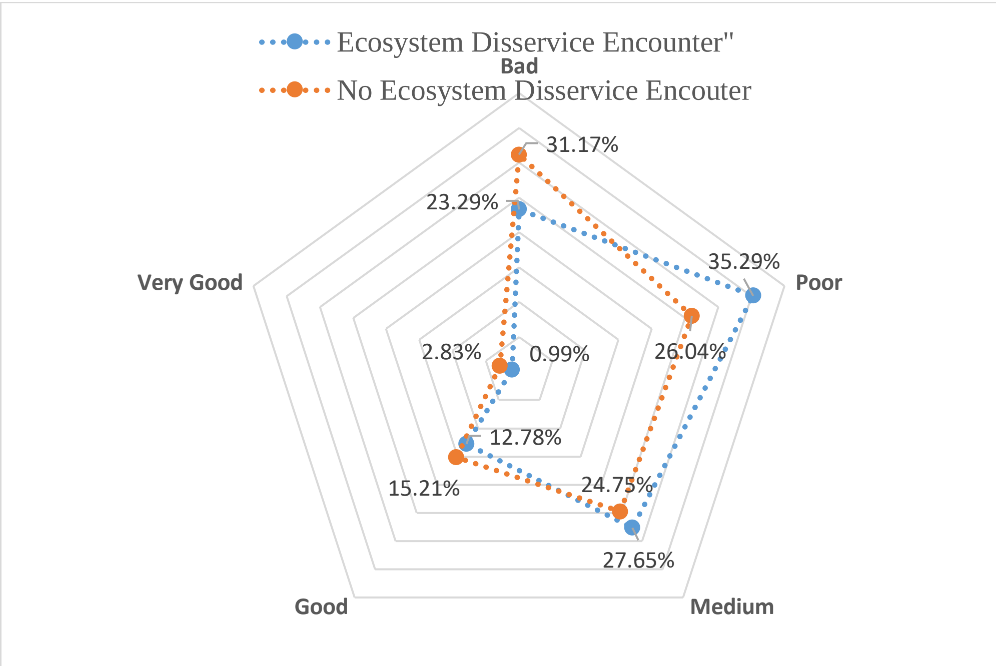


Figure 4.17 Correlation of Ecosystem Disservice Encounter with the Overall Assessment of Street Tree Planning and Management Practice

4.1.5 Challenges of Urban Street Tree Development and Management Practice

4.1.5.1 Urban Street Tree Development Practices

Urban street tree development practices; planning and planting has to take a range of considerations ranging from street user's interest, space allocation for movement, soil strata, public participation, planting location, overhead power line, infrastructures on the ground, and building setbacks to make the process successful and sustainable.

Key green development and related experts from Addis Ababa city were interviewed to reflect their agreement on whether these key considerations are taken while developing urban street trees in Addis Ababa. According to the results obtained, building setback comes on top with 10.53% strong agreement and 52.63% agreement on its consideration. Followed by planting location; as in the harmony, alignment, spacing and alike have 52.63% agreement, 31.58% disagreement, and 15.79% strong disagreement.

The remaining listed considerations are dominated with disagreement and strong disagreement. To name a few; public participation, street user interest, space allocation for movement, and alignment with other infrastructures on the ground have only 5.26% strong agreement each. Space allocation for movement seems to be not considered enough with 42.11% disagreement and 21.05% strong disagreement. The consideration of overhead power lines got positive reflection by 36.85% (10.53% strong agreement and 26.32% agreement), while the remaining 42.11% disagreed and 21.05% strongly disagreed. Figure 4.14 presents the detailed percentage of expert perception towards each consideration.

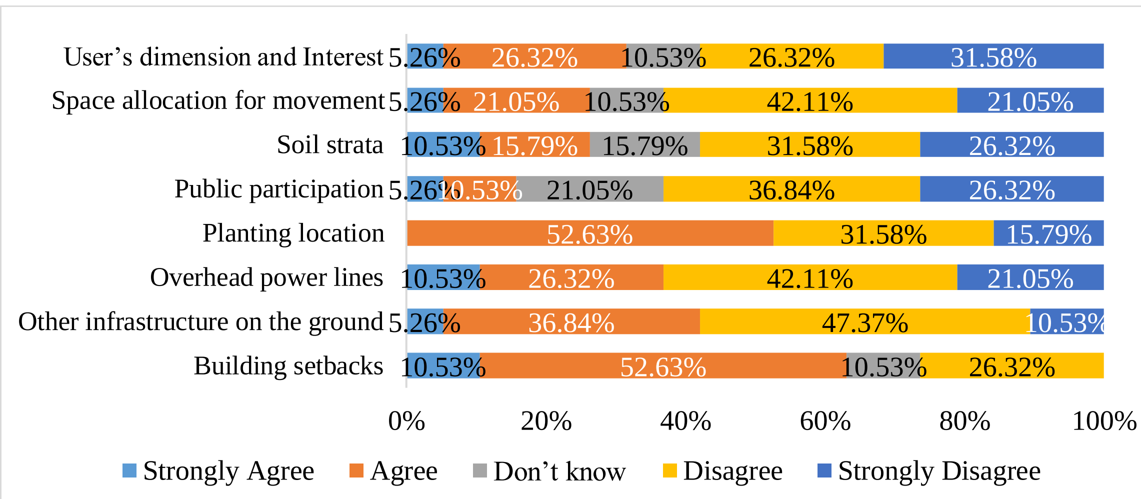


Figure 4.18 Expert's perception towards the considerations of street tree development

Experts were also questioned on the factors they would consider the most when determining the species of street trees in Addis Ababa. According to the results reported by 19 experts with a possibility of making multiple selections, species availability and ecosystem service provision ranked the highest with 63.16% of selection each. Moreover, experts mentioned the dominant ecosystem services considered were aesthetic and recreational services.

Durability and maintenance need, water demand, and native or exotic nature of street trees were the next highly considered factors in line with 52.63 %, 47.37%, and 42.11% respectively. Pollution resistance, cost (market value), and wood strength were on the other hand, the least considered factors with a respective value of 31.58%, 15.79%, and 5.26% selection (Table 4.19).

Table 4-22 Factors considered for urban street tree species selection

Factors considered for species selection	Frequency of experts	Percentage of experts (multiple selection)
Availability	12	63.16%
Cost / Finance	3	15.79%
Ecosystem service provision	12	63.16%
Native/Exotic	8	42.11%
Growth rate	7	36.84%
Wood strength	1	5.26%
Pest resistance	7	36.84%
Water demand	9	47.37%
Durability and maintenance need	10	52.63%
Pollution Resistance	6	31.63%

4.1.5.2 Urban Street Tree Development Challenges

The development of urban street trees in Addis Ababa faces challenges broadly related with their planning and design, as well as their implementation. Key experts in the subject area ranked the below mentioned list of developmental challenges, with the first rank requiring high priority and the last needing low priority to mitigate its impact.

Planning and design related Challenges

- **Species selection**: Out of all developmental challenges, 15.79% of key experts ranked the challenge of species selection as the first one requiring immediate action, second and third rank was given by 26.32% of experts each. While only 31.58% vote is given for fourth, fifth, and sixth rank that require less attention.
- **Space allocation**: taking the majority's share of developmental challenges ranked as the first priority (42.11%), space allocation is majorly identified planning and design challenge in Addis Ababa. Only 5.26% of key informants suggest the challenge of space for street tree development, to be less prioritized.

Implementation Challenges

- **Poor integration among stakeholders**: 31.58% of respondents believed that poor integration of stakeholders (institutions and the public) is threatening the successful implementation of street tree development in Addis Ababa. While 26.32% ranked the problem of stakeholder integration as the second most prioritized challenge.
- **Compacted soil condition**: Although 15.79% of respondents ranked the challenge of soil compactness as second and third, majority vote goes against it. The largest percentage of 42.11% of experts ranked soil compactness as the last challenge needing priority for mitigation. Both the fourth and fifth rank is given 21.05% of key experts.
- **Smaller size of planting pits**: the size of planting pits were founded to be thirty centimeter square (30cmx30cm) in most street corridors, and up to 50cm square on some streets. The only street corridor with wider planting pits was Churchill Road (1m x 1m). Accordingly, 10.53% of experts ranked this challenge as the first, while 15.79% suggested that widening of planting pits have to be our third most important task while implementing street tree development.
- **Finance**: following the challenge of soil compactness, financial issues are ranked the next least important thing to fix, with 36.84% ranking sixth position and 26.32% for fifth position. Figure 4.15 below shows the detailed percentage of all identified street development challenges per their given rank.

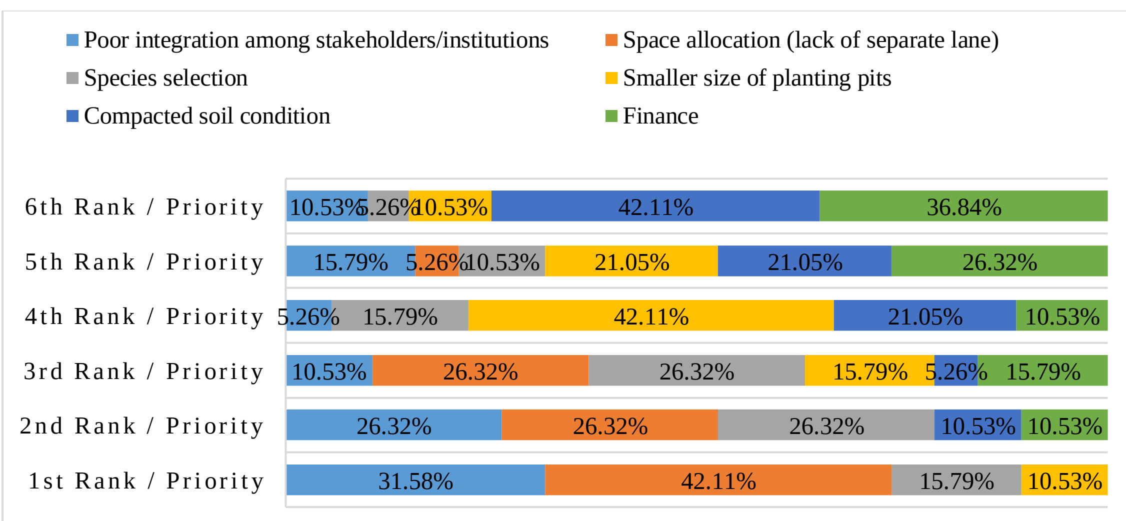


Figure 4.19 Expert's perception towards the challenges of street tree development

Crosstabulation of Education status and climate resilient species selection practices

The majority of respondents across all educational levels fall into the "Don't Know" category (236 out of 417 respondents, or 56.6%). This indicates a significant lack of awareness or understanding of climate-resilient species selection practices. A smaller proportion perceives the efforts as "High" (21 respondents, or 5.0%) or "Very High" (4 respondents, or 0.96%), suggesting limited recognition of strong practices in this area.

Table 4-23 Crosstabulation of Education status and climate resilient species selection practices

Educational Status		Don't Know	High	Low	Very High	Very Low	Total
Certificate/Diploma	72	7	9	1	25	0	114
Degree	50	4	14	1	17	4	90
Master’s and above	10	0	7	1	22	0	40
Read and Write	104	10	18	1	40	0	173
Total	236	21	48	4	104	4	417

Crosstabulation of Education status and climate resilient species selection practices

76 individuals with a certificate/diploma reported "Don't Know" regarding the challenges of infrastructure integration in street tree planning, suggesting a lack of awareness or clarity on the topic. 29 respondents from this group reported Very Low perceived challenges, indicating they feel street tree planning is not very difficult for infrastructure integration. Many individuals, regardless of education level, are unaware of or unsure about the complexities of this issue. However, a significant number of individuals, particularly those with higher education (degree and above), report lower perceived challenges, suggesting they may have a better understanding of the issue.

Table 4-24 Crosstabulation of Education status and climate resilient species selection practices

Educational Status		Don't Know	High	Low	Very High	Very Low	Total
Certificate/Diploma	76	4	4	1	29	0	114
Degree	49	4	6	1	30	0	90
Masters and above	11	1	10	1	15	2	40
Read and Write	111	5	14	3	39	1	173
Total	247	14	34	6	113	3	417

4.1.5.3 Urban Street Tree Management Practice

Urban street tree management practices involve a range of activities or attributes that were presented for experts to reflect their perception towards their achievement as very good, good, medium, low, and none. Adequate inspection on their health status, application of chemical treatment and technology for pest and related risks, mulching for soil fertility, and pruning of broken branches and overgrown crowns have only 5.26% of good achievement each. While proper fencing and protection of sapling trees got 10.53% of good achievement.

Considering the medium achievement of management practices, continuous watering and pruning of broken branches and overgrown crowns have been selected by 42.11% of experts each. Being the most selected option by experts, poor achievement scored in a range between 31.58% and 52.36% by all management activities. Application of chemical treatment and technology for pest and related risks is the one with the highest score of 47.37% selection as none. The next in line is an adequate inspection of their health status and the replacement of dead or dry trees, each selected by 36.84% of experts. Refer to Figure 4.16 for detailed information on the score of each management activity.

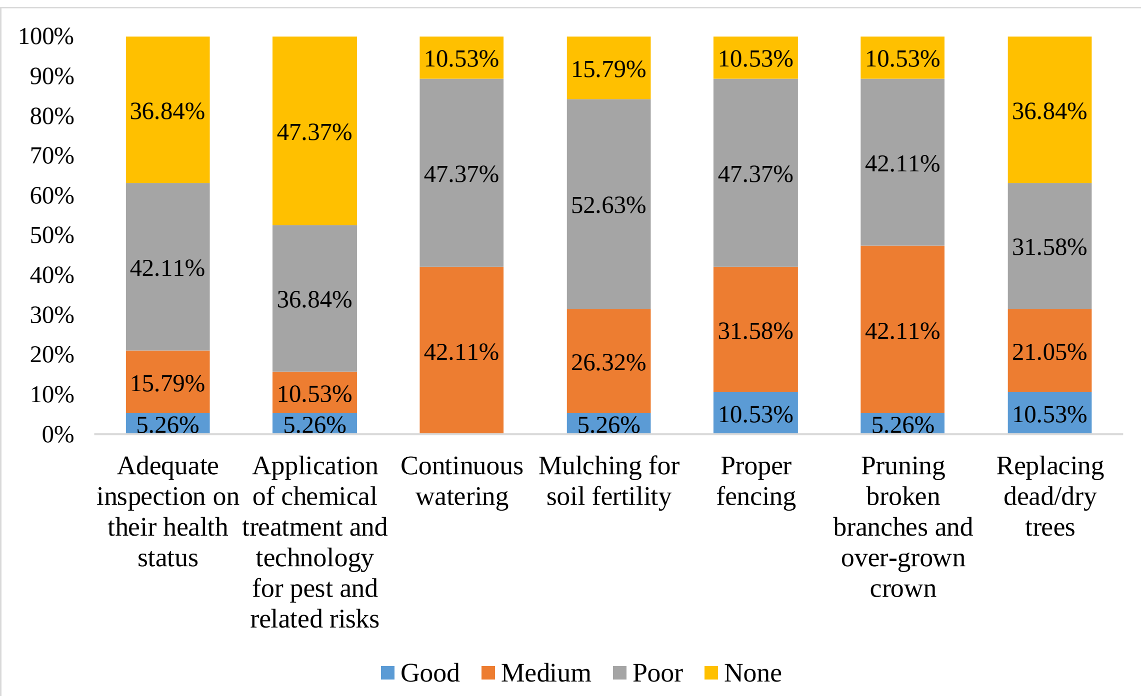


Figure 4.20 Expert's perception towards attributes of street tree management

4.1.5.4 Urban Street Tree Management Challenges

Similar to the assessment of developmental challenges, professionals were asked to rank the seven management challenges listed below in order of the importance of mitigating each one. Among the least ranked challenges, issues pertaining to stolen tree fences are ranked seventh by 57.89% of experts. Water consumption comes as the second least prioritized one with 21.05% selection, again for the seventh rank, 31.58% for the sixth rank, and 21.05% for the fifth rank.

On the contrary, conflict with infrastructure is a highly prioritized management challenge with first and second rank selected by 36.84% of experts each. The lack of skilled experts to undertake management activities is also a highly ranked challenge with first, second, and third prioritized by 26.32%, 15.79%, and 26.32% respectively. Refer to Figure… for each management practice per their ranked prioritization.

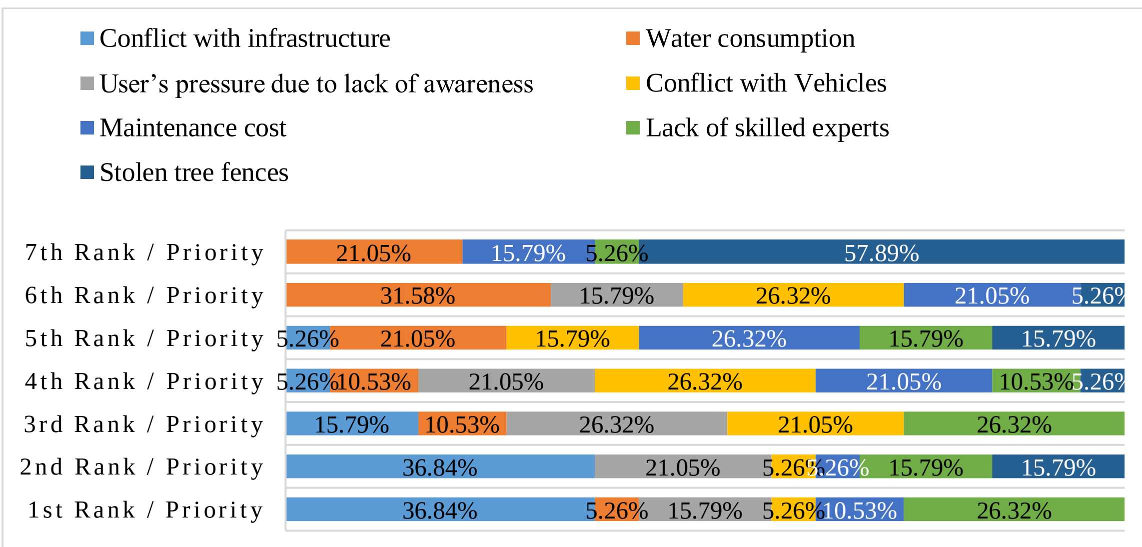


Figure 4.21 Expert perception towards challenges of street tree management

Crosstabulation of Educational status and Evaluation of City Administration's Street Tree Practices

Respondents with lower educational levels (e.g., "Read and Write") appear to have a more critical view of the city administration, as evidenced by the high "Poor" and "None" responses. As educational levels increase, the proportion of "Fair/Medium" and "Good" evaluations tends to rise slightly, suggesting that individuals with higher education may have a more measured or neutral perspective on the issue.

Across all educational groups, "Very Good" ratings are exceptionally low, with only 17 total responses. This indicates a general perception that the city administration's capacity and current practices are suboptimal. The large number of "Poor" and "None" ratings (combined 189 responses) highlights significant dissatisfaction or lack of recognition of effective city administration practices.

Table 4-25 Educational status and evaluation of city administrations street tree planning and management practice

Educational Status		Fair / Medium	Good	None	Poor	Very Good	Total
	Certificate/Diploma	28	22	29	29	6	114
	Degree	31	21	14	20	4	90
	Master's and above	16	9	6	8	1	40
	Read and Write	55	29	25	58	6	173
Total		130	81	74	115	17	417

Crosstabulation of Educational status and Evaluation of City Administration's Street Tree Practices

The most common rating across all usage frequencies is "Poor" (115 respondents), followed by "None" (74 respondents). These results indicate significant dissatisfaction with street tree planning and management practices among frequent and less frequent users alike. Positive ratings, including "Good" (81) and "Very Good" (17), are relatively rare compared to negative ratings. Users who engage less frequently (e.g., once a month) show a slightly better perception.

"Fair/Medium" received 130 responses, making it the second-highest category after "Poor." This suggests that many users perceive the planning and management practices as moderate, not fully satisfactory but not completely inadequate either. Frequent street users, especially those using streets daily or multiple times a day, are more likely to rate the practices as "Poor" or "None." This indicates a need for immediate improvements in tree planning and management to address their concerns.

Table 4-26 Crosstabulation of usage frequency with evaluation of city administration street tree practice

	How often do you use this street?	Fair / Medium	Good	None	Poor	Very Good	Total
	Daily	52	38	47	72	10	219
	Once a month	14	3	6	9	2	34
	Once a week	14	16	7	3	3	43
	Other	7	2	1	0	0	10
	Three times per day	7	3	3	5	1	19
	Twice per day	36	19	10	26	1	92
Total		130	81	74	115	17	417

4.1.6 Key Findings

- Lack of species diversity, street tree connectivity with trees in different street corridors, and with surrounding green infrastructure components, and poor adaptation to change
- Gaps regarding balancing the supply and demand of Ecosystem services (stormwater management, local climate regulation, aesthetics, recreation, human health, and biodiversity) show apparent urgency
- Poor integration of stakeholders (institutions and the public) is threatening the successful implementation of street tree development
- Species selection and space allocation are among highly prioritized planning and design challenges
- Issues with planting pits and pedestrian tile damage
- Challenges regarding obstruction of usable space and conflict with Infrastructure
- Street user pressure from lack of awareness, and lack of skilled experts were the most prioritized street tree management challenges that required immediate solution

4.2 Discussion

4.2.1 Resilience Assessment of Existing Urban Street Tree Planning and Management

Street trees are essential for improving the resilience and sustainability of urban settings (Säumel et al., 2016). The resilient assessment of existing urban street trees on the selected street corridors considers both the planning and management aspects, so does the study by Biggs et al., (2012). In light of the resilience principles outlined in the study's conceptual methodology, it was required to document the physical components—in this case, the species identification and count. Folke, (2016) also recommended this.

Species identification result shows, despite the different locational and zone characteristics, there is high similarity of street tree selection and implementation along CBD, Intermediate, and Periphery zones. Meaning, street tree planning and implementation strategies have to consider the dynamic environment of urban areas. (Falk and Millar, 2016) also stressed the need for resilience-based paradigm towards dynamic environments.

Diversity and Redundancy

The first resilience assessment on Addis Ababa's urban street trees has to deal with their diversity and redundancy. The study utilized Shannon diversity index to assess the species richness, while the Shannon Equitability Index was used to assess their evenness (Agrawal and Gopal, 2013). The inner-city zone's street corridors have the largest species diversity and redundancy because they are more likely to be visited by foreigners, tourists, investors, and media coverage. On the other hand, street corridors on the periphery zone are suffering from trees with similar species types and domination of one or two species types. While a study in South Africa shows completely diverging results where street trees in suburbs were more diversified and rich in species type, while inner cities were less dense and rich in species (Kuruneri-Chitepo and Shackleton, 2011).

As a result from expert respondents, experts became drawn to the lack of functional redundancy and species richness, showing results that converged with street user data that demonstrated limited diversity and redundancy.

Additionally, it was discovered that street corridors in the CBD had significant levels of the age diversity variable, which explains why site surveys yielded the highest Shannon diversity index. The selection criteria for street trees planted in the last ten years appear to have been overlooked, and the dominance of some species is apparent. The highest species' evenness and richness are seen in old streets that have historical and geographic advantages. In summary, managing diversity and redundancy is necessary to sustain ecosystem service (ES) output over the long run in the face of disturbance and change, as forwarded by Biggs et al.,(2012),

Connectivity

When evaluating the resilience of street trees in Addis Ababa, connectivity is yet another important factor to take into account (Woldegerima et al., 2017). It is critical to examine the layout and direction of urban streets to maintain connectivity (Sharifi, 2019). Unfortunately, the scope of the study and the number of street corridors that were inventoried made it challenging to include a spatial assessment of each tree's green connectedness with the surrounding green infrastructure elements as well as with other trees. Nonetheless, expert insight might still be taken into consideration.

Street trees, according to experts, have stronger connections with one another than with the environment. The standard of five to ten meters between plantations is the cause of this. However, failures among the planning, design and implementation experts to consider the bigger picture of urban green infrastructure resulted in relatively medium and low connectivity of street trees with their surroundings. Addressing this will help Addis Ababa create a thorough resilience plan for its street trees, which will ultimately improve the urban environment's adaptability and sustainability (Herslund et al., 2018; Rubio and Scott, 2020).

Participation

Street users are rarely offered the opportunity to take part in plantation programs, the survey found. They only had the chance to plant trees in their neighborhood (with their own motivation). As the study by Pauleit, (2003) shows, better ownership and responsibility for street trees can result from involving the community in decision-making processes. The ability of a management system to recognize and analyze shocks and disturbances could be improved with the help of stakeholder engagement, which is essential for enabling the teamwork needed to adapt to change in social-ecological systems (Sharifi and Yamagata, 2018). The study did yield some contradictory findings, though.

The incorporation of public perception was rarely applied while selecting species (on the planning and design phase). Correlation of obtained results was also made with gender, resulting in disproportionate participation of females. Furthermore, the categorized activity type reveals that, as opposed to providing, females were mostly engaged in plantation and management chores.

Adaptive Capacity

The capacity of urban street trees to adapt to changes from stresses and hazards is referred to as Adaptive Capacity (Brooks and Adger, 2005). Stresses from urbanization and domination of gray infrastructure comes to be very crucial when considering street trees (Seok et al., 2022). In evaluating Addis Ababa's urban street trees' adaptability, it's critical to take into account their resilience to shocks like disease outbreaks, severe weather, and urban expansion (Koricho and Song, 2021; Woldegerima et al., 2017).

As shown by a range of studies, mainstreaming trees in urban streets is never easy and requires a thorough consideration of strategies to make them withstand the stress posed from the urbanizing environment (Adem, 2020; Brandt et al., 2021).

The environment and its street users seem to be making it even harder for Addis Ababa's street trees to withstand the challenges. The findings indicate that older trees are having difficulty with maintenance, and smaller trees are having difficulty surviving; these factors together contribute to street trees' limited ability to adapt. Lack of water, poor management practices, improper installation of protective palettes, and other issues are causing suffering for saplings. While overgrown branches were falling onto streets due to improper pruning, older trees were also being taken down for new developments. According to the expert interview, the results are consistent with the physical observations and are primarily medium, low, or demonstrate no integration of adaptive ability resilience principles.

4.2.2 Urban Street Tree Ecosystem Service Supply and Demand Assessment

Ecosystem Service Supply

Given the political and governance factors on the most valuable street corridors of CBD compared to other zones, the implementation of street tree planning and management is at better level. Although it is yet to be perceived high, street users perception about CBD zone shows medium level of ES supply from street trees. A study by Buffam et al., (2022) also highlights local climate regulation, shade provision, air quality regulation, reduced UHI, stormwater management, and flood control perceived regulatory ES supplies.

Besides, cultural ES recorded the most sufficiently supplied ES along streets of CBD. On the contrary, supporting ES like habitat for wildlife and tree species diversity seems to be affected by the high interaction of urban activities and resulted in the least perceived ES. The high level of impervious surface construction on the other hand brought negative impact on the storm water management ES of street trees. The case of impervious surfaces and their forefront impact on stormwater management and flood risk is also discussed by Beecham and Lucke, (2015). Other studies also highlighted a medium level of cultural ES supply in Addis Ababa streets (Buffam et al., 2022).

The rest zones of Addis Ababa, on the other hand, shows lacking ES supply. Besides, all four categories of ES were perceived to be lacking by street users along the intermediate and peripheral zones. Other studies worldwide mentioned how street tree planning and management are related with human nature, and their interaction often involves biophilia, the use of orderly nature as a symbolic commodity, and, more recently, ecological stewardship (Laurian, 2019). Unfortunately, Addis Ababa's results show the lowest benefit being gained by its street users, and street trees are not serving their potential.

Ecosystem Service Demand

Except for edible fruit provision, and Habitat for wildlife ES, the remaining ES and indicators show high demand from the street user's side. On the contrary, similar studies (although they not only focused on street trees), show the highest demand for provisioning ES (Buffam et al., 2022). Cultural ES demand assessment also shows relatively limited value, showing the focus of government is already on street beautification.

The purpose and frequency of street users street usage had a major effect on the obtained result. More than half of street users surveyed were on the street for work or business, and for walking purpose. Whereas, street users who came for recreation, visiting and appointments were very limited in number. Hence, their demand must have been shaped towards regulating and supporting, rather than cultural. For example, commuters may prioritize noise and pollution reduction, whereas recreational street users may prioritize aesthetic and leisure benefits. Comparably, regular street users are more likely to recognize the everyday advantages of street trees (Chang Zhao, Heather A. Sander, 2015), than infrequent visitors who might take these benefits for granted.

Apparent Urgency Assessment (Supply vs Demand)

The apparent urgency assessment solely relied on street user perceptions, indicating that ES is urgently required when perceived supply is significantly less than demand. Apparent urgency towards the previously described ES exhibits respondents attachment to nature and greening efforts for human–nature interaction (Drew-Smythe et al., 2023a).

Regarding the obtained result, urgent ES demanded by street users were identified per each zones and street corridor (Table 4.17 and Annex V). As mentioned earlier, this assessment revealed the limited or no need for more cultural ES from urban street trees in CBD zones of Addis Ababa. Because of the green legacy initiatives in the country, sufficient ES supply and least demand is recorded regarding ‘street beautification’, ‘comfort for use’, ‘physical exercise’, and ‘inspiration’.

In terms of storm water management, a better understanding of the nature and extent of tree-storm water interactions is necessary for the effective use of trees (Berland et al., 2017). In essence, the highly increasing urbanization rate and continues covering of porous surfaces with impervious surfaces resulted in the intermediate urgency of storm water management ES along CBD streets. A study by Beecham and Lucke, (2015) also support this claim, where the more urbanized and impervious the site is, the more urgent ES is demanded.

Regarding the intermediate zones, street users tend to be needing urgent attention towards noise reduction, storm water management, street beautification, social setting improvement, and supporting biodiversity ES. Comparable to the rest ES indicators, 'local climate regulation' and 'Aesthetic value' were the only ES with low or medium level of urgency. Peripheral zones, on the contrary, highlighted the urgent need for ES on almost all ES categories.

Biodiversity is recognized as important for human health, and loss of biodiversity could have devastating effects on both human's habitus, food supply and hence overall survival (MEA, 2005), and yet the highest urgency along periphery zone was witnessed for this ES.

In summary, this study reveals the unbalanced green transition efforts being implemented, where selected key areas are developed and given priority while the rest street corridors (in particular, along the periphery zones) are forgotten. The diversified urgency for different ecosystem services categories highlights the need to implement balanced, well-networked, and multifunctional urban green infrastructure along urban streets, as recommended by ESPON EGTC, (2019).

Furthermore, Pataki et al., (2021) pointed out that the most potential benefits of urban trees for the environment and human health are those that may be achieved by carefully planned tree planting and site-specific design changes at the local, and municipal levels. The best results for tree planting at these scales will come from thoughtfully selected sites, careful observation, and adaptive management.

Correlation of Street user Types with Apparent Urgency Assessment (Supply vs Demand)

As each type of street user interacts with urban street trees in unique ways, leading to different ecosystem service demands, the correlation of the type of street users with the prioritized ES was necessary. Moreover, a study by Buffam et al., (2022), interpreted apparent urgency for ES as those with the potential to address urban challenges.

Pedestrians and street vendors are mostly looking for shade, cooling, and beautifying enhancements because of their interactions with the street. While businesses with street fronts prioritize visual attractiveness for greater financial returns, car owners gain from controlled stormwater runoff as well as enhanced parking convenience and security.

Hence, these findings help while suggesting possible solutions that are better suited for different types of street users.

4.2.3 Ecosystem Disservices from Urban Street Trees in Addis Ababa

Street trees ought to be considered in terms of street users' broader attitudes toward the natural environment and their ability to share resources and space (Woudstra and Allen, 2022), but it's also important to talk about their advantages and disadvantages. Urban street trees serve the environment and their street users in many ways (Burden, 2006; McPhearson et al., 2014). They however also have various drawbacks that may affect the urban environment and its residents (Lyytimäki, 2017; Lyytimäki and Sipilä, 2009; Masini et al., 2023). This research’s findings in Addis Ababa example indicate a high incidence of ecosystem disservices associated with, among other things, littering, infrastructural damage, and obstructing use of space.

Littering on sidewalks and roadways was caused by leaves, flowers, fruits, and branches dropped by street trees; this was particularly prevalent along the Alembank, Sengatera, Saris, and Addisu Gebeya street corridors. Tree roots along the Lamberet roadway segment harm roads, walkways, and underground utilities as they spread in search of water and nutrients. Furthermore, the spread of tree roots near buildings destroys foundations, walls, and pavement, requiring building owners to pay high repair costs (McPhearson et al., 2014).

Regarding obstruction of space, overgrown trees with low-hanging branches obstruct pedestrian walkways, diminishing accessibility and providing a safety risk, notably along Megenagna, Sengatera, and Piassa street corridors. Similarly, Masini et al., (2023) assessed the negative impacts that urban street trees pose, and discovered that the impact increases with tree size. Ecosystem disservices can lead to a range of negative perceptions about urban street tree planning and management ranging from demand for better management, preference for alternative solutions, and resistance towards urban greening initiatives. The prevalence of disservices makes affected groups skeptical about the benefit of street trees, thereby perceiving lower planning and management practices. Exposure to disservices also leads to better demand for street tree management including frequent maintenance, species selection, and alike.

4.2.4 Challenges of Urban Street Tree Development and Management Practice

Street tree Development Practice

In urban environments, there is a strong need to increase systematic work on selection and even breeding of trees and shrubs adapted to urban conditions, with the aim of finding genotypes that can easily be propagated, produced, and established in urban streets (Sæbø et al., 2005). This is particularly true if planners and practitioners are to be successful in expanding the variety of tree species used in cities. The study also noted that adaptability to site conditions, function of street trees, and the cost required for development and management have to be the three main considerations taken while selecting tree species.

On the contrary, results obtained from experts in Addis Ababa shows the dominance of limited types of tree species. On which, their selection mainly considers availability and cultural (recreation and aesthetics) ecosystem service provision, while adaptability to site conditions and cost of development and management were recorded to be the least considerations made while selecting species.

Street tree Development challenges

Given the influence of urbanization on urban trees, species selection will be either an advantage (AARP Livable Communities and Walkable and Livable Communities Institute) or a challenge. In the case of Addis Ababa's practice, monotonous species selection is being a challenge hindering the benefits that would have come with diversified street trees. A study by Zerihun also highlighted the three most prominent barriers to tree planting, from which, limited knowledge about which species are suitable for planting was the major one (Workneh, 2021). Besides, the proper selection and planting of trees reduces sidewalk repair costs and potential damage to utilities in urban neighborhoods.

Implementation of street tree development is also better realized with the integration of a range of stakeholders be it from provisioning, management or other activities. Unfortunately, respondents in Addis Ababa believed that there is poor integration of stakeholders in the process. Likewise, a study by Aynachew, (2014) and Workneh, (2021) have put a resembling result showing a low level of street users satisfaction with respect to municipal's tree planting and management practices.

The wider the planting pits are, the better-suited conditions are created for street tree growth and maturity (Adem, 2020). Doing so would ease the effort of water, soil, and mulch provision (Monteiro et al., 2019; Pauleit, 2003). Addis Ababa's street side planting pits seem to be changing for the good on recently implemented street development practices like Churchill, and some are still being a challenge on other parts of the city.

Considering the high value and focus given for green legacy and tree planting efforts by Ethiopia's government, finance for tree plantation is never an issue. Unfortunately, a study by Toxopeus and Polzin, (2021) shows the development of street trees is being hampered financially by a lack of cooperation between public and private financiers as well as by the exclusion of the benefits of nature-based solutions from accounting and valuation techniques.

Street Tree Management Practice

Urban street tree planning, design, and implementation will bear the required fruits of ES for the intended street user, only when proper management practice is undertaken (Pauleit, 2003). Adequately inspecting their health status, applying treatments to protect them from pests, providing water and mulch for better growth rate, proper fencing, pruning and replacement of dead or dry trees are among the activities practiced to manage street trees in shape.

Street tree Management challenge

Conflict with infrastructure is a highly prioritized management challenge that needs immediate response. Given the lack of integration among different concerned bodies in the infrastructure development sector (Adem, 2020; Workneh, 2021), street trees in Addis are being impacted negatively. Such practices are threatening the intended maturity of newly planted street tree saplings, which in turn will bring huge gap of ES supply and demand.

Lack of skilled experts, street user pressure from lack of awareness, maintenance costs, and alike were among other management challenges. Study by (Buffam et al., 2022) also shows how the effort of street tree management is being challenged.

4.3 Planning Implications of the Study

The study has implications for other cities in developing countries regarding urban street tree planning and management. The thoughtful consideration of ecosystem services and disservices rather than mere aesthetics and availability is the first crucial point in realizing balanced and long-term ecosystem service from urban street trees. Future directions has to focus on identifying tree species that are well suited to local environmental conditions and provide multiple ecosystem services, while utilizing strategic tree plantation that takes into account the location to provide maximum ecosystem services.

Second, the use of resilience thinking in street tree planning and management enables well-adapted, diverse, inclusive, and localized streetscapes, hence providing a suitable and contextualized implementation for the entire process. It is also implied that promoting integration by complementing other green infrastructure elements with urban street trees should be a priority. Developing comprehensive maintenance and management plans to ensure long-term ecosystem service provision and resilience of street trees comes at the very end of planning implications forwarded by this study.

Chapter 5: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In urban settings, street tree planning and maintenance represent a crucial intersection of ecological resilience and ecosystem provision. In recent years, the importance of urban greenery has expanded to include more environmental, social, and economic advantages beyond mere aesthetics. Street trees are essential to resilient urban ecosystems because they reduce air pollution, control urban microclimates, improve biodiversity, and foster mental health. In light of the aforementioned issues with urbanization and climate change, this study examined the synergies between resilience and ecosystem services supply and demand, thereby providing insightful analysis and workable recommendations for the promotion of resilient, livable, and green cities.

This study gives due attention to shed light on the various challenges and research gaps related to ES assessment and resilience thinking in the context of street trees. In addition, this study aimed to bridge the gap between the supply and demand for ES while simultaneously highlighting ecosystem services and disservices of urban street trees.

Moving on, Addis Ababa's street tree planning and management practice has been found to have uniformity in tree species selection. Among the numerous tree species recorded on separate street corridors, Grevillea robusta and *Phoenix canariensis* were the predominant tree species along Addis's streets, reflecting a common selection trend across CBD, Intermediate, and Periphery zones. Despite varying environmental characteristics, there was a high similarity in street tree selection and implementation, suggesting the need for adaptable planning strategies considering urban dynamics.

The dominance of Grevillea robusta highlights potential shortcomings in the municipality's tree selection criteria, emphasizing the importance of considering factors like ecosystem services, origin, durability, maintenance needs, and resistance to pests and pollution for sustainable urban forestry practices.

In the frame of resilience; diversity and redundancy, connectivity, participation and integration, and adaptive capacity were the resilience principles utilized to assess the current situation of street tree planning and management. From which the first two were related to Natural and societal conditions of the Ecosystem Service Cascade Model, whereas, participation, and adaptive capacity were coined with the governance framework of the model.

As per the results obtained from resilience assessment, in particular, the natural and societal domain of Ecosystem Service Cascade, lack of functional redundancy and species richness revealed the limited diversity and redundancy of street trees in Addis Ababa. Moreover, street trees lack connectivity with trees in different street corridors, and with surrounding green infrastructure components. In essence, the supply of ecosystem services is affected.

Regarding the governance framework of Ecosystem Service Cascade (planning and management), participation of relevant stakeholders, in particular, public integration was not achieved through street tree development and management procedures, and correlation of participation with gender revealed disproportionate participation of females. Besides, older trees are having difficulty with maintenance, overgrown branches were falling onto streets due to improper pruning, and older trees are being taken down for new developments. Lack of water, poor management practices, improper installation of protective palettes, and other issues are causing suffering for saplings, resulting in difficulty in adaptive capacity.

As per the assessment of supply and demand, the provision of ES from urban street trees resulted in a gap that require apparent urgency. Regulating ES, in particular, storm water management and local climate regulation show high apparent urgency in CBD, intermediate, and periphery zones of Addis Ababa. Whereas cultural ES, in particular, aesthetics, recreation, and human health are the most urgent ES in the intermediate and periphery zones, and the least urgent in CBD of Addis Ababa. Besides, supporting ES like tree species diversity shows high apparent urgency in intermediate and periphery zones of Addis Ababa. While provisioning ES like Edible fruit production shows intermediate demand and less urgency in Addis's streets.

Regarding the assessment of Ecosystem Disservices, findings indicated a high incidence of ecosystem disservices associated with, among other things, littering, infrastructural damage, and obstructing use of space. Species selection and space allocation were among the identified planning and design challenges with high priority in this study. Hence, availability, ES provision, maintenance need and durability should all be among the most recognized factors for street tree species selection.

Poor integration of stakeholders (institutions and the public) is also threatening the successful implementation of street tree development. While financial issues are ranked among the least priorities to fix regarding street tree implementation. Adequate inspection of their health status, application of chemical treatment and technology for pest and related risks, mulching for soil fertility, and pruning of broken branches and overgrown crowns have recorded the least achievement regarding street tree management in Addis Ababa. On the contrary, conflict with infrastructure, street user pressure from lack of awareness, and lack of skilled experts were the most prioritized street tree management challenges that require immediate solution.

Given the above major findings, this study concludes by forwarding two identified planning implication for future studies and researchers. The findings emphasize how crucial it is to give ecosystem services a higher priority than mere aesthetics and beautification when planning and maintaining urban street trees in developing cities. Besides, it highlights the importance of species selection that considers adaptation to the local environment, and their capacity to offer a variety of ES. Finally, the need to integrate urban street trees with other green infrastructure elements by fostering varied, inclusive, and contextually appropriate streetscapes through the use of resilience thinking in street tree planning has been implied by this study.

5.2 Recommendations

In the dynamic urban landscape of Addis Ababa, the effective management of street trees stands as a crucial endeavor to ensure long-term and resilient ecosystem services. Recognizing the pivotal role of street trees in enhancing environmental quality, biodiversity, and overall urban well-being, this section also endeavors to devise comprehensive solutions and recommendations aimed at fostering long-term resilience and ecosystem service provision.

5.2.1 Recommendations from Resilience and Long-term Ecosystem Service provision perspective

Enhancing and balancing the provision of ecosystem services through urban street trees' increased resilience requires a recommendation that considers street trees and their surrounding environment. Selecting climate considerate and suitable tree species that can close the supply and demand gaps of ecosystem service provision remains crucial intervention against the identified issues in this study. Hereunder are different resilience-based solutions categorized by the required ecosystem service gaps and identified challenges in Addis Ababa.

- **Recommendations for Stormwater Management**

Green Strips with Bioswales

- **Action:** Install continuous green strips along pedestrian pathways to manage stormwater using bioswales with permeable soil, and native vegetation
- **Implementation:** Map suitable pathways with urban planners. Design bioswales with proper water flow and establish a maintenance plan to prevent clogging.

Permeable Pedestrian Tiles

- **Action:** Replace solid paving with permeable tiles to reduce water stagnation
- **Implementation:** Target key pathways with waterlogging issues. Source durable, load-bearing permeable materials from reputable suppliers.

Linear Green Spaces & Rain Gardens

- **Action:** Create street-side green spaces with rain gardens to capture and absorb stormwater runoff.
- **Implementation:** Collaborate with landscape architects to design rain gardens tailored to local stormwater flow. Use native plants for optimal absorption and low maintenance.

Flood-Tolerant Trees for Bioswales

- **Action:** Plant flood-tolerant, fast-growing tree species in bioswales to enhance stormwater management and biodiversity.
- **Implementation:** Partner with horticulturists to select species suited to local conditions and ensure proper spacing and root management.

- **Recommendations for Local Climate Regulation**

Prioritize and Sustain Mature Trees

- **Action:** Preserve mature trees for their superior climate benefits.
- **Implementation:** Establish policies to protect these trees during construction and create a program for regular health assessments and maintenance.

Pollution-Tolerant, Locally Compatible Tree Species

- **Action:** Select tree species that tolerate pollution, adapt to local soil and climate, and resist carbon emissions.

- **Implementation:** Work with environmental experts to choose native species suited for urban conditions.

Strategic Tree Placement for Climate Benefits

- **Action:** Plant trees in high-traffic areas, near buildings to reduce heat gain, and along concrete surfaces to cut heat reflection.
- **Implementation:** Use GIS tools to identify the best locations for tree placement, ensuring adequate spacing for canopy growth and heat island mitigation.

Routine Maintenance and Species Diversity

- **Action:** Regularly maintain trees with pruning, watering, and fertilizing while ensuring species diversity to enhance resilience.
- **Implementation:** Schedule arborist-led care and plant a mix of native and adaptable species to minimize risks from pests or diseases.

Integrate Trees with Green Infrastructure

- **Action:** Combine trees with rain gardens, bioswales, and green roofs for improved stormwater management and climate regulation.
- **Implementation:** Design layouts that integrate trees with other green infrastructures, leveraging synergies for environmental benefits like stormwater absorption and cooling.

➢ **Recommendations for Recreation and Aesthetics**

- **Separate Green Zones and Street Furnishings:** Allocate distinct strips for greenery and street furniture for clarity and functionality in urban design.
- **Tree-Lined Pavements with Amenities:** Plant trees along pavements for shade and add benches, lighting, and seating to enhance pedestrian experience.
- **Pocket Parks and Small Green Spaces:** Create small green areas with trees, bushes, and seating along streets for relaxation and social interaction.
- **Creative Tree Planting Patterns:** Use alternating tree species, colors, and textures for visually pleasing, varied landscapes.
- **Ornamental Lighting for Nighttime Appeal:** Install energy-efficient lighting to highlight trees, enhancing aesthetics at night or during special events.
- **Community Tree Planting Days:** Organize volunteer tree planting events to engage locals and promote community ownership.

- **Routine Maintenance for Green Spaces:** Implement regular care routines (e.g., pruning, watering) to maintain the health and visual appeal of green spaces.

5.2.2 Recommendations regarding Ecosystem Disservices and Challenges

- Install root barriers that are made of impermeable materials to prevent tree roots from affecting underground utility lines, sidewalk pavements, and structures
- Select tree species whose mature sizes and non-invasive root systems are suitable for the available space and proximity to infrastructure
- Before planting trees, make arrangements with utility-providing organizations such as AAWSA, Ethio Telecom, Safari, EEP, and EEU to locate underground utility lines
- Maintaining the health and structural integrity of trees while reducing conflicts with neighboring structures and infrastructure requires frequent pruning and canopy management techniques
- When designing streetscapes and green areas, leave enough room for trees to flourish and take the long-term effects on the local infrastructure into account
- Check for damage or any conflicts by routinely monitoring and inspecting the surrounding infrastructure, including the trees
- Create awareness for the public and other concerned stakeholders about managing the conflict between street trees and infrastructure conflicts
- Finally, the utilization of linear greening approaches by fostering varied, inclusive, and contextually appropriate streetscapes using resilience thinking in street tree planning is recommended by this study.

5.2.3 Recommendation for Future Researchers

Future studies are encouraged to integrate biophysical assessments, such as tree species traits, soil quality, spatial connectivity assessments, and climate data, alongside perception-based approaches. Combining these perspectives would provide a more comprehensive understanding of ecosystem service provision and inform better urban planning and management strategies.

Suggested Species and Characteristics

Table 5-1 Tree species suggested, characteristics and the ecosystem services delivered for the cities of Addis Ababa

No	Species	Native /exotic	Strength	Weakness	Properties For delivering ES
1.	*Hypericum revolutum*	Native	Root system Elevation range Evergreen	Availability	Erosion control, ornamental, enhances soil stability.
2.	*Sethodia milofica*	Exotic	Showy flowers, accessible, semi evergreen	Limited height, shallow root system	Shade, ornamental, attracts pollinators.
3.	*Phomin reclanta*	Native	Dense canopy, strong root system	Long growth time	Shade, ornamental
4.	*Ficus benganisis*	Exotic	Evergreen Root system Not invasive	Don't allow under growth Closed canopy	Large canopy for shading, ornamental, carbon sequestration.
5.	*Olinia rochetiana*	Native	Root system and canopy	Availability	Ornamental and medicinal
6.	*Calsitemon citrinus*	Exotic	Canopy Root system Not invasive	Requires regular pruning	Ornamental, stormwater management,
7.	*Juniperus procera*	Native	Availability Easy to train	Spiny leaves Slow growth	Aesthetic Ornamental
8.	*Myrsine melanophloeos*	Native	Root system Canopy Evergreen	Availability Limited growth range	Soil stabilization, aesthetic value, shading.
9.	*Borassus aethiopium*	Native	Drought-resistant	Long growth time	
10.	*Erica arborea*	Native	Evergreen	Limited growth range Availability	Ornamental
11.	*Cupressus pyramidalis*	Exotic	Linear canopy Root system	Susceptible to pests	Ornamental
12.	*Arucaria microphylla*	Exotic	Evergreen Root system Canopy	Expensive	Ornamental
13.	*Terminalia sp.*	Exotic	Root system Canopy	Strong root system, dense canopy	Shade, ornamental, improves urban cooling.
14.	*Olea eroupea subsp. cuspidata*	Native	Evergreen No shading	Larger canopy	Erosion control, supports biodiversity.

References

AACPDC (2017) Addis Ababa City Structural Plan (2017-2027), Addis Ababa City Plan and Development Commission.

AARP Livable Communities and Walkable and Livable Communities Institute AARP Livability Fact Sheets - Street Trees.

Abunnasr, Y. F. (2013) Climate Change Adaptation: A Green Infrastructure Planning Framework for Resilient Urban Regions, Open Access Dissertations, University of Massachusetts Amherst [Online]. Available at https://doi.org/10.7275/yg71-qy42%20https://scholarworks.umass.edu/open_access_dissertations/775.

Addis, T., Simane, B. and Italemahu, T. (2022) 'Effectiveness of Urban Climate Change Governance in Addis Ababa City, Ethiopia', Urban Science, vol. 6, p. 64.

(2020) Addis Ababa Resilience Strategy, Addis Ababa Resilient Project Office.

Adem, H. (2020) The role of puplic sector institutions on space allocation for street greenery in Addis Ababa, Master's dissertation, Addis Ababa, Ethiopia, Ethiopian Institute of Architecture, Building Construction and City Development, EIABC.

Agrawal, A. and Gopal, K. (2013) 'Application of Diversity Index in Measurement of Species Diversity', in Agrawal, A. and Gopal, K. (eds) Biomonitoring of Water and Waste Water, India, Springer India, pp. 41–48.

Andersson-Sköld, Y., Klingberg, J., Gunnarsson, B., Cullinane, K., Gustafsson, I., Hedblom, M., Knez, I., Lindberg, F., Ode Sang, Å., Pleijel, H., Thorsson, P. and Thorsson, S. (2018) 'A framework for assessing urban greenery's effects and valuing its ecosystem services', Journal of environmental management, vol. 205, pp. 274–285.

Armson, D., Stringer, P. and Ennos, A. R. (2013) 'The effect of street trees and amenity grass on urban surface water runoff in Manchester, UK', Urban Forestry & Urban Greening, vol. 12, no. 3, pp. 282–286 [Online]. DOI: 10.1016/j.ufug.2013.04.001.

Aynachew, S. (2014) Assessment of urban green infrastructure in Addis Ababa: the case of Bole sub city, Master's dissertation, Addis Ababa, Ethiopia, Addis Ababa University.

Bartlett, J. E., Kotrlik, J. W. and Higgins, C. C. (2001) 'Determining Appropriate Sample Size in Survey Research', Information Technology, Learning, and Performance Journal, vol. 19, no. 1.

Beecham, S. and Lucke, T. (2015) 'Street Trees in Paved Urban Environments: The Benefits and Challenges' [Online]. Available at https://research.usc.edu.au/esploro/outputs/conferencePaper/Street-Trees-in-Paved-Urban-Environme.

Berland, A., Shiflett, S. A., Shuster, W. D., Garmestani, A. S., Goddard, H. C., Herrmann, D. L. and Hopton, M. E. (2017) 'The role of trees in urban stormwater management', Landscape and Urban Planning, vol. 162, pp. 167–177.

Biggs, R., Schlüter, M., Biggs, D., Bohensky, E. L., BurnSilver, S., Cundill, G., Dakos, V., Daw, T. M., Evans, L. S., Kotschy, K., Leitch, A. M., Meek, C., Quinlan, A., Raudsepp-Hearne, C., Robards, M. D., Schoon, M. L., Schultz, L. and West, P. C. (2012) 'Toward Principles for Enhancing the Resilience of Ecosystem Services', Annual Review of Environment and Resources, vol. 37, no. 1, pp. 421–448.

Borelli, S. (2016) Benefits of Urban Trees [Online], Rome, Italy, FAO.

Brandt, L. A., Johnson, G. R., North, E. A., Faje, J. and Rutledge, A. (2021) 'Vulnerability of Street Trees in Upper Midwest Cities to Climate Change', Frontiers in Ecology and Evolution, vol. 9, p. 1605.

Brooks, N. and Adger, W. N. (2005) Assessing and Enhancing Adaptive Capacity.

Buchel, S. and Frantzeskaki, N. (2015) 'Citizens' voice: A case study about perceived ecosystem services by urban park users in Rotterdam, the Netherlands', Ecosystem Services, vol. 12, no. 4, pp. 169–177.

Buffam, I., Hagemann, F. A., Emilsson, T., Gamstetter, D., Pálsdóttir, A. M., Randrup, T. B., Yeshitela, K. and Ode Sang, Å. (2022) 'Priorities and barriers for urban ecosystem service provision: A comparison of stakeholder perspectives from three cities', Frontiers in Sustainable Cities, vol. 4, p. 12.

Burden, D. (2006) 22 Benefits of Urban Street Trees, Glatting Jackson and Walkable Communities, Inc.

Chang Zhao, Heather A. Sander (Aug, 2015) 'Quantifying and Mapping the Supply of and Demand for Carbon Storage and Sequestration Service from Urban Trees', PLoS ONE, vol. 10, no. 8 [Online]. Available at doi://10.1371/journal.pone.0136392.

Church, S. P. (2018) 'From street trees to natural areas: Retrofitting cities for human connectedness to nature', Journal of Environmental Planning and Management, vol. 61, 5-6, pp. 878–903 [Online]. DOI: 10.1080/09640568.2018.1428182.

Colinas, J., Bush, P. and Manaugh, K. (2019) 'The socio-environmental impacts of public urban fruit trees: A Montreal case-study', Urban Forestry & Urban Greening, vol. 45, p. 126132 [Online]. DOI: 10.1016/j.ufug.2018.05.002.

Coutts, A. M., White, E. C., Tapper, N. J., Beringer, J. and Livesley, S. J. (2016) 'Temperature and human thermal comfort effects of street trees across three contrasting street canyon environments', Theoretical and Applied Climatology, vol. 124, 1-2, pp. 55–68.

Department of the Environment, Water, Heritage and the Arts (2009) Ecosystem services: Key concepts and applications, Department of the Environment, Water, Heritage and the Arts, Occasional Paper Series 1.

Drew-Smythe, J. J., Davila, Y. C., McLean, C. M., Hingee, M. C., Murray, M. L., Webb, J. K., Krix, D. W. and Murray, B. R. (2023a) 'Community perceptions of ecosystem services and disservices linked to urban tree plantings', Urban Forestry & Urban Greening, vol. 82, p. 127870 [Online]. DOI: 10.1016/j.ufug.2023.127870.

Drew-Smythe, J. J., Davila, Y. C., McLean, C. M., Hingee, M. C., Murray, M. L., Webb, J. K., Krix, D. W. and Murray, B. R. (2023b) 'Community perceptions of ecosystem services and disservices linked to urban tree plantings', Urban Forestry & Urban Greening, vol. 82, p. 127870 [Online]. DOI: 10.1016/j.ufug.2023.127870.

Durfee, E. (2021) Central Business District Street Tree Plan.

Elmqvist, T., Fragkias, M., Goodness, J., Güneralp, B., Marcotullio, P., McDonald, R. I., Parnell, S., Schewenius, M., Sendstad, M., Seto, K. C. and Wilkinson, C. (eds) (2013) Urbanization, Biodiversity and Ecosystem Services Challenges and Opportunities: A Global Assessment, Dordrecht, Springer Netherlands; Imprint: Springer.

Elmqvist, T., Redman, C., Barthel, S. and Costanza, R. (2013) 'History of Urbanization and the Missing Ecology', in Elmqvist, T., Fragkias, M., Goodness, J., Güneralp, B., Marcotullio, P. J., McDonald, R. I., Parnell, S., Schewenius, M., Sendstad, M., Seto, K. C. and Wilkinson, C. (eds) Urbanization, Biodiversity and Ecosystem Services: Challenges and Opportunities: A Global Assessment, Dordrecht, Springer Netherlands, pp. 13–30.

Escobedo, F. J., Kroeger, T. and Wagner, J. E. (2011) 'Urban forests and pollution mitigation: Analyzing ecosystem services and disservices', Environmental pollution, vol. 159, 8-9, pp. 2078–2087.

Eshetu, S. B., Yeshitela, K. and Sieber, S. (2021) 'Urban Green Space Planning, Policy Implementation, and Challenges: The Case of Addis Ababa', Sustainability, vol. 13.

ESPON EGTC (2019) Planning for green infrastructure:: Methods to support practitioners and decision-making.

Falk, D. A. (2017) 'Restoration Ecology, Resilience, and the Axes of Change', Annals of the Missouri Botanical Garden, vol. 102, no. 2, pp. 201–216.

Falk, D. A. and Millar, C. I. (2016) 'The Influence of Climate Variability and Change on the Science and Practice of Restoration Ecology', in Palmer, M. A., Zedler, J. B. and Falk, D. A. (eds) Foundations of Restoration Ecology, Washington, DC, Island Press/Center for Resource Economics, pp. 484–513.

Federal Democratic Republic Of Ethiopia (1997) Environmental policy, environmental protection authority and ministry of economic development and cooperation.

Folke, C. (2016) ‘Resilience (Republished)’, Ecology and Society, vol. 21, no. 4.

Folke, C., Carpenter, S., Walker, B., Scheffer, M., Elmqvist, T., Gunderson, L. and Holling, C. S. (2004) ‘Regime Shifts, Resilience, and Biodiversity in Ecosystem Management’, Annual Review of Ecology, Evolution, and Systematics, vol. 35, no. 1, pp. 557–581.

Gómez Martín, E., Giordano, R., Pagano, A., van der Keur, P. and Máñez Costa, M. (2020) ‘Using a system thinking approach to assess the contribution of nature based solutions to sustainable development goals’, The Science of the total environment, vol. 738, p. 139693.

Güneralp, B., Lwasa, S., Masundire, H., Parnell, S. and Seto, K. C. (2017) ‘Urbanization in Africa: Challenges and opportunities for conservation’, Environmental Research Letters, vol. 13, no. 1, p. 15002.

Hale, J., Pugh, T., Sadler, J., Boyko, C., Brown, J., Caputo, S., Caserio, M., Coles, R., Farmani, R., Hales, C., Horsey, R., Hunt, D., Leach, J., Rogers, C. and MacKenzie, A. (2015) ‘Delivering a Multi-Functional and Resilient Urban Forest’, Sustainability, vol. 7, no. 4, pp. 4600–4624.

Herslund, L. B., Backhaus, A., Fryd, O., Jørgensen, G., Jensen, M. B., Limbumba, T. M., Liu, L., Mguni, P., Mkupasi, M., Workalemahu, L. and Yeshitela, K. (2018) ‘Conditions and opportunities for green infrastructure – Aiming for green, water-resilient cities in Addis Ababa and Dar es Salaam’, Elsevier BV, vol. 180, pp. 319–327 [Online]. DOI: 10.1016/j.landurbplan.2016.10.008.

Hopton, M. and Berland, A. (2014) Municipa Street Tree Structure and Ecosystem Services, US EPA, ORD, Sustainable Technologies Division.

Kardan, O., Gozdyra, P., Misic, B., Moola, F., Palmer, L. J., Paus, T. and Berman, M. G. (2015) ‘Neighborhood greenspace and health in a large urban center’, Scientific Reports, vol. 5, no. 1, p. 11610 [Online]. DOI: 10.1038/srep11610.

Kasa, L., Zeleke, G., Dawit, A., Hagos, F. and Heinimann, A. (2011) 'Impact of urbanization of Addis Abeba city on peri-urban environment and livelihoods'.

Kiss, M., Takacs, A., Pogacsas. Reka and Gulyas, A. (2015) 'The role of ecosystem services in climate and air quality: Evaluating carbon sequestration and air pollution removal by street and park trees in Szeged (Hungary)', Meravian Geographical Reports, vol. 23.

Knudsen, C., Moreno, E., Arimah, B., Otieno Otieno, R. and Ogunsanya, O. (2020) World Cities Report 2020: The Value of Sustainable Urbanization, UN-HABITAT.

Koricho, H. H. and Song, S. (2021) 'Assessment of Urban Greenery Status in Major Cities of Oromia, Ethiopia', Research in ecology [Online]. DOI: 10.30564/re.v3i3.3638.

Krejcie, R. V. and Morgan, D. W. (1970) 'Determining sample size for research activities', educational and psychological measurement, no. 30, pp. 607–610.

Kuruneri-Chitepo, C. and Shackleton, C. M. (2011) 'The distribution, abundance and composition of street trees in selected towns of the Eastern Cape, South Africa', Urban Forestry & Urban Greening, vol. 10, no. 3, pp. 247–254 [Online]. DOI: 10.1016/j.ufug.2011.06.001.

Laurian, L. (2019) 'Planning for Street Trees and Human–Nature Relations: Lessons from 600 Years of Street Tree Planting in Paris', Journal of Planning History, vol. 18, no. 4, pp. 282–310 [Online]. DOI: 10.1177/1538513218820525.

Lyytimäki, J. (2017) 'Disservices of urban trees', in.

Lyytimäki, J. and Sipilä, M. (2009) 'Hopping on one leg–The challenge of ecosystem disservices for urban green management', Urban Forestry & Urban Greening, vol. 8, no. 4, pp. 309–315.

Marjan van den Belt (2016) Chapter 3: Scientific Understanding of Ecosystem Services, United Nations.

Martínez-Harms, M. J. and Balvanera, P. (2012) 'Methods for mapping ecosystem service supply: A review', International Journal of Biodiversity Science, Ecosystem Services & Management, vol. 8, 1-2, pp. 17–25.

Maru, M., Worku, H. and Birkmann, J. (2021) 'Factors affecting the spatial resilience of Ethiopia's secondary cities to urban uncertainties: A study of household perceptions of Kombolcha city', Heliyon, vol. 7, no. 12, e08472 [Online]. DOI: 10.1016/j.heliyon.2021.e08472.

Masini, E., Tomao, A., Corona, P., Fattorini, L., Giuliarelli, D., Portoghesi, L. and Agrimi, M. (2023) 'The ecosystem disservices of trees on sidewalks: A study based on a municipality urban tree inventory in Central Italy', Urban Forestry & Urban Greening, vol. 86, p. 128007 [Online]. DOI: 10.1016/j.ufug.2023.128007.

McPhearson, T., Hamstead, Z. A. and Kremer, P. (2014) 'Urban ecosystem services for resilience planning and management in New York City', Ambio, vol. 43, no. 4, pp. 502–515.

MEA (2005) Ecosystems and Human Well-being: A Framework for Assessment, Island Press.

Monteiro, M. and Doick, K. J. (2021) 'The role of urban trees and greenspace in reducing urban air temperatures.: Trees, green spaces and urban cooling', Forestry Commission Research Note [Online]. Available at www.forestresearch.gov.uk.

Monteiro, M. V., Morison, J. I., Handley, P. and Doick, K. J. (2019) The role of urban trees and greenspaces in reducing urban air temperatures, Forest research [Online]. Available at www.forestry.gov.uk/forestresearch.

Mullaney, J., Lucke, T. and Trueman, S. J. (2015) 'A review of benefits and challenges in growing street trees in paved urban environments', Landscape and Urban Planning, vol. 134, pp. 157–166 [Online]. DOI: 10.1016/j.landurbplan.2014.10.013.

Nagendra, H. and Gopal, D. (2010) 'Street trees in Bangalore: Density, diversity, composition and distribution', Urban Forestry & Urban Greening [Online]. DOI: 10.1016/j.ufug.2009.12.005.

Paetzold, A., Warren, P. H. and Maltby, L. L. (2010) ‘A framework for assessing ecological quality based on ecosystem services’, Ecological Complexity, vol. 7, no. 3, pp. 273–281.

Pataki, D. E., Alberti, M., Cadenasso, M. L., Felson, A. J., McDonnell, M. J., Pincetl, S., Pouyat, R. V., Setälä, H. and Whitlow, T. H. (2021) ‘The Benefits and Limits of Urban Tree Planting for Environmental and Human Health’, Frontiers in Ecology and Evolution, vol. 9, p. 5.

Pauleit, S. (2003) ‘Urban street tree plantings: identifying the key requirements’, 43-50.

Richards, N. A. (1983) ‘Diversity and stability in a street tree population’, Urban Ecology, no. 7, pp. 159–171.

Roman, L. A., Conway, T. M., Eisenman, T. S., Koeser, A. K., Ordóñez Barona, C., Locke, D. H., Jenerette, G. D., Östberg, J. and Vogt, J. (2021) ‘Beyond 'trees are good': Disservices, management costs, and tradeoffs in urban forestry’, Ambio, vol. 50, no. 3, pp. 615–630.

Roy, S., Byrne, J. and Pickering, C. (2012) ‘A systematic quantitative review of urban tree benefits, costs, and assessment methods across cities in different climatic zones’, Urban Forestry & Urban Greening, vol. 11, pp. 351–363.

Rubio, R. G. and Scott, T. J. (2020) ‘(PDF) Resilient Urban Ecologies: Adaptive Sustainable Infrastructures for Addis Ababa’ [Online]. Available at https://www.researchgate.net/publication/349289625_Resilient_Urban_Ecologies_Adaptive_Sustainable_Infrastructures_for_Addis_Ababa.

Sæbø, A., Benedikz, T. and Randrup, T. (2003) ‘Selection of trees for urban forestry in the Nordic countries’, Urban Forestry & Urban Greening, vol. 2, pp. 101–114.

Sæbø, A., Borzan, Ž., Ducatillion, C., Hatzistathis, A., Lagerström, T., Supuka, J., García-Valdecantos, J. L., Rego, F. and van Slycken, J. (2005) ‘The Selection of Plant Materials for Street Trees, Park Trees and Urban Woodland’, in Konijnendijk, C., Nilsson, K., Randrup, T. and

Schipperijn, J. (eds) Urban Forests and Trees: A Reference Book, Berlin, Heidelberg, Springer Berlin Heidelberg, pp. 257–280.

Saghir, J. and Santoro, J. (2018) Urbanization in Sub-Saharan Africa:: Meeting Challenges by Bridging Stakeholders, Center for Strategic and International Studies.

Salmond, J. A., Tadaki, M., Vardoulakis, S., Arbuthnott, K., Coutts, A., Demuzere, M., Dirks, K. N., Heaviside, C., Lim, S., Macintyre, H., McInnes, R. N. and Wheeler, B. W. (2016) 'Health and climate related ecosystem services provided by street trees in the urban environment', Environmental health : a global access science source, 15 Suppl 1, p. 36.

Sandström, U. G., Angelstam, P. and Mikusiński, G. (2006) 'Ecological diversity of birds in relation to the structure of urban green space', Landscape and Urban Planning, vol. 77, no. 1, pp. 39–53 [Online]. DOI: 10.1016/j.landurbplan.2005.01.004.

Säumel, I., Weber, F. and Kowarik, I. (2016) 'Toward livable and healthy urban streets: Roadside vegetation provides ecosystem services where people live and move', Environmental Science & Policy [Online]. DOI: 10.1016/j.envsci.2015.11.012.

Seok, Y., Yim, H., Moon, T. and Chon, J. (2022) 'Street Tree Planning to Improve Public Health and Ecosystem Resilience in Urban Areas: A Scenario Analysis Using a System Dynamics Model', International journal of environmental research and public health, vol. 19, no. 3.

Shackleton, C. M., Ruwanza, S., Sinasson Sanni, G. K., Bennett, S., Lacy, P. de, Modipa, R., Mtati, N., Sachikonye, M. and Thondhlana, G. (2016) 'Unpacking Pandora's box: Understanding and categorising ecosystem disservices for environmental management and human wellbeing', Ecosystems, vol. 19, pp. 587–600.

Sharifi, A. (2019) 'Resilient urban forms: A review of literature on streets and street networks' [Online]. Available at https://doi.org/10.1016/ j.buildenv.2018.09.040.

Sharifi, A. and Yamagata, Y. (eds) (2018) Resilience-Oriented Urban Planning: Theoretical and Empirical Insights, Cham, Springer International Publishing; Imprint: Springer.

Sousa-Silva, R., Cameron, E. and Paquette, A. (2021) 'Prioritizing Street Tree Planting Locations to Increase Benefits for All Citizens: Experience From Joliette, Canada', Frontiers in Ecology and Evolution, vol. 9, p. 191.

Tallis, M., Taylor, G., Sinnett, D. and Freer-Smith, P. (2011) 'Estimating the removal of atmospheric particulate pollution by the urban tree canopy of London, under current and future environments', Landscape and Urban Planning, vol. 103, pp. 129–138.

Tan, X., Hirabayashi, S. and Shibata, S. (2021) 'Estimation of Ecosystem Services Provided by Street Trees in Kyoto, Japan', Forests, vol. 12, no. 3, p. 311.

Tegenu, T. (2010) Urbanization in Ethiopia: Study on Growth, Patterns, Functions and Alternative Policy Strategy, Department of Human Geography, Stockholm University.

Tehrani, S. S., Falls, L. C. and Mesher, D. (2015) 'Road users' perception of roughness and the corresponding IRI threshold values', Canadian Journal of Civil Engineering, vol. 42, no. 4, pp. 233–240.

Teketay, D. (2001) 'Vegetation types and forest fire management in Ethiopia'.

Tigabu, t. and Semu, g. (2008) Ethiopia: Addis Ababa urban profile, Nairobi, UN-Habitat Regional and Technical Cooperation Division.

Toxopeus, H. and Polzin, F. (2021) 'Reviewing financing barriers and strategies for urban nature-based solutions', Journal of environmental management, vol. 289, p. 112371 [Online]. DOI: 10.1016/j.jenvman.2021.112371.

Uakarn, C., Chaokromthong, K. and Sintao, N. (2021) 'Sample Size Estimation using Yamane and Cochran and Krejcie and Morgan and Green Formulas and Cohen Statistical Power Analysis by G*Power and Comparisons', apheit international journal, pp. 76–88.

UN Habitat (2017) Habitat III Regional Report Africa: Transformational Housing and Sustainable Urban Development in Africa, UN Habitat III Secretariat.

Vailshery, L. S., Jaganmohan, M. and Nagendra, H. (2013) ‘Effect of street trees on microclimate and air pollution in a tropical city’, Urban Forestry & Urban Greening, vol. 12, no. 3, pp. 408–415.

Walker, B. and Salt, D. (2006) Resilience thinking: Sustaining ecosystems and people in a changing world, Island press.

Williams, E. R. A. (ed) (2000) environmental planning for sustainable urban development.

Woldegerima, T., Yeshitela, K. and Lindley, S. (2017) ‘Ecosystem services assessment of the urban forests of Addis Ababa, Ethiopia’, Urban Ecosystems, vol. 20, no. 3, pp. 683–699.

Wolff, S., Schulp, C.J.E. and Verburg, P. H. (2015) ‘Mapping ecosystem services demand: A review of current research and future perspectives’, Ecological Indicators, vol. 55, pp. 159–171 [Online]. DOI: 10.1016/j.ecolind.2015.03.016.

Workneh, Z. (2021) Urban Dwellers’ Attitude and Management Practice towards Tree Planting in Wolkite town, Guraghe Zone, South Nations Nationalities People Regional State, Masters Thesis, Addis Ababa, Ethiopia, Addis Ababa University.

World Population review (2022) Addis Ababa Population [Online]. Available at https://worldpopulationreview.com/world-cities/addis-ababa-population.

Woudstra, J. and Allen, C. (eds) (2022) The Politics of Street Trees, London.

Yao, J., Chen, N., Guo, F., Liu, M., Chen, W. and He, X. (2022) Variation in ecosystem services of street tree assemblages can guide sustainable urban development [Online].

Annex I Publishable Manuscript

Urban Street Trees and their Ecosystem Service Provision: A Supply and Demand Assessment from Stakeholders Perception in Addis Ababa, Ethiopia

Addis Ababa University, EiABC November , 2024

Abstract

Unplanned and unmanaged urbanization represents a threat to environmental sustainability. Likewise, Addis Ababa is experiencing a significant strain on the city's ecosystem, causing a mismatch between ES supply and Demand. In essence, this study performed ES supply and demand assessment in Addis Ababa. The research is an exploratory study that employs quantitative method. Key-informant interviews and questionnaire survey were employed for data collection. Using ES Cascade model as a framework, the research performed thematic and apparent urgency analysis based on expert and street user perception. Regarding zone-based ES supply and demand quantification, species diversity (2.67 periphery, 2.29 intermediate), followed by aesthetics (2.09 periphery, 1.72 intermediate), stormwater management (1.93 intermediate, 1.72 periphery), and local climate regulation (1.34 intermediate) revealed a gap that requires apparent urgency. The prevalence of Grevillea robusta and Phoenix canariensis, species with 51% and 15% respective dominance indicates uniformity in tree species selection, implying the necessity for adaptable solutions that consider urban dynamics. Prioritizing ecosystem services than mere aesthetics, selection of climate-resilient and locally adaptable species, and integrating them with surrounding UGI components were among the recommendations forwarded.

Keywords*: Ecosystem Service (ES), ES supply and demand, ES cascade model, Street Tree, Addis Ababa*

1. Introduction

Unregulated and improperly managed urban growth threatens the ecological balance, while thoughtfully planned urbanization promotes favorable development outcomes and can act as a catalyst for improved general prosperity and quality of life, all in line with green development principles (Knudsen et al., 2020). In the Sub-Saharan Africa region, there is a 4.1 percent fastest annual rate of urbanization compared to the global 2.0 percent rate (Saghir and Santoro, 2018). Unfortunately, many parts of the region endure urbanization with unwise utilization of natural resources, facing one of the biggest challenges in the world (Güneralp et al., 2017).

On the contrary, Urban Green Infrastructure, particularly urban street trees, are a form of nature-based solutions to the contemporary urban and environmental challenges that help to ensure ecosystem efficiency (Escobedo et al., 2011; Hopton and Berland, 2014). Considering urban street trees as part of the urban forest (Escobedo et al., 2011; Pataki et al., 2021), their balanced ecosystem service (ES) provision could help in realizing several sustainable development goals (SDGs). While, the major consideration lies in SDG 15; intending to protect, restore, and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, reduce and reverse land degradation and prevent biodiversity loss.

Hence, protecting and restoring ecology through the integration of urbanism and nature should be encouraged (Williams, 2000), and it requires the integration of urban street trees (Marjan van den Belt, 2016). Urban street trees, being an integral component of the urban ecosystem (Yao et al., 2022), provide a range of ES that spurs the path of resilient and sustainable development (Burden, 2006; Monteiro and Doick, 2021). Managing storm water, protecting biodiversity, 150kg CO^2 annual sequestration, cooling city streets from 2 to 4 degrees, filtering particle pollutants, enhancing aesthetics, increasing land value by 20%, food provision, and improving public health are among the many benefits of urban street trees (Borelli, 2016; Monteiro et al., 2019).

Although greening streets is effective in increasing ES capacities (McPhearson et al., 2014), the ability of street trees is dependent on the social, ecological/biophysical, and technological factors all contributing to their specific context (Marjan van den Belt, 2016). Moreover, integrating a social-ecological perspective contributes to the achievement of better urban sustainability by integrating the perceptions of stakeholders (Elmqvist, Redman et al., 2013). Besides, societies gain social benefits through ecological and environmental services, and ecological and environmental services are preserved through optimum management practices, and the study by (Abunnasr, 2013), proves more to the point.

Therefore, street tree planning should identify the benefits or services which are being delivered by urban street trees. The value being given by the street users along with the actual demands of ES is also crucial when contemplating their relationship with the city and its green infrastructure elements. Hereafter, the assessment of ES supply and demand with the aim of balancing and enhancing ES provision from urban street trees remains important.

In developing countries, more is being learned about the profound negative environmental effects of treeless urban streets as they face a larger risk of failing to sustain service delivery over time (Walker and Salt, 2006). Likewise, Addis Ababa, an exemplar of Ethiopia's fast urbanization and transformation (Tegenu, 2010), achieves only 1.5m^2 green area coverage per capita and is experiencing extensive population growth and migration, placing a significant strain on the city's ecosystem (Kasa et al., 2011).

Although it's hardly implemented, Addis Ababa's ongoing development considers a 30% increment towards green development intending to change the low priority given to urban forestry and green infrastructure planning in developing sub-Saharan countries (Eshetu et al., 2021). Particularly on street trees, a study by (Adem, 2020; Buffam et al., 2022) highlighted the benefits that street trees bring to improve human wellbeing, while also indicating problems related to space allocation for street greenery in Addis Ababa.

According to (Buffam et al., 2022), future researchers should focus on improving the lack of studies on urban green infrastructure (UGI) planning and management for improved ES provisioning. Unfortunately, there seems to be a missing piece of literature that assess the supply and demand of ecosystem services from urban street trees in Addis Ababa.

Besides, a mismatch between the scales at which street trees are supplied, demanded, and managed is evident (McPhearson et al., 2014). Unless we bridge the gap between ES supply and demand from urban street trees, their long-term ES provision may be affected, thereby hindering the realization of enhanced urban sustainability, ecosystem resilience, and human wellbeing.

In light of the aforementioned problems, this study aims at bridging gaps between the supply and demand of Ecosystem Services from urban street trees in Addis Ababa, Ethiopia. In doing so, the study incorporated stakeholder's perception towards the current ES supply by street trees, future demands for it, barriers to the realization of a balanced ES provision, and potential future directions.

2. Urban Street Trees and their Ecosystem Services Provision

2.1. Definition of Concepts

It is necessary to acquaint readers to the situation at hand by going over the major phrases and conceptual premises under the main theme of street trees and ES provision.

Ecosystem Services (ES): are defined as "the benefits people obtain from ecosystems" (MEA, 2005). They are classified into four categories, provisioning, regulating, cultural, and supporting. When considering from urban perspective are services and benefits provided by urban ecosystems, in which urban ecosystems are often portrayed as embedding both the built infrastructure and the ecological infrastructure (Elmqvist, Fragkias et al., 2013).

ES Supply: is the total amount of ES that may be obtained in a given area (Marjan van den Belt, 2016), as well as the capacity of an ecosystem's ecological processes or biophysical components to generate ES (Martínez-Harms and Balvanera, 2012).

ES Demand: is the sum of all ecosystem goods and services currently consumed or utilized in a particular area over a given time (Wolff et al., 2015).

2.2. Ecosystem Service Assessment, Supply and Demand

Ecosystem services assessments are important tools that highlight benefits and trade-offs between different options, ideally by integrating biophysical and socioeconomic methods

(MEA, 2005). When considering ES, the current level of service provision may not be an accurate reflection of the level at which the service can be sustained over the long term (Paetzold et al., 2010), and its value is dependent on specific management context (land use, population density, local climate). According to Marjan van den Belt (2016), supply and demand are dynamically interconnected and a "gap" between the them suggests either scarcity or abundance, affecting also any value attributed to ES.

Conceptually, the **Ecosystem Cascade Model** (Andersson-Sköld et al., 2018) tries to describe the supply side by relating the biophysical domain with function or performance of the ecosystem to provide services. Whereas the demand side is represented with the societal domain and it's highly associated with how they value the service being provided and the actual benefit lured from the ecosystem. The balanced point of ES provision, on the other hand, is placed at the middle of these two domains, indicating little or no gap between supply of and demand for ES.

Buffam et al., (2022) also reported that the Cascade model of ES provision to be a useful framework for identifying city-specific resources and barriers around ES provision. Ecosystem Service Cascade model representing the natural ES supply side (green box) and the societal ES demand side (pink box), along with the governance framework of ES assessment is presented in Figure 2.1 below.

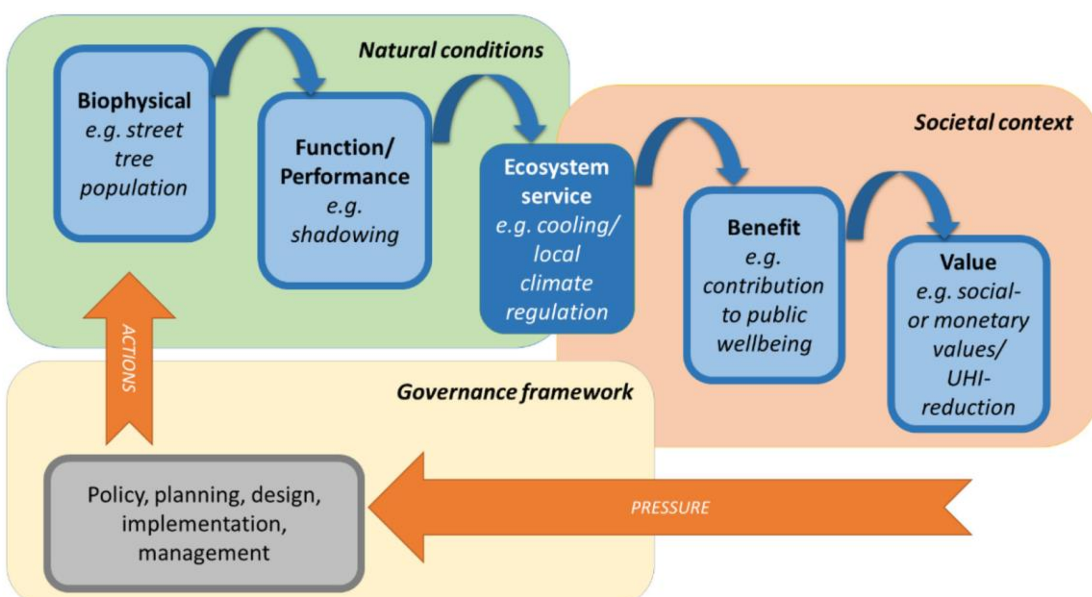


Figure 2.1 Ecosystem Cascade Model - A conceptual Framework of the study

2.3. Ecosystem Services from Urban Street trees

Street trees in cities are an important part of the urban environment and offer a variety of ecosystem services. Nowadays, understanding the ecosystem services that urban street trees offer has attracted more attention. This section lists and describes the ecosystem services urban street trees provide in four categories: regulating, provisional, cultural, and supporting ecosystem services (see section 2.2.1 for a detailed definition of used terminology).

A. Regulating Ecosystem Services

Local climate regulation: It is well known that asphalt and concrete parking lots and roadways raise the temperature of cities by 3 to 7 degrees. The cost of energy for customers and homes is considerably impacted by these temperature rises. A properly shaded area, mostly from urban street trees, may lower a household's energy costs by 15% to 35% (Burden, 2006).

By evapotranspiration, providing shade, and reflecting sunlight, trees can reduce air temperature. By combining transpiration with the evaporation of water from the soil and other surfaces, the process of evapotranspiration absorbs heat energy from solar radiation and cools the air around it. Trees reflect sunlight and offer shade. As a result, shaded structures and other man-made surfaces absorb and store less energy, which reduces their ability to release heat at night. Since trees and green areas tend to be lighter in color than built surfaces, they also absorb and store less energy than built surfaces (Coutts et al., 2016; Monteiro et al., 2019).

Air quality regulation: Reduced air quality in cities is turning into a major problem for worldwide health. Urban road traffic is the main source of emissions for dangerous particulate matter (Tallis et al., 2011). Urban tree stands modify the city’s climatic characteristics and air quality by the sequestration of carbon dioxide and the removal of various air pollutants (Chang Zhao, Heather A. Sander, 2015; Kiss et al., 2015).

Vailshery et al., (2013) found that road segments with tree cover have lower ambient air temperature, road surface temperature humidity, and air pollution. In urbanized areas with significant public traffic, such as streets and market places, where most trees have actually been chopped down rather than grown in recent years, street tree planting can have a bigger influence on microclimatic improvement and air pollution reduction.

Storm water management: Urbanization has a substantial impact on an area's hydrology because it decreases the quantity of water that penetrates into the soil and accelerates surface runoff, elevating peak discharge rates. Engineers typically expand the number and size of sewage and drainage channels to address these phenomena. Trees, on the other hand, use rainwater absorption to speed up infiltration and slow down surface runoff (Berland et al., 2017).

Through their leaf system, trees absorb the first 30% of the majority of precipitation, enabling evaporation to return to the atmosphere. Never does this moisture contact the earth. Up to 30% of precipitation is also absorbed back into the ground, taken up by the root system, kept there, absorbed, and then transpired back into the atmosphere. Additionally, some of this water naturally seeps into the aquifer and groundwater (Burden, 2006).

Particularly in urban areas, “Surfaces such as asphalt respond quickly to rainfall and can shed 90% of received rainfall to drain pushing the limits of drainage systems in heavy rainfall events. Many studies have shown that significant amounts of rainwater can be held and evaporated from tree canopies, reducing and delaying the response of an area to rainfall events…. However, the gross interception rate varies greatly with species, tree size, planting density and previous canopy wetness, resulting in a large spread of gross interception values.” (Armson et al., 2013).

B. Cultural Ecosystem Services

Aesthetic value and Recreation: Urban street trees has the potential to make the environment more green and beautiful, increasing the aesthetic quality of the street and overall corridor. Trees create more pleasant walking environments, bringing about increased walking, talking, pride, care of place, association and therefore actual ownership of homes, blocks, neighborhoods plazas, businesses and other civic spaces (Burden, 2006).

Reduced and more appropriate urban traffic speeds: Urban street trees create vertical walls framing streets, and a defined edge, helping motorists guide their movement and assess their speed (leading to overall speed reductions). Street safety comparisons show a reduction of run-off-the-road crashes and overall crash severity when street tree sections are compared with equivalent treeless streets (Burden, 2006).

Human health (Reduced blood pressure, improved overall emotional and psychological health): Small-scale spatial maintenance of urban tree populations appears to have a major impact on human health. Exposure to urban street trees has been associated to improved respiratory health outcomes, such as decreased incidence of asthma and other respiratory disorders, as well as improved mental health outcomes, such as decreased stress, anxiety, and depression (Kardan et al., 2015).

Even in congested cities with little room to grow urban forests, the health benefits of trees may be a very essential element of the advantages of urban forests. This is due to the strong possibility that exposure to urban forests, parks, and minor plants may improve people's health (Pataki et al., 2021).

Improved business: Businesses on treescape streets show 20% higher income streams, which is often the essential competitive edge needed for main street store success, versus competition from plaza discount store prices (Burden, 2006).

Reduced Infrastructure cost: the shade provided by urban street trees can extend the lifespan of expensive asphalt by 40–60% (Burden, 2006). This factor is based on the asphalt's decreased daily heating and cooling, or expansion and contraction. Roadway overlays will represent a substantial cost savings for sustaining a more economical road infrastructure as peak oil prices rise. In addition, when the risk of flooding to urban areas and storm water runoff is reduced, so is the expense of building storm water infrastructure.

C. Provisioning Ecosystem Services

Edible fruit provision: despite having a conflicting street user perception towards having edible trees in urban streets, urban forests provide food for people (Colinas et al., 2019).

D. Supporting Ecosystem Services

Biodiversity: urban street trees can be a home for wildlife, where they can contribute to increased biodiversity by serving as important habitats for birds and other animals (Sandström et al., 2006).

2.4.Ecosystem Service Supply and Demand

Street trees provide a range of ES where they act us catalysts of UGI interconnectedness and multifunctionality. With proper planning and implementation, balancing the gap between supply and demand would be easier. Unfortunately,

A study by (Adem, 2020; Buffam et al., 2022) highlighted the benefits that street trees bring to improve human wellbeing, while also indicating problems related to space allocation for street greenery in Addis Ababa.

According to Buffam et al., (2022), future researchers should focus on improving the lack of studies on urban green infrastructure (UGI) planning and management for improved ES provisioning. This section highlights the supply, demand, supply and demand assessment. Unfortunately, there seems to be a limited piece of literature that assess the supply and demand of ecosystem services from urban street trees in Addis

Hereunder are reviewed the supply and demand of ES from urban street trees and the potential gaps assessed by researchers.

Supply of Ecosystem Services: Addis Ababa's ecosystem service supply from urban street trees (section 2.3.1) is affected by a range of factors that exacerbate the gap between anticipated demand.

1. **Limited Green Coverage**: As a result of inadequate tree planting and poor maintenance of existing trees, the recommended standards of green coverage is below standard (Eshetu et al., 2021), indicating a huge factor for unbalanced supply of ecosystem services from urban green infrastructure components like urban street trees
2. **Species Diversity**: Imported species being the new normal, their effectiveness towards adapting to local climatic conditions and provision of full benefits is compromised (Biggs et al., 2012). This indicated the lack of diverse and native tree species furthered the gap among the anticipated demand and provided supply.
3. **Urban Expansion**: Unplanned and unmanaged urbanization represents a threat to environmental sustainability, whereas, planned urbanization leads to positive

development outcomes and can be leveraged for improved quality of life and overall prosperity (Kasa et al., 2011; Knudsen et al., 2020). In addition, the prioritization of gray infrastructure development aggrivated the neglection of street trees in urban areas.

Demand for Ecosystem Services: The demand for the ecosystem services provided by urban street trees is increasing. Given the increasing temprature and urban density, street users tend to look for shadeed areas and street trees are the major ones (Buchel and Frantzeskaki, 2015). Moreover, Addis Ababa being the major center and capital of the country, increased population and vehicular emission is wtnessed over the years. Likewise, the increased demad for air purification service by street trees is heightened. Besides, urban residents increasingly seek green spaces for recreation and mental well-being, placing further demand on the limited green infrastructure (Burden, 2006).

Supply-Demand Gap: Additionally, there is a growing disparity in Addis Ababa between the supply and demand for ecological services. Urban development frequently fails to incorporate green infrastructure, which results in an imbalance between the availability and demand for ecosystem services. Furthermore, the growth and appropriate upkeep of urban street trees are hampered by a lack of technical and financial resources. The mismatch between supply and demand is further exacerbated by poor enforcement of laws pertaining to urban greening and the lack of precise rules for incorporating street trees into urban development.

3. Research Methodology

3.1. Description of the Study Area

Addis Ababa, Ethiopia's capital and diplomatic center of Africa, had a population of 2,112,737 in 1994 (Tigabu and Semu, 2008), and the World Population review (2022) estimates that, it now has a population of 5.22 million. Spanning over 54,000 hectares, Addis Ababa is located at the heart of Ethiopia, between 8^{o} 51’ 0’’ and 9^{o} 6’ 0’’ N and 38^{o} 39’ 0’’ and 38^{o} 54’ 0’’ E. The city's dominance over other Ethiopian cities may be shown in terms of politics, market, population, service, and infrastructure.

Urban streets are found to be distributed over the spatial extent of the city with more density on the intermediate and inner city zones rather than the periphery. To make the site selection more representative of the whole city, this study focuses on main urban street trees, eight different street corridors distributed over the spatial extent of Addis Ababa, on which the site selection made use of a range of criteria listed below.

- **Street hierarchy**: Considering the street hierarchy proposed by the (AACPDC, 2017), the availability of street side infrastructures, and the habit of planning and managing urban street trees in Addis Ababa, this study only selects from PAS and SAS street hierarchy.
- **Availability of street trees**: the number of trees on that specific street corridor can determine the total tree population, thereby affecting the supply of ecosystem services. Hence, availability of street trees is also used as one of the site selection criteria.
- **Zoning and type of surrounding land use**: Addis Ababa is classified into three zones comprised of a range of land uses. The use and function of a land can shape the type of activities, type of street users and associated provision of services, including ecosystem service from nature. Thus, having these land uses as a selection criteria was founded to be crucial.
- **Spatial Distribution**: taking into consideration of level of activity and potential for future development, the structure plan of Addis Ababa delineated main, secondary, tertiary, special, and woreda level city centers. Since these centers are distributed across the spatial boundary of the city, the street corridor selection considers streets radiating from or within the close distance of primary, secondary, and tertiary city centers.
- **Level of activity and traffic flow**: As the study is focusing on urban street trees, the level of activity and traffic flow on a street corridor can dictate the way street users interact with the environment and street trees, which is useful while assessing their demand for ecosystem services.

Table 3.1 - Summarized Characteristics of selected street corridors

Selected street corridors	Hierarchy	Width (m)	Length (Km)	Zoning	Dominating land use
Churchill	PAS	50	2.3	Inner City	Commercial and Administrative
Sengatera/Goma kuteba to filweha	SAS	30	1.4	Inner city	Administration and Service
Meskel square to Lancha	PAS	40	1.74	Inner city/ Intermediate	Mixed Commerce
Megenagna to Signal	SAS	25	2.25	Intermediate	Mixed Commerce, Service, and Residence
Piassa Giorgis to Addisu gebeya	PAS	30	3.32	Intermediate	Mixed Commerce and Pure residence
Saris Adeyabeba to Kality Maseltegna	PAS	40	2.8	Intermediate	Manufacturing and Industry
Lamberet to Wesen	SAS	30	2.27	Periphery	Pure residence, Manufacturing, and Service
Ayertena Kidanemihret to Alembank	PAS	35	1.6	Periphery	Pure residence,

Source: (AACPDC, 2017), Google earth pro, (2022)

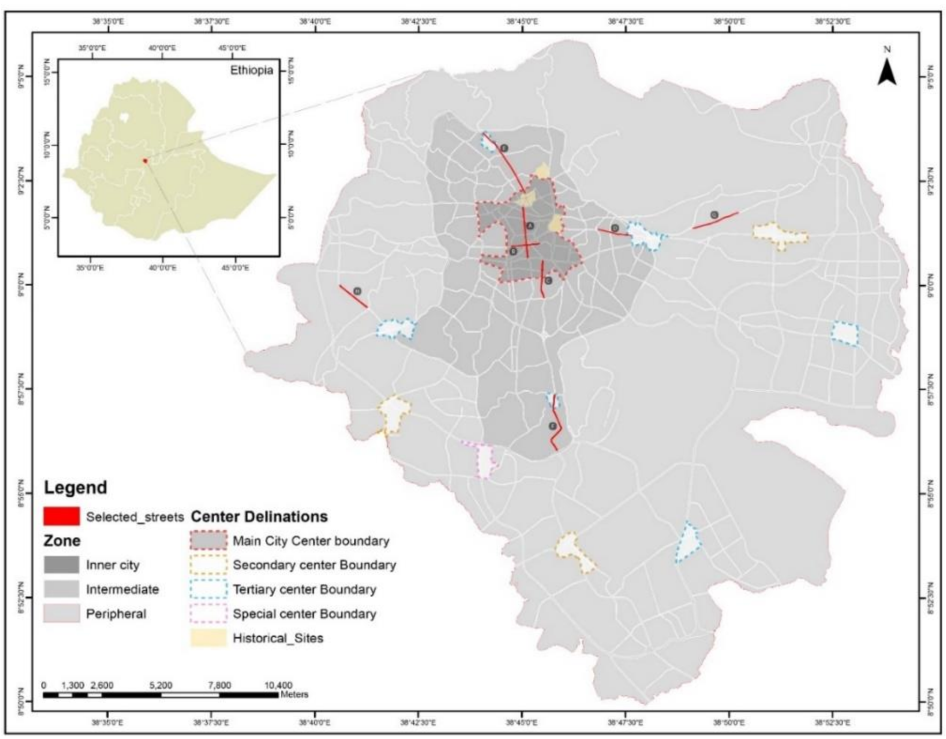


Figure 3.1 - Location Map of the Study Area

3.2. Methods and Materials

The research is an exploratory study that employs quantitative method. Key-informant interviews and questionnaire survey were employed for data collection. Using EC Cascade model as a framework, the research performed thematic and apparent urgency analysis based on expert and street user perception (Table 3.2).

Table 3.2 Research methodology used on this study

Research Design	Exploratory
Research Approach	Quantitative
Data to be collected	• List of ES being supplied/demanded by/from urban street trees • Street users perception towards the level of ES service supply and demand
Source of Data	• Street tree users • Experts from A.A municipal office • Experts from A.A green and beautification office
Method of Sampling	• Cluster random sampling for street users • Purposive sampling for experts
Method of data collection	• Key informant interview • Structured questionnaire
Method of data analysis	• Descriptive statistics • Apparent-Urgency Analysis
Instruments Used	• Questionnaire • Voice recorder

4. Results and Discussions

Given the relationship between diversity (richness, and abundance) of street trees and their ecosystem service provision, ecosystem service supply assessment of urban street tree required the identification of tree species planted on each street, while the demand assessment has to deal with the street user society and expert profile.

4.1. Results

The overall calculated values of ES supply, demand, and apparent urgency is described below as per the defined zones of Addis Ababa; commercial business district, intermediate zone, and periphery zone (Refer Table 3.1 for details). Moreover, Annex V presented detailed computed mean value for each street corridors.

4.1.1. Ecosystem Service Supply Assessment

Commercial business district (CBD) zone:

As the inner-city zone of Addis Ababa, CBD exhibits a higher supply of all regulating, cultural, and supporting services in comparison to the peripheral and intermediate areas. With a mean value of 3.87, the cultural ecosystem services stand out as having a sufficient supply along the inner city. Besides, the regulating and supporting services show 3.13 and 2.99 mean value of ES supply respectively (Figure 4.9).

In particular to the individual ecosystem services and sub-services, street beautification, comfort for use, inspiration and motivation, as well as social setting were the highest supplied cultural ES with a mean value of 4.4, 4.09, 4.03, and 3.85 respectively. The lowest mean results from a total value of five (5) were calculated for noise reduction, storm water management, and habitat for wildlife, with respective values of 2.45, 2.66, and 2.69.

Local climate regulation, air quality regulation, recreation, species diversity shows relatively intermediate mean values on the inner city of Addis Ababa. Although they share similar least supplied ES, Sengatera to Filweha street corridor has substantially lower mean values when compared to Churchill street corridor (Annex V).

Intermediate Zone:

Located between the inner city and periphery zone of Addis Ababa, the intermediate zone resulted in lower mean value of ES supply, especially the supporting services. Computed as per the ES categories, the regulating and cultural services ranked first and second with lower intermediate values of 2.65 and 2.59 respectively. Besides, with a mean score of 1.95, supporting ES services were found to be the least supplied. The highest value for local climate regulation (3.13) and the lowest for habitat for wildlife (1.85), respectively, demonstrate the magnitude of the lack of ES supply in this zone.

Among the four street corridors grouped under the intermediate zone, Saris to Kality and Piassa to Addisu Gebeya street corridors show relatively higher mean values of ES supply. On the contrary, Megenagna to Signal and Meskel Square to Lancha street corridors indicate the lowest mean values of ES supply respectively.

Among the least offered ES in the street corridors of Megenagna and Meskel Square are aesthetic quality, species diversity, storm water management, and noise reduction. Local climate regulation, recreation and human health ES are among the highly supplied services along Saris and Addisu Gebeya street corridors (Annex V).

Periphery Zone:

Like the intermediate zone, lower mean values of ES supply are witnessed from the periphery zone of Addis Ababa. The mean values of ES supply for regulating, cultural, and supportive ES were 2.79, 2.59, and 1.75 respectively, ranking from highest to lowest. Air quality regulation, in particular, dust removal and noise reduction are the least provided regulating ES with typical values of 2.22 and 2.21. Regarding cultural ES, physical exercise, social setting, and human health resulted in 2.03, 2.06, and 2.35 mean values. Local climate regulation, when compared to other factors, received the highest intermediate score of 3.31 mean ES supply.

Supporting longer pavement life (1.76) and physical exercise (1.68) are two of the least ES supplied in lamberet to wesen street corridor, while species diversity and habitat for wildlife are the lowest of all in Alembank to Ayertena street corridor with 1.65 and 1.55 mean values respectively (Annex V).

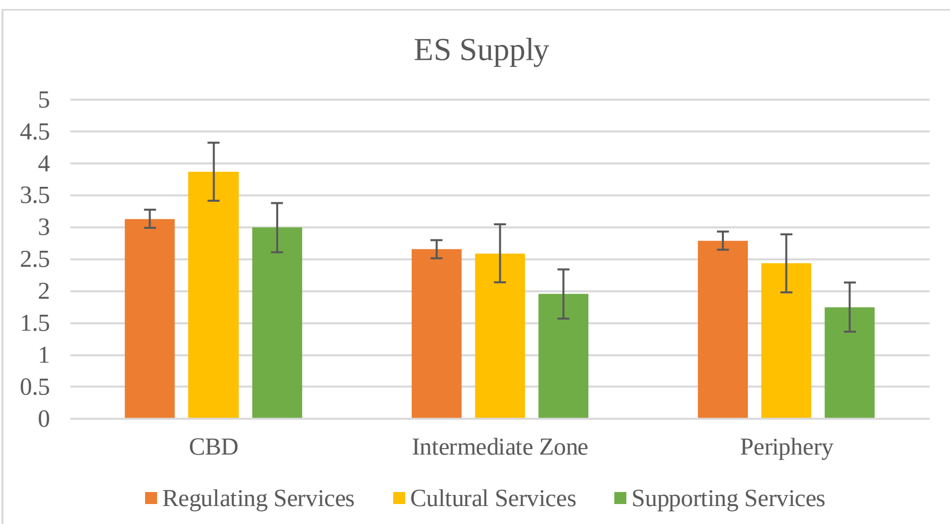


Figure 5.1 Ecosystem service supply assessment

4.1.2. Ecosystem Service Demand Assessment

Commercial business district (CBD) zone:

Demands for regulating ES exhibits highest cumulative value of 4.3, from which Local climate regulation ES shows significantly higher individual rating of 4.63 from overall list of regulating ES. Cultural ES demand ranked second with 4.17 cumulative mean value. Further articulated from individual ES and sub services perspective, comfort for use, street beautification, and social setting obtained highest value of 4.46, 4.42, and 4.37 respectively. On the other hand, creating sense of space and physical exercise were among the least scoring 3.77 and 3.8 values respectively.

Besides, low scoring demand for supporting ES was computed to be 3.95, from which, habitat for wild life (3.69) scored the lowest individual mean value. Being the least demanded of all, edible fruit provision service scored 3.46 mean value in CBD.

Intermediate Zone:

Cultural, regulating, and supporting ES all shows higher demand from street users with respective mean value of 4.29, 4.22, and 4.14. Regarding each individual ES and sub services, physical exercise (3.96), habitat for wildlife (3.93), and food provision (3.24) are the only ES with a score of lower than 4. Aesthetics, comfort for use, and thermal comfort scored top three demanded ES in intermediate zone of Addis Ababa with individual mean values of 4.64, 4.61, and 4.42 respectively.

ES demand on a street corridor from Piassa to Addisu Gebeya indicates the highest among other streets with emphasis on local climate regulation, carbon sequestration, street beautification, and human health; all scoring higher than 4.72, which is very highly demanded.

Periphery Zone:

The periphery zone of Addis Ababa shows the highest cultural (4.4) and regulating (4.32) ES demand from the rest zones. Likewise, supporting service (4.1) is highly demanded. To be specific, local climate regulation and storm water management scored 4.47 and 4.35 respective mean values from list of regulating ES.

While comfort for use, street beautification, and social setting ranked the top among cultural ES with mean values of 4.71, 4.68, and 4.57 respectively. Moreover, tree species diversity shows highest demand of 4.42 while habitat for wildlife scored the lower 3.78 mean value from list of supporting ES.

In particular to specific street corridors, Lamberet to Wesen street corridor shows high demand for cultural ES, all scoring higher than 4.5, except for human health (4.48) and physical exercise (4.28). Refer Figure 4.10 for graphical illustration of Ecosystem Service demand assessment in the inner city, intermediate, and peripheral zones of Addis Ababa.

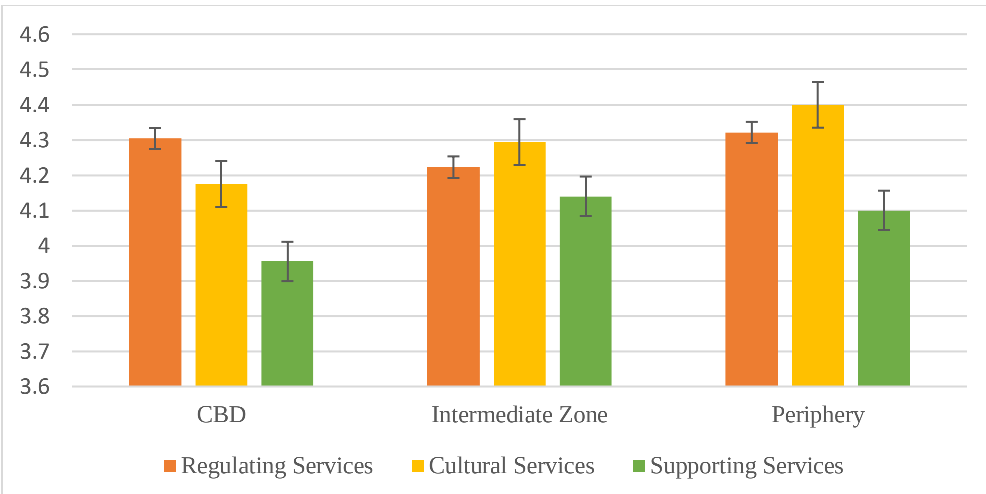


Figure 5.2 Ecosystem service demand assessment.

4.1.3. Results from Apparent-Urgency Analysis (Supply vs. Demand)

Commercial business district (CBD) zone:

Cultural ES shows the highest sufficiency with lowest difference value of 0.36 in contrast to regulating (1.17) and supporting (0.96) ES in the inner city. Overall, the CBD of Addis Ababa recorded the smallest urgency for ES when compared with the intermediate and periphery zones (Figure 4.11).

Regarding the regulating ES in CBD, noise reduction, rainwater trapping, and flood/runoff control noted intermediate urgency values of 1.61 1.45, and 1.42 mean difference respectively. All ecosystem services and sub services scoring less than 0.65, the CBD zone of Addis Ababa does not show urgency for cultural ES. Likewise, supporting ES scored less than one.

Intermediate Zone:

Supporting ES show 2.19 normalized mean difference, which is the most urgent in the intermediate zone. With an individual men difference computation, tree species diversity shows higher urgency of 2.29, while habitat for wildlife shows 2.08. Both the regulating (1.56) and cultural (1.73) ES show medium to high urgency when compared with CBD.

Among others, street beautification, social setting, and physical exercise are the highest cultural ES that show urgency value of 2.04, 1.97, and 1.9 respectively. Regarding regulating services, noise reduction, rainwater trapping, and flood control services indicate relatively highest urgency value of 1.95, 1.93, and 1.85 respectively. Megenagna to Signal and Meskel Square to Lancha street corridors indicate the highest urgency for street beautification with a mean difference of 2.96 and 2.70 respectively. Again, species diversity is demanded in urgency with a respective values of 2.19 and 2.89 in both streets.

Periphery Zone:

Periphery zone is the one with highest urgency values in relation to the remaining two zones of Addis Ababa. Regulating ES recorded 1.53 intermediate urgency mean value, while cultural and supporting ES shows the highest 2.03 and 2.35 urgency values respectively.

Considering the individual regulating ES list, dust reduction (2.03) and noise reduction (2.01) are the only regulating ES with difference value of greater than two. However, five of seven cultural ES show highest urgency mean values of greater than two. To name a few, social setting and comfort for use recorded 2.51 and 2.12 respectively. Meanwhile, both supporting ES; species diversity and habitat for wildlife show high urgency with 2.67 and 2.03 values.

Lamberet to Wesen street corridor indicated the highest urgency for cultural ES, in particular, longer pavement life, comfort for use, social setting, and physical exercise with respective vales of 2.94, 2.80, 2.76, and 2.60. Meanwhile, species diversity (2.70) is the only highest ES demanded in urgency along the Alembank to Ayertena street corridor.

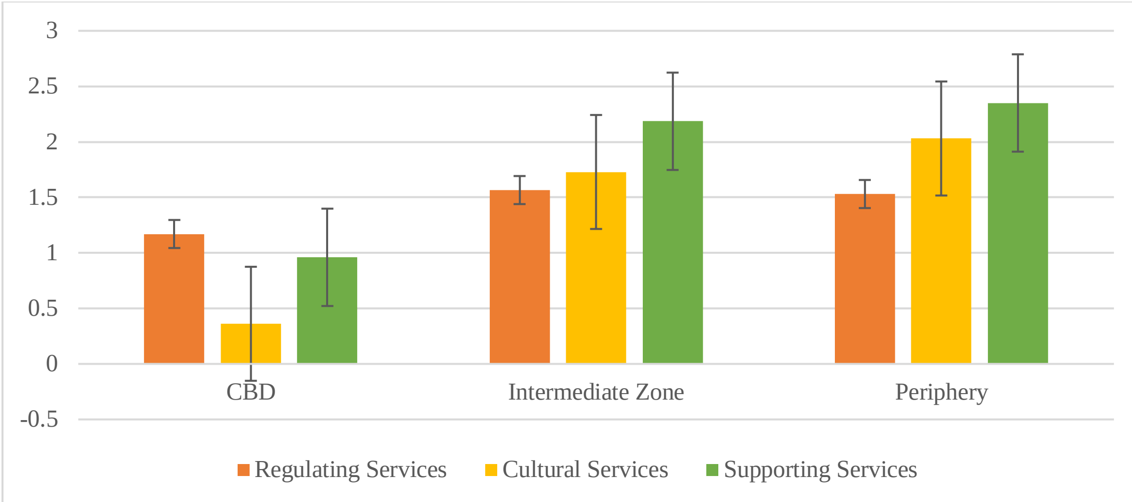


Figure 5.3 Ecosystem service apparent urgency assessment (Supply vs Demand

Table 5-2 Summarized street user-based mean assessment of ecosystem service supply, demand, and apparent urgency from urban street trees in the inner city (CBD), Intermediate zone (Inter), and Periphery zone (Peri) of Addis Ababa, Ethiopia.

Ecosystem Services	Ecosystem Sub-services (Indicators)	Perceived Supply			Future Demand			Apparent Urgency		
Regulating Services		**CBD**	**Inter**	**Peri**	**CBD**	**Inter**	**Peri**	**CBD**	**Inter**	**Peri**
Local Climate Regulation	Thermal comfort	3.7	3.08	3.26	4.6	4.42	4.45	0.9	1.34	1.19
	Shade provision	3.69	3.19	3.36	4.65	4.25	4.49	0.96	1.06	1.13
Air Quality Regulation	Dust reduction / removal	3.43	2.65	2.22	4.28	4.05	4.25	0.85	1.4	2.03
	Carbon sequestration	3.34	2.83	2.99	4.34	4.26	4.14	1	1.43	1.15
	Noise reduction	2.45	2.08	2.21	4.06	4.03	4.22	1.61	1.95	2.01
Storm water Management	Flood/runoff control	2.69	2.43	2.81	4.11	4.28	4.29	1.42	1.85	1.48
	Trapping Rainwater	2.64	2.34	2.69	4.09	4.27	4.41	1.45	1.93	1.72
Cultural Services		**CBD**	**Inter**	**Peri**	**CBD**	**Inter**	**Peri**	**CBD**	**Inter**	**Peri**
Aesthetic Value	Inspiration / Motivation	4.03	3.06	2.87	4.19	4.31	4.46	0.16	1.25	1.59
	Street beautification	4.4	2.6	2.59	4.42	4.64	4.68	0.02	2.04	2.09
	Supporting longer pavement life	3.58	2.74	2.56	4.07	4.26	4.37	0.49	1.52	1.81
	Creating sense of Place				3.77	4.1	3.94			
Recreation and Human Health	Physical exercise	3.47	2.06	2.03	3.8	3.96	4.07	0.33	1.9	2.04
	Emotional and psychological health	3.68	2.46	2.35	4.32	4.2	4.4	0.64	1.74	2.05
	Social setting	3.85	2.3	2.06	4.37	4.27	4.57	0.52	1.97	2.51
	Comfort for use	4.09	2.93	2.59	4.46	4.61	4.71	0.37	1.68	2.12
Supporting Services		**CBD**	**Inter**	**Peri**	**CBD**	**Inter**	**Peri**	**CBD**	**Inter**	**Peri**
Biodiversity	Tree species diversity	3.3	2.06	1.75	4.22	4.35	4.42	0.92	2.29	2.67
	Habitat for wildlife	2.69	1.85	1.75	3.69	3.93	3.78	1	2.08	2.03
Provisioning Services		**CBD**	**Inter**	**Peri**	**CBD**	**Inter**	**Peri**	**CBD**	**Inter**	**Peri**
Food provision	Edible Fruit Provision				3.46	3.24	3.31			

Legend: Lacking or Urgent — Intermediate — Present or Sufficient

Correlation between Ecosystem Service Apparent Urgency and Type of Street user

In this study, apparent urgency for ES is shown towards local climate regulation, stormwater management, and aesthetics and recreation. Local climate regulation, particularly shade provision and thermal comfort is identified as the urgently demanded ES by pedestrians and street vendors with a 1.21 mean value, while car users show only a 0.04 difference from the supply and demand assessment.

When it comes to stormwater management, in particular, runoff reduction and rainwater trapping; street vendor's and car user's responses show great urgency with respective mean values of 2.1 and 1.88 difference from supply and demand assessment. Aesthetics and recreation, on the other hand, is urgently demanded by pedestrians, street vendors, and street fronts with 1.54, 1.47, and 1.24 mean values respectively.

In general, the correlation shows how pedestrians tend to demand local climate regulation and aesthetics rather than stormwater management. Whereas Sreet vendors and car users show great interest in stormwater management.

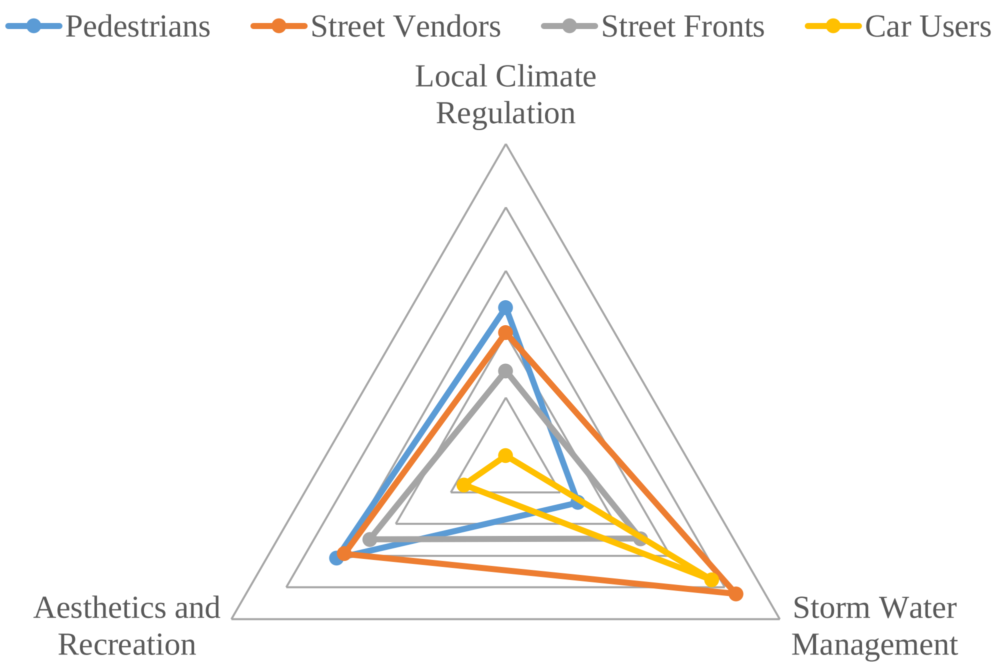


Figure 5.4 Correlation between Ecosystem Service Apparent Urgency and Type of Street user

4.2. Discussion

Results obtained from the assessment of Addis Ababa's street tree ecosystem service supply and demand are insightful and informative enough to demonstrate how the socio-spatial and governance components of city planning are related to all four types of ecosystem services (ES); regulating, cultural, supporting, and provisioning. In our instance, street users were selected along different street corridors to represent the inner city (CBD), intermediate zone, and periphery of Addis Ababa. The findings have been discussed to emphasize the apparent urgency of ecosystem services from urban street trees.

Ecosystem Service Supply

Under the category of regulating services, local climate and air quality regulation services of urban street trees seems to be supplied to some level in CBD zone of Addis Ababa. Given the political and governance factors on the most valuable street corridors of CBD, the implementation of street tree planning and management is at better level, when compared with the remaining zones. Although it is yet to be perceived high, street users perception about CBD zone shows medium level of ES supply from street trees. A study by Buffam et al., (2022) also highlights perceived regulatory ES supplies from street trees; in particular, local climate regulation, shade provision, air quality regulation, reduced UHI, stormwater management, and flood control.

Besides, cultural ES recorded the most sufficiently supplied ES along streets of CBD. Here, the political and governance pressures play a vital role. On the contrary, supporting ES like habitat for wild life and tree species diversity seems to be affected by the high interaction of urban activities and resulted in the least perceived ES. The high level of impervious surface construction on the other hand brought negative impact on the storm water management ES of street trees. The case with impervious surfaces and their forefront impact on storm water management and flood risk is also discussed by Beecham and Lucke, (2015). Other studies also highlighted medium level of cultural ES supply in Addis Ababa streets (Buffam et al., 2022).

The rest zones of Addis Ababa, on the other hand, shows lacking ES supply. Besides, all four categories of ES were perceived to be lacking by street users along the intermediate and peripheral zones. Especially, provisioning ES categories were the least supplied ES followed by cultural (social setting, physical exercise, ad health), and regulating (Air quality, noise) ES.

Other studies worldwide mentioned how street tree planning and management is related with human nature, and their interaction often involve biophilia, the use of orderly nature as a symbolic commodity and, more recently, ecological stewardship (Laurian, 2019). Unfortunately, Addis Ababa's result show the lowest benefit being gained by its street users, and street trees are not serving to their potential.

Ecosystem Service Demand

Except edible fruit provision, and Habitat for wildlife ES, the remaining ES and sub services show high demand from street user's side. On the contrary, similar studies (although it not only focused on street trees), show the highest demand for provisioning ES (Buffam et al., 2022). The argument for this result was that people in Addis are relying on food provisions from trees. Cultural ES demand assessment also shows relatively limited value, showing the focus of government is already on street beautification and alike activities. Thereby indicating the need to balance between all four ES categories.

The purpose and frequency of street users street usage had major effect on the obtained result. More than half of street users surveyed were on the street for work or business, and walking purpose. Whereas, street users who came for recreation, visiting and appointment were very limited in number. Hence, their demand must have been shaped towards regulating and supporting, rather than cultural.

For example, commuters may prioritize noise and pollution reduction, whereas recreational street users may prioritize aesthetic and leisure benefits. Comparably, regular street users are more likely to recognize the everyday advantages of street trees; such as improved air quality and shade (Chang Zhao, Heather A. Sander, 2015), than infrequent visitors who might take these benefits for granted.

Apparent Urgency Assessment (Supply vs Demand)

The apparent urgency assessment solely relied on street user perceptions, indicating that ES is urgently required when perceived supply is significantly less than demand. The connection between street users and street trees is improved by incorporating a variety of scales and types of nature, one of which is street trees, and by offering opportunities for hands-on activity in nature (Church, 2018).

Street users' apparent urgency towards the previously described ES exhibits their attachment to nature and their stand on greening efforts for human–nature interaction (Drew-Smythe et al., 2023a).

Regarding the obtained result, urgent ES demanded by street users were identified per each zones and street corridors (Table 4.17 and Annex V). As mentioned earlier, this assessment revealed the limited or no need for more cultural ES from urban street trees in CBD zones of Addis Ababa. Because of the green legacy initiatives in the country, sufficient ES supply and least demand is recorded regarding ‘street beautification’, ‘comfort for use’, ‘physical exercise’, and ‘inspiration’.

In terms of storm water management, a better understanding of the nature and extent of tree-storm water interactions is necessary for the effective use of trees (Berland et al., 2017). In essence, the highly increasing urbanization rate and continues covering of porous surfaces with impervious surfaces resulted in the intermediate urgency of storm water management ES along CBD streets. A study by Beecham and Lucke, (2015) also support this claim, where the more urbanized and impervious the site is, the more urgent ES is demanded.

Regarding the intermediate zones, street users tend to be needing urgent attention towards noise reduction, storm water management, street beautification, social setting improvement, and supporting biodiversity ES. Comparable to the rest ES indicators, ‘local climate regulation’ and ‘Aesthetic value’ were the only ES with low or medium level of urgency. Peripheral zones, on the contrary, highlighted the urgent need for ES on almost all ES categories.

Biodiversity is recognized as important for human health, and loss of biodiversity could have devastating effects on both human’s habitus, food supply and hence overall survival (MEA, 2005), and yet the highest urgency along periphery zone was witnessed for this ES.

Correlation of Street user Types with Apparent Urgency Assessment

As each type of street user interacts with urban street trees in unique ways, leading to different ecosystem service demands, the correlation of the type of street users with the prioritized ES was necessary. Moreover, a study by Buffam et al., (2022), interpreted apparent urgency for ES as those with the potential to address urban challenges.

Pedestrians and street vendors are mostly looking for shade, cooling, and beautifying enhancements because of their interactions with the street. While businesses with street fronts prioritize visual attractiveness for greater financial returns, car owners gain from controlled stormwater runoff as well as enhanced parking convenience and security. Hence, these findings help while suggesting possible solutions that are better suited for different types of street users.

In summary, this study reveals the unbalanced green transition efforts being implemented, where selected key areas are developed and given priority while the rest street corridors (in particular, along the periphery zones) are forgotten. The diversified urgency for different ecosystem services categories highlight the need to implement balanced, well networked, and multifunctional urban green infrastructure along urban streets, as recommended by ESPON EGTC, (2019).

Furthermore, Pataki et al., (2021) pointed out that the most potential benefits of urban trees for the environment and human health are those that may be achieved by carefully planned tree planting and site-specific design changes at the local, and municipal levels. The best results for tree planting at these scales will come from thoughtfully selected sites, careful observation, and adaptive management.

4.3. Planning Implications

The study has implications for other cities in developing countries regarding urban street tree planning and management. The thoughtful consideration of ecosystem services and disservices rather than mere aesthetics and availability is the first crucial point in realizing balanced and long-term ecosystem service from urban street trees. Future directions has to focus on identifying tree species that are well suited to local environmental conditions and provide multiple ecosystem services, while utilizing strategic tree plantation that takes into account the location to provide maximum ecosystem services.

5. Conclusion and Recommendations

5.1. Conclusion

The incorporation of street trees into urban landscapes is a complex intersection of environmental sustainability and urban planning. Street trees not only add to the aesthetic appeal of cities, but they also provide ecosystem services. However, the supply and demand dynamics for street trees and their ecosystem services are complex, with significant gaps. On the one hand, there is a growing demand for the benefits of street trees, which is being driven by urbanization and increased environmental awareness.

However, problems like a lack of green space, poor maintenance, and pressure from urban development can limit the supply of these services. Maximizing the benefits of street trees on urban settings and promoting sustainable urban development in the face of rapidly increasing global urbanization and climate change require an understanding of and ability to bridge these supply and demand gaps.

In light of the aforementioned issues, this study examined the supply and demand of ecosystem services from urban street trees, thereby providing insightful analysis and workable recommendations to bridge the gap between the supply and demand for ES, and for the promotion of livable and green cities.

As per the assessment of supply and demand, the provision of ES from urban street trees resulted in a gap that require apparent urgency. Regulating ES, in particular, storm water management and local climate regulation shows high apparent urgency in CBD, intermediate, and periphery zones of Addis Ababa. Whereas cultural ES, in particular, aesthetics, recreation and human health are the most urgent ES in the intermediate and periphery zones, and the least urgent in CBD of Addis Ababa. Besides, supporting ES like tree species diversity show high apparent urgency in intermediate and periphery zones of Addis Ababa. While provisioning ES like Edible fruit production shows intermediate demand and less urgency in Addis's streets.

Given the above major findings, this study concludes by forwarding two identified planning implication for future studies and researchers. The findings emphasize how crucial it is to give ecosystem services a higher priority than mere aesthetics and beautification when planning and maintaining urban street trees in developing cities.

Besides, it highlights the importance of species selection that considers adaptation to local environment, and their capacity of offering a variety of ES.

5.2.Recommendation

Enhancing and balancing the provision of ecosystem services requires a multi-layered strategy that considers street trees and their surrounding environment. Gaps regarding balancing the supply and demand of Ecosystem services show apparent urgency for storm water management, local climate regulation, aesthetics, recreation, human health, and biodiversity. Hence, the following recommendations are forwarded.

➢ Recommendations for Stormwater Management

Green Strips with Bioswales

- **Action:** Install continuous green strips along pedestrian pathways to manage stormwater using bioswales with permeable soil, and native vegetation
- **Implementation:** Map suitable pathways with urban planners. Design bioswales with proper water flow and establish a maintenance plan to prevent clogging.

Permeable Pedestrian Tiles

- **Action:** Replace solid paving with permeable tiles to reduce water stagnation
- **Implementation:** Target key pathways with waterlogging issues. Source durable, load-bearing permeable materials from reputable suppliers.

Linear Green Spaces & Rain Gardens

- **Action:** Create street-side green spaces with rain gardens to capture and absorb stormwater runoff.
- **Implementation:** Collaborate with landscape architects to design rain gardens tailored to local stormwater flow. Use native plants for optimal absorption and low maintenance.

Flood-Tolerant Trees for Bioswales

- **Action:** Plant flood-tolerant, fast-growing tree species in bioswales to enhance stormwater management and biodiversity.
- **Implementation:** Partner with horticulturists to select species suited to local conditions and ensure proper spacing and root management.

➢ Recommendations for Local Climate Regulation

Prioritize and Sustain Mature Trees

- **Action:** Preserve mature trees for their superior climate benefits.
- **Implementation:** Establish policies to protect these trees during construction and create a program for regular health assessments and maintenance.

Pollution-Tolerant, Locally Compatible Tree Species

- **Action:** Select tree species that tolerate pollution, adapt to local soil and climate, and resist carbon emissions.
- **Implementation:** Work with environmental experts to choose native species suited for urban conditions.

Strategic Tree Placement for Climate Benefits

- **Action:** Plant trees in high-traffic areas, near buildings to reduce heat gain, and along concrete surfaces to cut heat reflection.
- **Implementation:** Use GIS tools to identify the best locations for tree placement, ensuring adequate spacing for canopy growth and heat island mitigation.

Routine Maintenance and Species Diversity

- **Action:** Regularly maintain trees with pruning, watering, and fertilizing while ensuring species diversity to enhance resilience.
- **Implementation:** Schedule arborist-led care and plant a mix of native and adaptable species to minimize risks from pests or diseases.

Integrate Trees with Green Infrastructure

- **Action:** Combine trees with rain gardens, bioswales, and green roofs for improved stormwater management and climate regulation.
- **Implementation:** Design layouts that integrate trees with other green infrastructures, leveraging synergies for environmental benefits like stormwater absorption and cooling.

➢ **Recommendations for Recreation and Aesthetics**

- **Separate Green Zones and Street Furnishings:** Allocate distinct strips for greenery and street furniture for clarity and functionality in urban design.
- **Tree-Lined Pavements with Amenities:** Plant trees along pavements for shade and add benches, lighting, and seating to enhance pedestrian experience.
- **Pocket Parks and Small Green Spaces:** Create small green areas with trees, bushes, and seating along streets for relaxation and social interaction.

- **Creative Tree Planting Patterns:** Use alternating tree species, colors, and textures for visually pleasing, varied landscapes.
- **Ornamental Lighting for Nighttime Appeal:** Install energy-efficient lighting to highlight trees, enhancing aesthetics at night or during special events.
- **Community Tree Planting Days:** Organize volunteer tree planting events to engage locals and promote community ownership.
- **Routine Maintenance for Green Spaces:** Implement regular care routines (e.g., pruning, watering) to maintain the health and visual appeal of green spaces.

➢ **Recommendation for Future Researchers**

Future studies are encouraged to integrate biophysical assessments, such as tree species traits, soil quality, spatial connectivity assessments, and climate data, alongside perception-based approaches. Combining these perspectives would provide a more comprehensive understanding of ecosystem service provision and inform better urban planning and management strategies.

References

Abunnasr, Y. F. (2013) Climate Change Adaptation: A Green Infrastructure Planning Framework for Resilient Urban Regions, Open Access Dissertations, University of Massachusetts Amherst [Online]. Available at https://doi.org/10.7275/yg71-qy42%20https://scholarworks.umass.edu/open_access_dissertations/775.

Adem, H., Advisor, A. and Seifu, S. (2020) The role of puplic sector institutions on space allocation for street greenery in addis ababa.

Borelli, S. (2016) Benefits of Urban Trees [Online], Rome, Italy, FAO.

Buffam, I., Hagemann, F. A., Emilsson, T., Gamstetter, D., Pálsdóttir, A. M., Randrup, T. B., Yeshitela, K. and Ode Sang, Å. (2022) 'Priorities and barriers for urban ecosystem service provision: A comparison of stakeholder perspectives from three cities', Frontiers in Sustainable Cities, vol. 4, p. 12.

Burden, D. (2006) 22 Benefits of Urban Street Trees, Glatting Jackson and Walkable Communities, Inc.

Elmqvist, T., Redman, C. L., Barthel, S. and Costanza, R. (2013) 'History of Urbanization and the Missing Ecology', in Elmqvist, T., Fragkias, M., Goodness, J., Güneralp, B., Marcotullio, P. J., McDonald, R. I., Parnell, S., Schewenius, M., Sendstad, M., Seto, K. C. and Wilkinson, C. (eds) Urbanization, Biodiversity and Ecosystem Services: Challenges and Opportunities: A Global Assessment, Dordrecht, Springer Netherlands, pp. 13–30.

Escobedo, F. J., Kroeger, T. and Wagner, J. E. (2011) 'Urban forests and pollution mitigation: Analyzing ecosystem services and disservices', Environmental pollution (Barking, Essex : 1987), vol. 159, 8-9, pp. 2078–2087.

Eshetu, S. B., Yeshitela, K. and Sieber, S. (2021) 'Urban Green Space Planning, Policy Implementation, and Challenges: The Case of Addis Ababa', Sustainability, vol. 13.

Forest research (2021) Trees, green spaces and urban cooling.

Güneralp, B., Lwasa, S., Masundire, H., Parnell, S. and Seto, K. C. (2017) 'Urbanization in Africa: Challenges and opportunities for conservation', Environmental Research Letters, vol. 13, no. 1, p. 15002.

Hopton, M. and Berland, A. (2014) Municipa Street Tree Structure and Ecosystem Services, US EPA, ORD, Sustainable Technologies Division.

Jamal Saghir and Jena Santoro (2018) ‘Urbanization in Sub-Saharan Africa: Meeting Challenges by Bridging Stakeholders’.

Kasa, L., Zeleke, G., Dawit, A., Hagos, F. and Heinimann, A. (2011) ‘Impact of urbanization of Addis Ababa city on peri-urban environment and livelihoods’.

Knudsen, C., Moreno, E., Arimah, B., Otieno Otieno, R. and Ogunsanya, O. (2020) World Cities Report 2020: The Value of Sustainable Urbanization, UN-Habitat.

Marjan van den Belt (2016) Chapter 3: Scientific Understanding of Ecosystem Services, United Nations.

McPhearson, T., Hamstead, Z. A. and Kremer, P. (2014) ‘Urban ecosystem services for resilience planning and management in New York City’, Ambio, vol. 43, no. 4, pp. 502–515.

Monteiro, M. V., Morison, J. I., Handley, P. and Doick, K. J. (2019) The role of urban trees and greenspaces in reducing urban air temperatures, Forest research.

Pataki, D. E., Alberti, M., Cadenasso, M. L., Felson, A. J., McDonnell, M. J., Pincetl, S., Pouyat, R. V., Setälä, H. and Whitlow, T. H. (2021) ‘The Benefits and Limits of Urban Tree Planting for Environmental and Human Health’, Frontiers in Ecology and Evolution, vol. 9, p. 5.

Tegenu, T. (2010) Urbanization in Ethiopia:: Study on Growth, Patterns, Functions and Alternative Policy Strategy, Department of Human Geography, Stockholm University.

Walker, B. and Salt, D. (2006) Resilience thinking: Sustaining ecosystems and people in a changing world, Island press.

Williams, E. R. A. (ed) (2000) Environmental planning for sustainable urban development.

Yao, J., Chen, N., Guo, F., Liu, M., Chen, W. and He, X. (2022) Variation in ecosystem services of street tree assemblages can guide sustainable urban development [Online].

Annex II Questionnaire and Interview Guidelines

A. Questionnaire for Street Users

Dear respondent, I request your voluntary cooperation in providing primary data requested to address a M.Sc. thesis research entitled "**Urban street tree planning and management for resilient ecosystem service provision in Addis Ababa, Ethiopia".** Your participation in the study is completely voluntary the study will consider full anonymity and confidentiality of the respondents and the data collected.

- **Select one street corridor that you are most familiar with**

  i. Churchill Road
  ii. Sengatera/Goma kuteba to filweha
  iii. Meskel square to Lancha
  iv. Megenagna to Signal
  v. Shola (Giorgis) to Addisu gebeya
  vi. Saris Adeyabeba to Saris Abo station
  vii. Lamberet to Wesen
  viii. Ayertena Kidanemihret to Alembank

a) Demographic and General Assessment questions

1. Respondent Code ____________
2. Gender a) Male b) Female
3. Age a) Below 18 b) 18 - 30 c) 31-64 d) 65 and above
4. Educational Status a) Read and Write b) Certificate/Diploma c) Degree d) Masters and above
5. Occupational status a) Unemployed b) Employed c) Private Business d) Student
6. Type of respondents (street users)
   a) Pedestrian
   b) Street fronts
   c) Street Vendor
   d) Cyclists
   e) Car user
7. How do you typically access this street?
   a) on foot
   b) by bicycle
   c) by public transportation
   d) by car
   e) other ______
8. How often do you use this street?
   a) Daily
   b) Twice per day
   c) Three times per Day
   d) Once a week
   e) Other ______
9. For what purpose do you use this street? (Multiple selection allowed)
   a) Walking
   b) Shopping
   c) Education
   d) Work/business
   e) Recreation
   f) Waiting for public transport
   g) Appointment
   h) Other ________

b) Ecosystem Service Supply Assessment

10. In your perception, how well are the following ecosystem services being supplied by street trees in Addis Ababa? (1 = not at all, 2 = Poor supply, 3= Medium supply, 4= Good supply, 5 = Very Good supply)

Ecosystem Service Category	Benefits / Values provided	None	Poor	Medium	Good	Very Good	Overall value
		1	2	3	4	5	
Local climate regulation	Thermal comfort						
	Shade provision						
Air quality regulation	Dust removal						
	Carbon sequestration (Smoke free air)						
	Noise reduction						
Storm water management	Flood/runoff control						
	Trapping Rainwater						
Aesthetic value	Inspiration						
	Street beautification (green and colorful)						
	Longer pavement life						
Recreation and human health	Physical exercise						
	Emotional and psychological health						
	Social setting						
	Comfort for use						
Biodiversity	Tree species diversity						
	Habitat for wildlife						

11. Overall, how do you evaluate the capacity and current practice of the city administration in developing and managing street trees?

Very Poor	Poor	Medium	Good	Very Good

c) Ecosystem Service Demand Assessment

12. In your perception, how well are the following ecosystem services demanded from street trees in Addis Ababa? If there are any other Ecosystem Services you demand, you may add them to the table. (1 = not at all, 2 = Poor supply, 3= Medium supply, 4= Good supply, 5 = Very Good supply)

Ecosystem Service Category	**Benefits / Values provided**	**None (Very low)**	**Low**	**Medium**	**High**	**Very High**	**Overall value**
		1	**2**	**3**	**4**	**5**	
Local climate regulation	Thermal comfort						
	Shade provision						
Air quality regulation	Dust removal						
	Carbon sequestration (Smoke free air)						
	Noise reduction						
Storm water management	Flood/runoff control						
	Trapping Rainwater						
Aesthetic value	Inspiration						
	Street beautification (green and colorful)						
	Longer pavement life						
Recreation and human health	Physical exercise						
	Emotional and psychological health						
	Social setting						
	Comfort for use						
Biodiversity	Tree species diversity						
	Wildlife						
Food Provision	Edible Fruits						
Sense of Place	Safe and Familiar place						

d) Ecosystem Disservice Assessment Questions

13. Have you encountered any of street tree ecosystem disservices/problems listed on question 14?

    a) Yes   b) No

14. If yes, please select the ones you encountered (Multiple selection allowed)

    a) Tree branch falling
    b) Dead or dried trees
    c) Littering and Poor aesthetic quality
    d) Blocking view
    e) Causing drainage problems
    f) Damage to cars, property, and buildings
    g) Obstructing use of space
    h) Hiding traffic signs and lighting
    i) Other _________

15. If yes, rate the influence of below listed solutions towards mitigating aforementioned dis-services/problems?

Possible Solutions	Very low	Low	Don't know	High	Very High
Climate-resilient species selection					
Creating proper integration among institutions					
Use of root barriers					
Pruning/cutting nonstructural roots, broken branches, and over grown crown					
Timely inspection and maintenance on a regular basis					
Fostering public participation					
Using strong and durable fence material, and close checkup for security issues					
Other ___________________					

e) Public Participation

16. Have you ever participated on street tree development or management practices in Addis Ababa?

    a) Yes   b) No

17. If yes, please select on which activity you participated (Multiple selection allowed)

    a) Street tree (Sapling) provision
    b) Financial support
    c) Street tree plantation
    d) Watering
    e) Mulching
    f) Pruning
    g) Fencing
    h) Other ________

B. Interview Guideline for Experts at the Addis Ababa City Administration Urban Green Development and Beautification Bureau

Dear respondent, I request your voluntary cooperation in providing primary data requested to address a M.Sc. thesis research entitled "**Urban street tree planning and management for resilient ecosystem service provision in Addis Ababa, Ethiopia".** Your participation in the study is completely voluntary the study will consider full anonymity and confidentiality of the respondents and the data collected.

I. General Background Questions

1. Respondent Code ____________
2. Educational Qualification ________________________________
3. Specific Work unit / Position in the institution ____________________________________
4. Work Experience
    a) Total work experience ____________
    b) Work experience in current position ____________

II. Interview Questions on the current street tree development and management practice

5. What factors do you consider the most when determining type of street tree species? (Select 3 - 5)
    a) Availability
    b) Cost / Finance
    c) Ecosystem service provision
    d) Native/Exotic
    e) Growth rate
    f) Wood strength
    g) Pest resistance
    h) Pollution resistance
    i) Water demand
    j) Durability and maintenance need
6. List ecosystem services that are considered when planting existing street trees in Addis Ababa
    ____
7. How well do your organization consider these National policy documents, strategies and standards on the development and management of street trees?

Policy documents, Strategies, and Standards	None	Low	Medium	High	Very High
Urban Development Policy					
Climate change Resilient urban green development strategy					
Ethiopian national urban green infrastructure standard					
Other __________________					

8. Indicate the integration of listed institutions on Addis Ababa's street tree development management

List of organizations / Institutions	No involvement	Planning	Implementation	Management
Environment and Green Development Commission				
The Addis Ababa City Planning and Development Commission (AAPDC)				
The Ministry of Urban Development and Housing (MUDH)				
Gullele Botanical Garden				
The Addis Ababa City Road Authority (AACRA)				
Addis Ababa Water and Sewerage Authority (AAWSA)				
Other ____________________				

9. Rate the level of involvement / influence of listed organizations in direct relation with the planning, implementation and management of urban street trees in Addis Ababa?

List of organizations / Institutions	**None**	**Low**	**Medium**	**High**	**Very High**
Environment and Green Development Commission					
The Addis Ababa City Planning and Development Commission (AAPDC)					
The Ministry of Urban Development and Housing (MUDH)					
Gullele Botanical Garden					
The Addis Ababa City Road Authority (AACRA)					
Other ______________________________					

10. Rate your level of agreement on whether these considerations are taken while planting street trees in Addis Ababa or not?

Street tree planting Considerations	Strongly Disagree	Disagree	Don't know	Agree	Strongly Agree
Planting location					
User's dimension and Interest					
Overhead power lines					
Other infrastructure on the ground					
Building setbacks					
Public participation					
Space allocation for movement					
Soil strata					
Other ____________________					

11. How well do you think are urban street trees being maintained in Addis Ababa?

Attributes of street tree Management	None	Poor	Medium	Good	Very Good
Continuous watering					
Mulching for soil fertility					
Pruning broken branches and over-grown crown					
Adequate inspection on their health status					
Replacing dead/dry trees					
Proper fencing					
Application of chemical treatment and technology for pest and related risks					
Other ____________________					

12. What are the key challenges of the street tree development? (Rank them as their prioritization)

Challenges of street tree development	Rank (1st, 2nd, 3rd, 4th, …)
Species selection	
Space allocation	
Compacted soil condition	
Size of planting pits	
Finance	
Poor integration among stakeholders/institutions	
Other ____________________	

13. What are the major challenges of the street tree management? (Rank them as their prioritization)

Challenges of street tree management	**Rank (1st, 2nd, 3rd, 4th, …)**
Conflict with infrastructure	
Conflict with Vehicles	
Lack of skilled experts	
User's pressure due to lack of awareness	
Maintenance cost	
Water consumption	
Stolen tree fences	
Other ___________________	

14. Please mention the time of street tree implementation/plantation on listed street corridors?

List of street corridors	**Plantation Time**	**List of street corridors**	**Plantation Time**
Churchill Road		Shola (Giorgis) to Addisu gebeya	
Sengatera to filweha		Saris Adeyabeba to Saris Abo station	
Meskel square to Lancha		Lamberet to Wesen	
Megenagna to Signal		Ayertena Kidanemihret to Alembank	

15. Could you please suggest possible solutions to mitigate the above developmental and management challenges?

____

____

____

____

____

III. Interview Questions from a Resilience perspective

16. Rate the overall level to which Addis Ababa's Street tree development and management practices integrated/considered the indicators of the resilience principle outlined below.

Resilience Principles	Indicators	Level of Integration					Overall value
		None	Low	Medium	High	Very High	
Diversity	Species diversity (Quantity wise)						
	Age diversity						
Redundancy	Repetition and harmonization of street tree plantation on the specified segment						
	Spacing of street tree plantation (Density)						
	Diversity of tree species with similar function (Functional redundancy)						
Connectivity	Urban street trees with each other along street corridors						
	Urban street trees with other GI components of the city						
Participation and Integration	Public involvement in tree plantation programs						
	Public involvement in tree management						
	Integration with infrastructure providing institutions (Shared planning, decision making, shared public disclosure)						
Adaptability	Protective structures against user pressure						
	Less water demanding species selection						
	Pest resistance species selection						

	Fast growth rate species selection						
	Provision of adequate maintenance						
	Wider planting pits that consider street tiles						

C. Interview Guideline for Key Experts

Dear respondent, I request your voluntary cooperation in providing primary data requested to address a M.Sc. thesis research entitled "**Urban street tree planning and management for resilient ecosystem service provision in Addis Ababa, Ethiopia".** Your participation in the study is completely voluntary the study will consider full anonymity and confidentiality of the respondents and the data collected.

Name of the Institution / organization ___________________________________

i. General Background Questions

1. Respondent Code ____________
2. Educational Qualification ________________________________
3. Specific Work unit / Position in the institution _________________________
4. Work Experience
   a) Total work experience ____________
   b) Work experience in current position ____________

ii. Interview Questions on the current street tree development and management practice

5. What factors would you consider the most when determining street tree species? (Select 3 - 5)

A. Availability
B. Cost / Finance
C. Ecosystem service provision
D. Native/Exotic
E. Growth rate
F. Wood strength
G. Pest resistance
H. Water demand
I. Durability and maintenance need

6. Rate your level of agreement on whether these considerations are taken while planting street trees in Addis Ababa or not?

Street tree planting Considerations	Strongly Disagree	Disagree	Don't know	Agree	Strongly Agree
Planting location					
User's dimension and Interest					
Overhead power lines					
Other infrastructure on the ground					
Building setbacks					
Public participation					
Space allocation for movement					
Soil strata					
Other __________________					

7. How well do you think are urban street trees being maintained in Addis Ababa?

Attributes of street tree Management	**None**	**Poor**	**Medium**	**Good**	**Very Good**
Continuous watering					
Mulching for soil fertility					
Pruning broken branches and over grown crown					
Adequate inspection on their health status					
Replacing dead/dry trees					
Proper fencing					
Application of chemical treatment and technology for pest and related risks					
Other ___________________					

8. What do you think are the challenges of street tree development? (Rank them as their prioritization)

Challenges of street tree development	**Rank (1st, 2nd, 3rd, 4th, …)**
Species selection	
Space allocation	
Compacted soil condition	
Size of planting pits	
Finance	
Poor integration among stakeholders/institutions	
Other ___________________	

9. What do you think are challenges of street tree management? (Rank them as their prioritization)

Challenges of street tree management	**Rank (1st, 2nd, 3rd, 4th, …)**
Conflict with infrastructure	
Conflict with Vehicles	
Lack of skilled experts	
User's pressure due to lack of awareness	
Maintenance cost	
Water consumption	
Stolen tree fences	
Other ___________________	

10. Rate your organization's involvement / influence in direct relation with the planning, implementation and management of urban street trees in Addis Ababa?

Category of Involvement	None	Low	Medium	High	Very High
Planning					
Implementation					
Management					

iii. Interview Questions from a Resilience perspective

11. Rate the overall level to which Addis Ababa's street tree development and management practices integrated/considered the indicators of the resilience principle outlined below.

Resilience Principles	Indicators	Level of Integration					Overall value
		None	Low	Medium	High	Very High	
Diversity	Species diversity (Quantity wise)						
	Age diversity						
Redundancy	Repetition and harmonization of street tree plantation on the specified segment						
	Spacing of street tree plantation (Density)						
	Diversity of tree species with similar function (Functional redundancy)						
Connectivity	Urban street trees with each other along street corridors						
	Urban street trees with other GI components of the city						
Participation and Integration	Public involvement in tree plantation programs						
	Public involvement in tree management						

	Integration with infrastructure providing institutions (Shared planning, decision making, shared public disclosure)						
Adaptability	Protective structures against user pressure						
	Less water demanding species selection						
	Pest resistance species selection						
	Fast growth rate species selection						
	Provision of adequate maintenance						
	Wider planting pits that consider street tiles						

Annex III Observation Checklist for Physical Survey

Chair of Environmental Planning and Landscape Design

Name of street corridor

Inventoried________________________

- **Using base map, aerial photo of the area and Site visits**

1. Identifying trees species (scientific and local name) on each street corridor
2. Identification of existing land use and dominating activities along the street
3. Identification of available UGI elements within 1km from both sides of the street
4. Major constraints of current street tree development and Ecosystem dis-services
5. Identification of site conditions (Water supply, ground cover (reasoning matters), soil compactness, tree planting pits, landscaping)

- **Check list from Ecosystem Service Perspective**

Ecosystem Services	Properties to be checked	Observation Remark
Local climate regulation	Tree canopy size	---- Meter on average
	Crown density	Good / Bad
Storm water management	Availability of drainage infrastructure	Yes / No
	Condition of drainage infrastructure	Good / Medium / Bad
	Street permeability	High / Medium / Low
	Level of water / rain in the area	High / Medium / Low
Aesthetic value	Availability of seasonal beauty foliage tree	Yes / No
	Tree crown shape	
	Harmony and plantation alignment	
	Comfort for movement	Good / Medium / Bad
Recreation	Availability of street amenities under tree	Yes / No
	Space for recreation	Yes / No
Biodiversity	Availability of birds and other wildlife	Yes / No

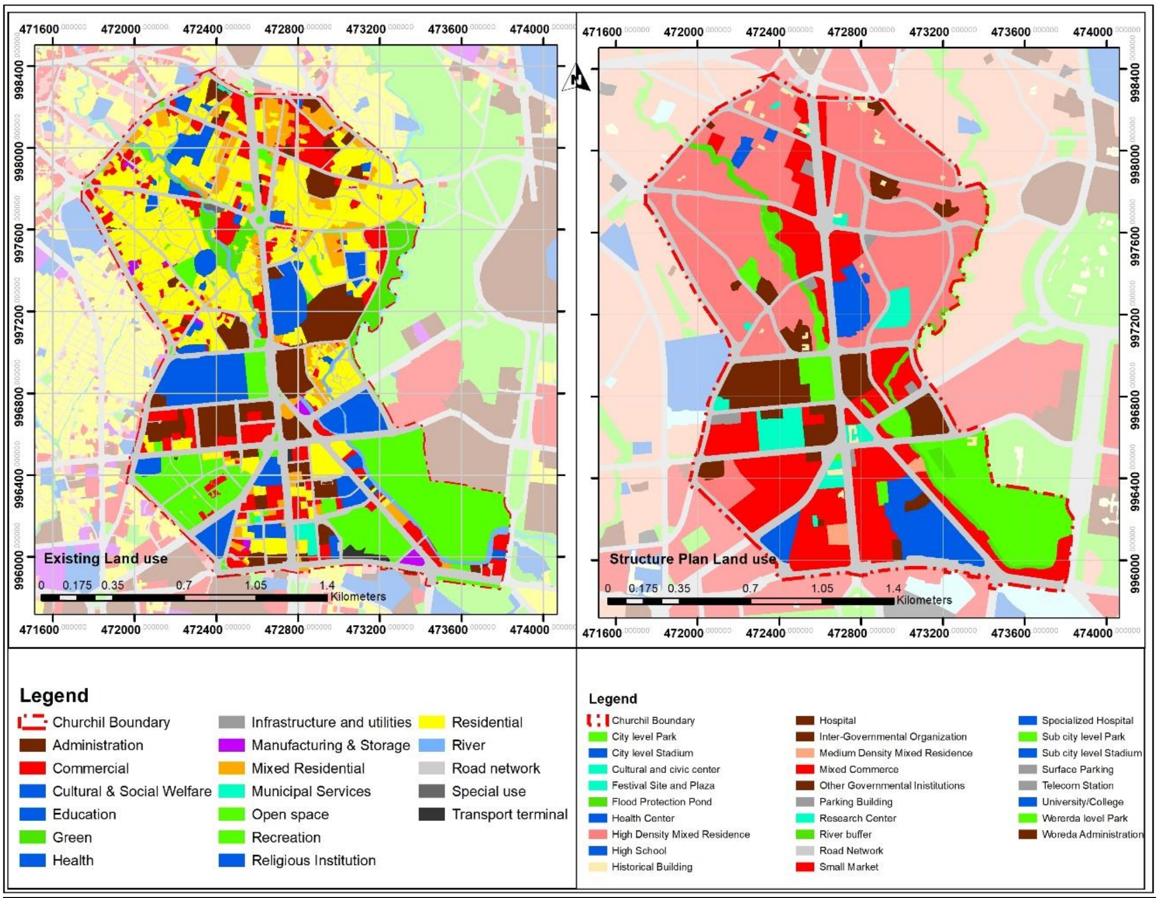
- **Check list from Resilience Perspective**

Resilience principles	Parameters to be checked	Observation Remark
Diversity	Species diversity	In number -----
	Age diversity	In number -----
Redundancy	Repetition and harmonization of street tree plantation on the specified segment	Yes / No
	Spacing of street tree plantation	----- Meter on average
Connectivity	Urban street trees with each other along street corridors	Yes / No
	Urban street trees with other GI components of the city	Yes / No
Adaptation	Fence availability	Yes / No
	Size of planting pits	----- x ------ in cm

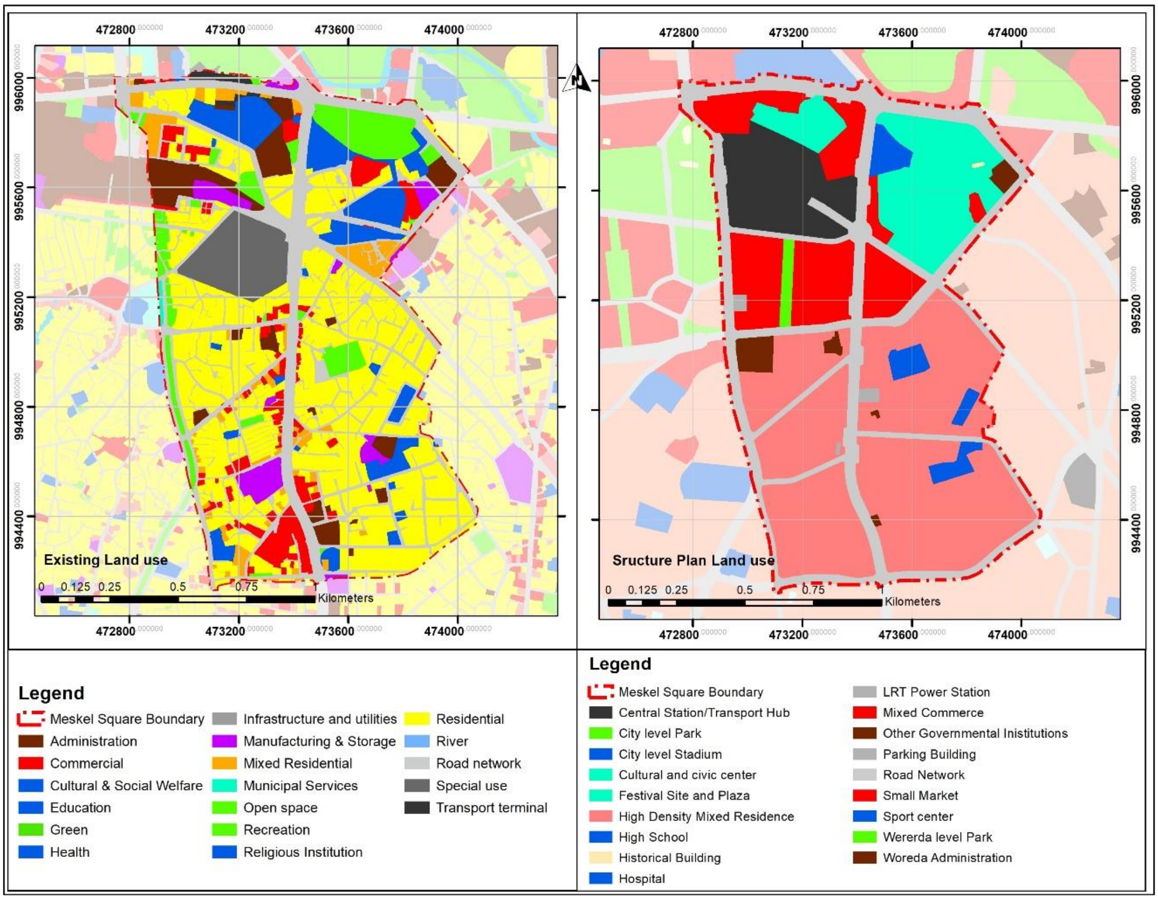
Annex IV Existing and Proposed Land use Maps for selected street corridors

A. **A street corridor from Legahare to Piassa (Churchil Road)**

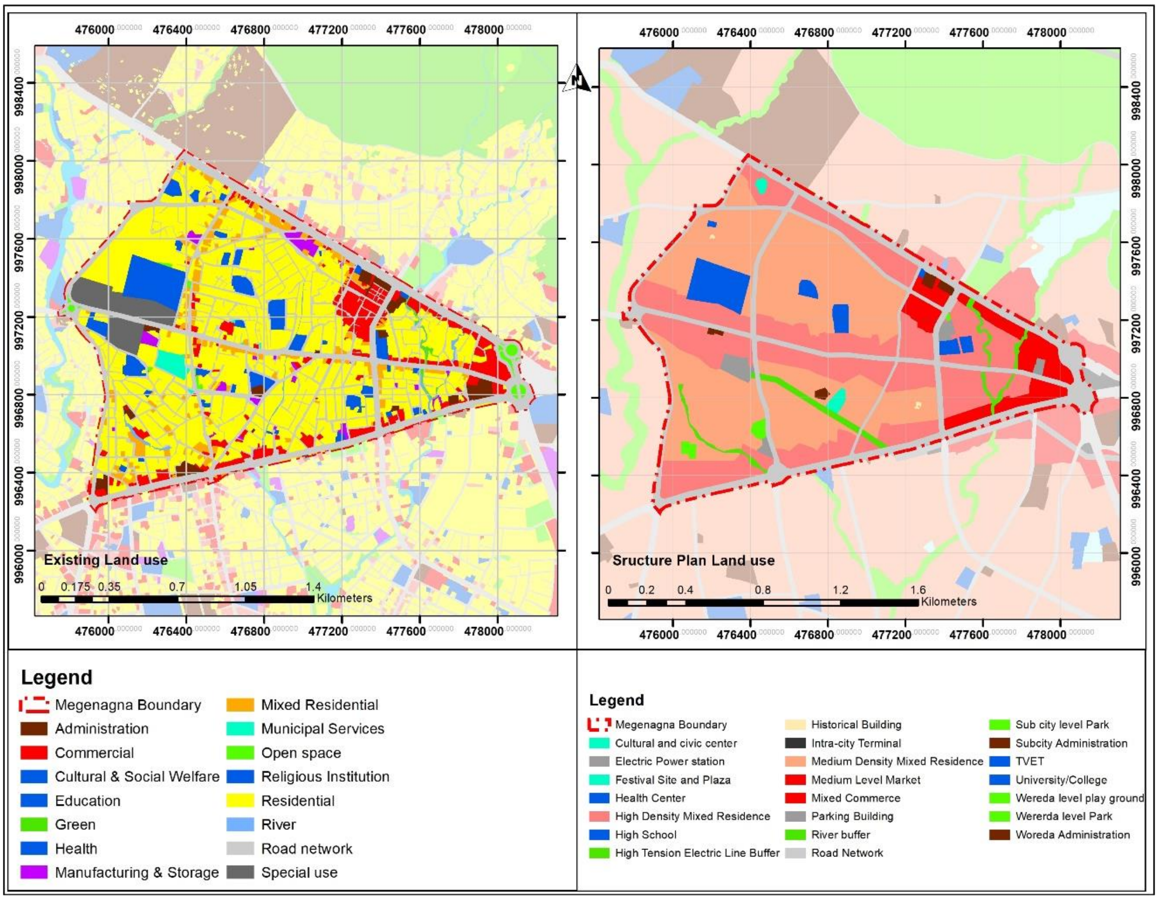
B. **A street corridor from Sengatera/Goma kuteba to filweha**



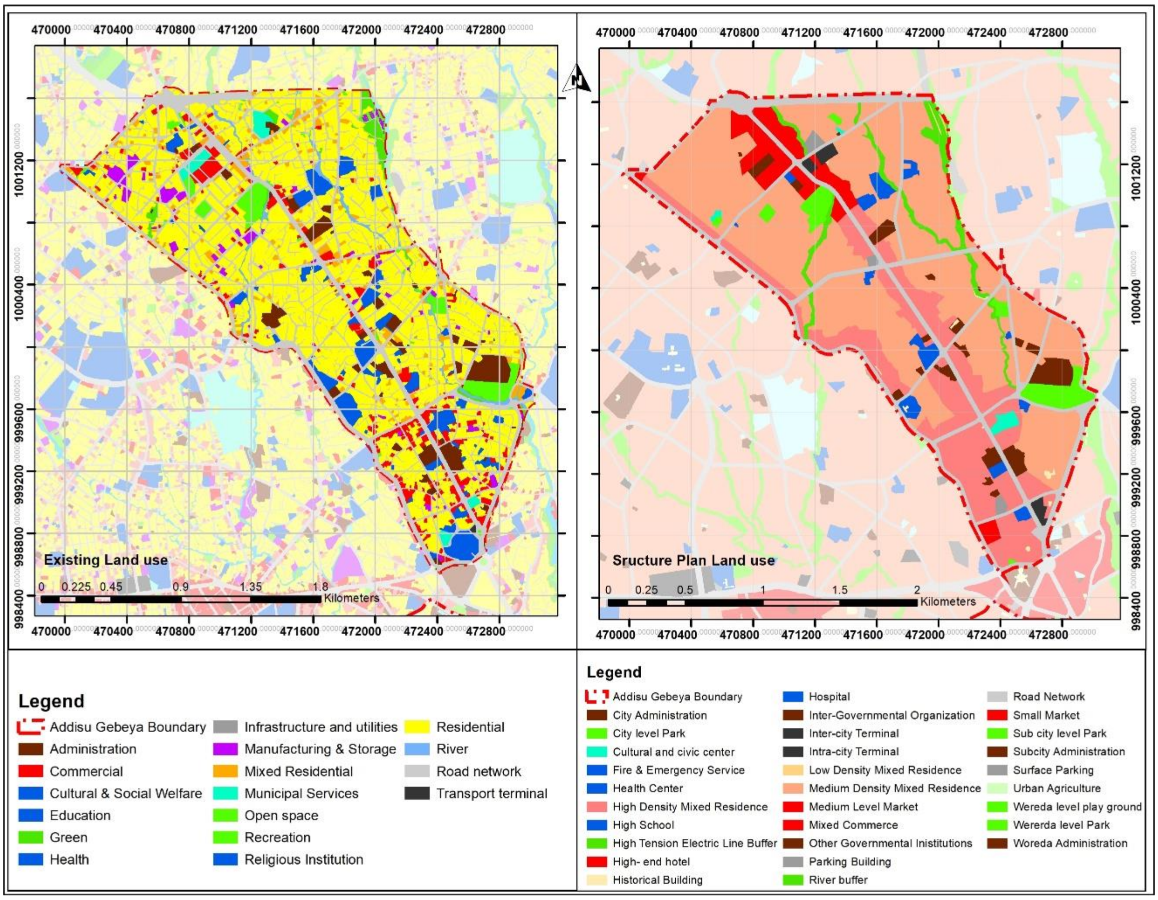
C. A street corridor from Meskel square to Lancha



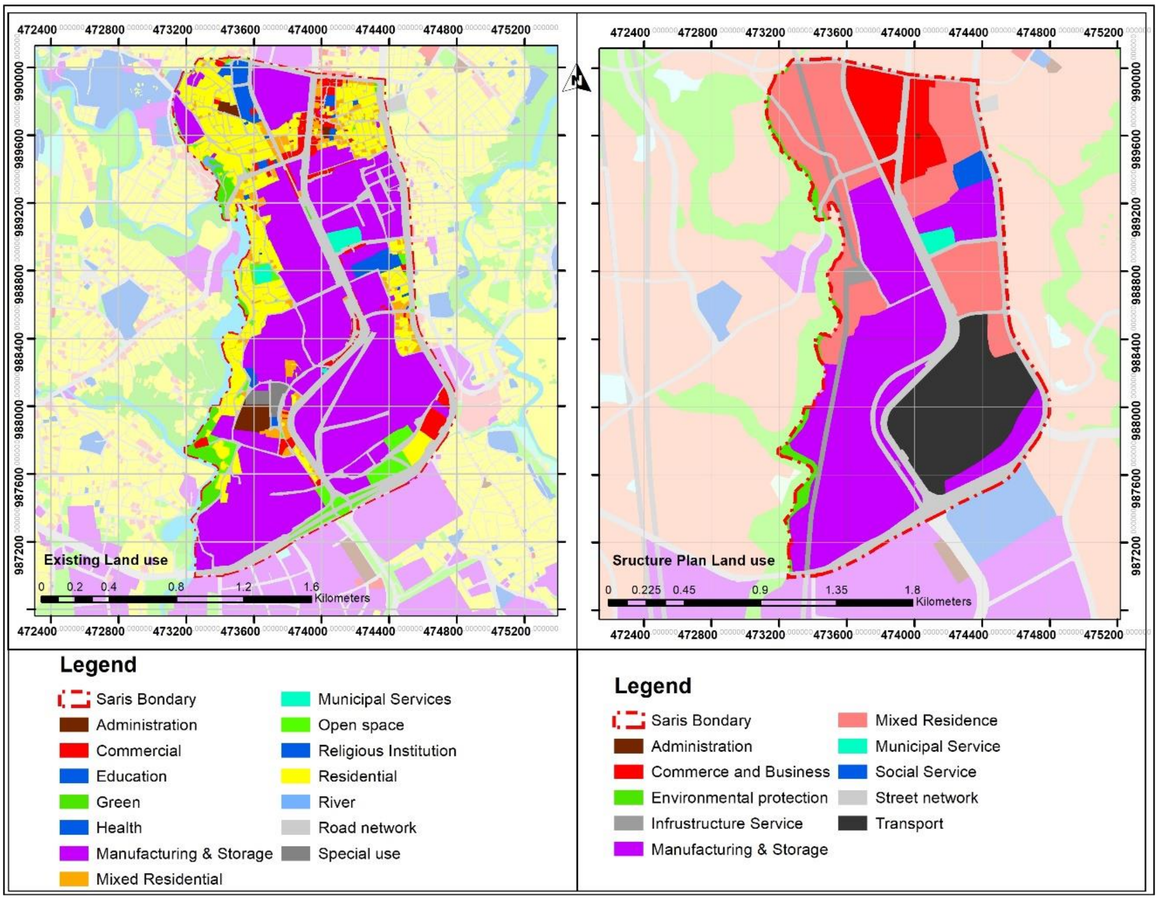
D. A Street corridor from Megenagna to Signal / Waryt square



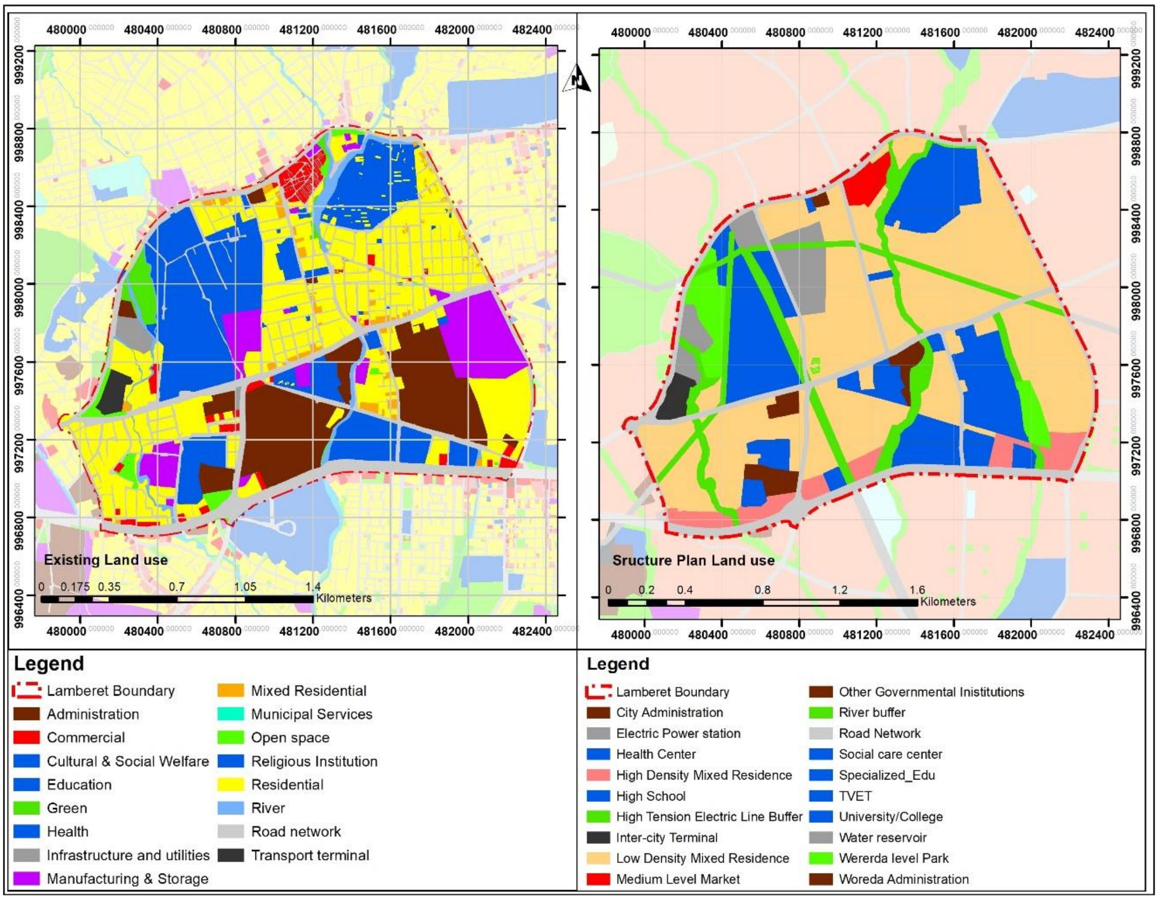
E. A Street corridor from Piassa Giorgis to Addisu gebeya



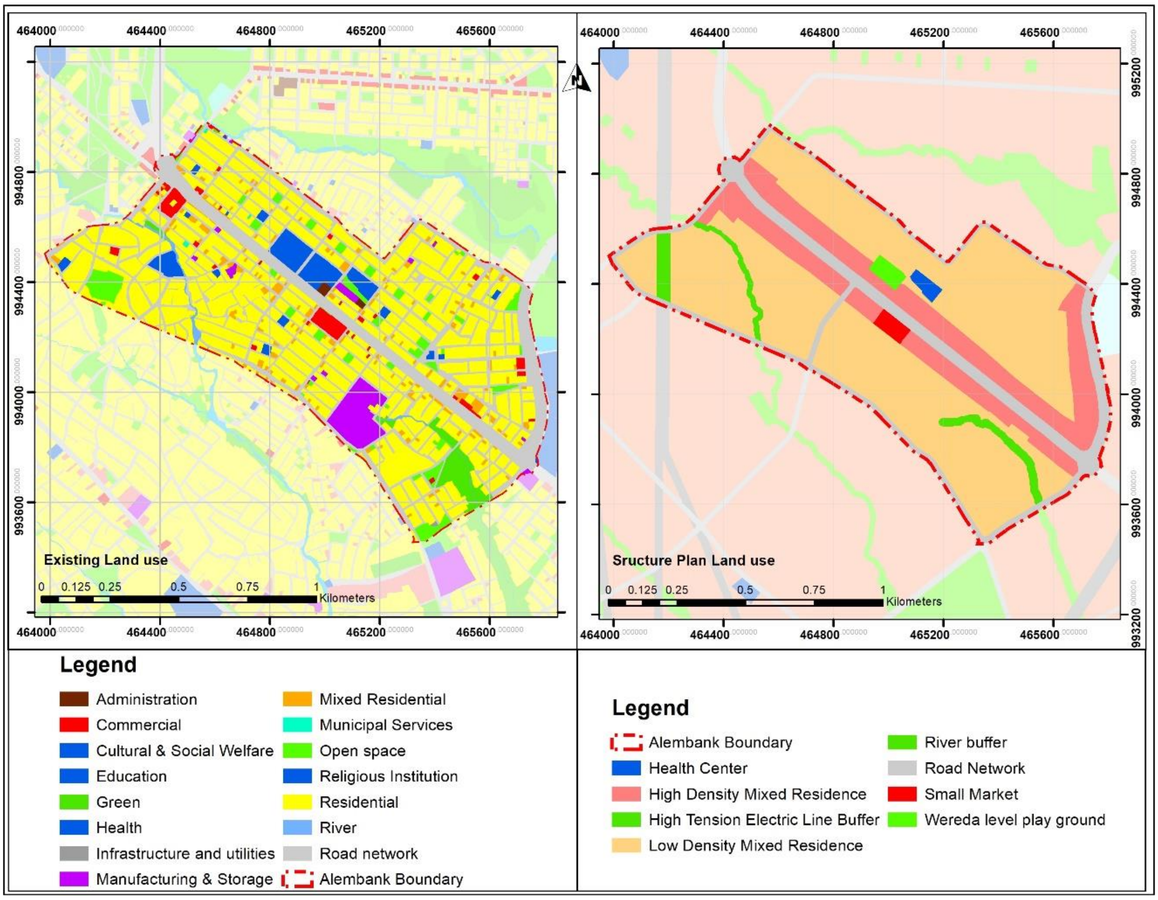
F. A Street corridor from Saris Adeyabeba to Saris Abo station



G. A Street corridor from Lamberet to Wesen



H. A Street corridor from Ayertena Kidanemihret to Alembank



Annex V Ecosystem Service Supply and Demand Assessment per each Street corridors

ES Categories	Regulating Services							Cultural Services							Supporting Services	
ES Services	Thermal comfort	Shade provision	Dust reduction / removal	Carbon sequestration (Car smoke free air)	Noise reduction	Flood/runoff control	Trapping Rainwater	Inspiration / Motivation	Street beautification (green and colorful trees)	Longer pavement life	Physical exercise	Emotional and psychological health	Social setting	Comfort for use	Tree species diversity	Habitat for wildlife
Churchill Road ES SUPPLY Vs. DEMAND																
ES Supply mean	3.73	3.64	3.58	3.51	2.47	2.76	2.53	4.25	4.71	4.05	4.13	4.00	4.18	4.51	3.42	2.75
ES Demand mean	4.60	4.53	4.27	4.31	4.07	3.98	3.84	3.89	4.02	3.95	3.82	4.36	4.24	4.24	4.11	3.71
Supply Vs. Demand	-0.87	-0.89	-0.69	-0.8	-1.6	-1.22	-1.31	0.36	0.69	0.1	0.31	-0.36	-0.06	0.27	-0.69	-0.96
Sengatera to Filweha ES SUPPLY Vs. DEMAND																
ES Supply mean	3.68	3.75	3.28	3.17	2.43	2.62	2.75	3.81	4.09	3.11	2.81	3.36	3.53	3.68	3.19	2.64
ES Demand mean	4.60	4.77	4.28	4.38	4.06	4.25	4.34	4.49	4.83	4.19	3.77	4.28	4.51	4.68	4.34	3.68
Supply Vs. Demand	-0.92	-1.02	-1	-1.21	-1.63	-1.63	-1.59	-0.68	-0.74	-1.08	-0.96	-0.92	-0.98	-1	-1.15	-1.04
Meskel Square to Lancha ES SUPPLY Vs. DEMAND																

ES Supply mean	3.02	3.47	2.54	3.15	2.29	2.12	2.10	2.79	2.17	2.63	2.06	2.33	1.94	3.10	1.46	1.52
ES Demand mean	4.56	4.19	3.71	3.96	3.77	4.31	4.21	4.23	4.87	4.29	3.77	3.94	4.08	4.71	4.35	3.62
Supply Vs. Demand	-1.54	-0.72	-1.17	-0.81	-1.48	-2.19	-2.11	-1.44	-2.70	-1.66	-1.71	-1.61	-2.14	-1.61	-2.89	-2.10
Megenagna to Signal ES SUPPLY Vs. DEMAND																
ES Supply mean	2.40	2.45	2.38	2.23	1.45	1.87	2.36	2.60	1.47	2.45	1.17	1.68	1.62	2.79	1.96	1.57
ES Demand mean	4.32	4.21	4.04	4.32	4.04	4.23	4.13	4.21	4.43	4.19	3.85	4.02	4.09	4.51	4.15	3.81
Supply Vs. Demand	1.92	-1.76	1.66	-2.09	-2.59	-2.36	-1.77	-1.61	-2.96	-1.74	2.68	-2.34	-2.47	-1.72	-2.19	-2.24
Piassa Giorgis to Addisu Gebeya ES SUPPLY Vs. DEMAND																
ES Supply mean	3.59	3.26	2.62	2.81	2.12	2.79	2.14	3.29	3.21	2.62	2.41	2.74	2.47	2.59	2.17	1.86
ES Demand mean	4.74	4.72	4.50	4.74	4.22	4.47	4.52	4.60	4.83	4.33	4.26	4.83	4.66	4.78	4.53	4.24
Supply Vs. Demand	-1.15	-1.46	-1.88	-1.93	-2.10	-1.68	-2.38	-1.31	-1.68	-1.71	-1.85	-1.92	-2.19	-2.19	-2.36	-2.40
Saris to Kality Maseltegna ES SUPPLY Vs. DEMAND																
ES Supply mean	3.32	3.60	3.08	3.13	2.49	2.96	2.77	3.58	3.57	3.28	2.62	3.11	3.19	3.28	2.64	2.43

ES Demand mean	4.06	3.91	3.96	4.04	4.09	4.11	4.23	4.23	4.42	4.25	3.98	4.04	4.28	4.47	4.40	4.08
Supply Vs. Demand	-0.74	-0.31	-0.88	-0.91	-1.60	-1.15	-1.46	-0.65	-0.85	-0.97	-1.36	-0.93	-1.09	-1.19	-1.76	-1.65
Lamberet to Wesen ES SUPPLY Vs. DEMAND																
ES Supply mean	3.32	3.30	2.12	2.86	2.28	2.58	2.52	3.00	2.78	1.76	1.68	2.48	1.90	1.98	1.84	1.94
ES Demand mean	4.54	4.66	4.36	4.26	4.26	4.50	4.56	4.62	4.78	4.70	4.28	4.48	4.66	4.78	4.50	4.08
Supply Vs. Demand	-1.22	-1.36	-2.24	-1.40	-1.98	-1.92	-2.04	-1.62	-2.00	-2.94	-2.60	-2.00	-2.76	-2.80	-2.66	-2.14
Alembank to Ayertena kidanemihret ES SUPPLY Vs. DEMAND																
ES Supply mean	3.20	3.43	2.33	3.12	2.14	3.04	2.86	2.73	2.41	3.37	2.39	2.22	2.22	3.20	1.65	1.55
ES Demand mean	4.37	4.33	4.14	4.02	4.18	4.08	4.27	4.31	4.57	4.04	3.86	4.33	4.49	4.63	4.35	3.49
Supply Vs. Demand	-1.17	-0.90	-1.81	-0.90	-2.04	-1.04	-1.41	-1.58	-2.16	-0.67	-1.47	-2.11	-2.27	-1.43	-2.70	-1.94
Note: Highest negative values indicate highly demanded ecosystem services in relative to existing ecosystem service supply																