

FROM TRANSIT CORRIDOR TO ECOLOGICAL CORRIDOR: DEVELOPING A GREEN URBAN SPINE FRAMEWORK FOR BIODIVERSITY CONSERVATION AND CLIMATE-RESPONSIVE URBANISM IN LAHORE

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ABSTRACT

The alarming rate of urbanization has led to the disappearance of green spaces, fragmentation of the landscape, reduction in biodiversity and poor environmental conditions in Lahore. The Lahore Metro Bus Corridor is one of the important public transportation infrastructures in Lahore and has a potential of acting beyond mobility and can be used as a continuous green urban spine of Lahore. The potential of Lahore Metro Bus Corridor for the integration of green infrastructure to improve biodiversity connectivity, environmental quality and public health has been evaluated in this study, which covers the distance from Shahdara to Gajjumata. The following mixed-method research approach was used: site observations, GIS-based spatial analysis, vegetation assessment, and international best practices. The results indicate that while there is existing vegetation and landscape elements along the corridor, they are limited and fragmented to provide meaningful ecological connectivity. Spatial analysis revealed important green gaps, ecological barriers and opportunities for green enhancements, with a particular focus on the pedestrian areas, station and medians. International precedents like Curitiba's Green BRT Corridors and Seoul's Cheonggyecheon Restoration Project are explored, reflecting the benefits of embedding ecological services into transport infrastructure. A conceptual Green Urban Spine Framework is suggested based on the findings, focusing on the continuous green corridors, the greening of the stations, and connectivity between pedestrians and cyclists. Finally, the study recommends that Lahore Metro Bus Corridor can be developed as a multifunctional ecological corridor, that not only will conserve biodiversity, but also be resilient to climate change, promote sustainable mobility and improve the living standards of the city's inhabitants, and offer a replicable model for future transit-oriented green infrastructure projects across Pakistan.

Keywords: Green Urban Spine, Biodiversity Connectivity, Green Infrastructure, Lahore Metro Bus Corridor.

INTRODUCTION & BACKGROUND

Urbanization is unprecedented in many cities in the developing world, where population

increases have brought about dramatic changes in the cities' physical, social and ecological fabric (Saleemi et al. 2025). The scenario is no different in Pakistan as Lahore is one of the fastest growing metros in South Asia (Shah et al., 2025). In the last decades, population growth, urban development and infrastructure construction have drastically changed the spatial structure of the city. The expansion of these types of growth, which has promoted economic development and increased mobility, has also created a host of environmental problems, such as the loss of urban green spaces, habitat fragmentation, the loss of biodiversity, greater air pollution, and the enhancement of urban heat island effects (Fazal & Bhatti, 2025). Natural ecosystems are becoming a smaller and smaller part of the urban landscape as it continues to grow, decreasing ecological resilience and the scope for sustainable urban development (Hussain and Nadeem 2021). In this context, transportation infrastructure has a very special role in influencing urban space. Inland transportation corridors (roads, highways, railways and mass transport) take up significant linear space within cities and often act as physical barriers to ecological connectivity and the loss of ecological linkages (Adeel et al. 2021). But in recent years, theories in urban planning and landscape architecture are becoming increasingly aware that the transportation corridor also has other functions than mobility. These corridors are not just engineering infrastructure but rather reimagined as multifunctional urban systems to serve environmental, social and ecological functions (Nieberler-Walker et al. 2023). In the case of the High Line in New York, Seoulo 7017 in Seoul, and several green transportation corridors in Europe, transport infrastructure is being reimagined as an ecological asset that can boost biodiversity, quality of the environment and urban sustainability (Rathore and Ali 2015). The Lahore Metro Bus Corridor is one of the biggest transportation projects in Pakistan that has been undertaken in recent history.

The corridor runs from Shahdara in the north to Gajjumata in the south and passes through many urban settings serving thousands of commuters each day. The project has achieved good results in terms of public transportation accessibility and mobility, but the possibility of improving ecological sustainability in urban areas has not yet been fully explored. The corridor forms part of a linear space in the city, and has unique spatial features that might facilitate the creation of an integrated green infrastructure network. It might serve as a 'green urban spine' that helps to connect the broken-up green network, to provide ecological connectivity and to enhance the environment along its path (Tabassum 2025). This green infrastructure has become a key element of sustainable urban development and climate-adaptive city development. Green infrastructure is contrasted from traditional grey infrastructure, by integrating natural and semi-natural systems into urban areas to provide several ecosystem services. These range from stormwater management, carbon sequestration, biodiversity, temperature control, air quality and public health benefits. The use of green infrastructure in transport corridors can offer opportunities to establish continuous ecological networks, that enable species to move, improve habitat quality and strengthen urban resilience to climate change effects.

The need for such interventions in Lahore is growing more and more urgent. The city is grappling with many environmental issues such as poor air quality, higher temperatures, less vegetation cover and pressure on urban ecosystems (Rana and Bhatti 2018). The development of green infrastructure on the Metro Bus Corridor can play a significant role in resolving these problems, by providing a continuous ecological corridor that will increase biodiversity, improve the microclimate of the area and provide environmental benefits for the surrounding communities and for commuters. In addition, these interventions are in line with current planning concepts

that focus on sustainable mobility, nature-based solutions, and adaptation strategies to climate change (Jiang 2014).

The idea of eco-connections along transportation corridors is a creative way to achieve urban sustainability. This is done not as two separate fields, but to connect the mobility infrastructure to the ecological systems to create multi-functional urban landscapes. With thoughtful planning, landscaping elements, incorporation of native vegetation, and design features that promote biodiversity, the Lahore Metro Bus Corridor could become a green urban spine that not only serves as a vital transportation network but also aids in ecological restoration. Thus, it is a timely and necessary to explore the potential of the corridor for ecological enhancement, especially in the broader context of sustainable urban development and climate resilience for Lahore.

PROBLEM STATEMENT

Though the Lahore Metro Bus Corridor has greatly enhanced the movement of people in Lahore, its core orientation remains towards efficient conveyance and lesser attention has been paid to ecological functions and environmental sustainability. The current green spaces along the corridor are fragmented, isolated and not well connected to form a connected network that facilitates the movements of biodiversity and the resilience of ecosystems. Concrete surfaces, transportation systems, and urban development are dominant features that create physical and ecological barriers that limit the movement of birds, pollinators and other urban wildlife species and reduce habitat availability. Also, the absence of green infrastructure at the site contributes to environmental challenges of increased temperatures, air quality, and reduced environmental quality along the corridor. Poor vegetation cover and shading is a negative impact on thermal comfort of commuters mainly during the extreme summer season of Lahore and limits the corridor to offer valuable ecosystem services.

The constantly growing demand for more and more sustainable urban development in Lahore, due to rapid urbanization and climate change, calls for rethinking the Metro Bus Corridor as a green multi-functional urban spine. The inclusion of continuous green infrastructure and ecological connectivity along the corridor has the potential to promote biodiversity conservation, environmental quality, climate resilience, create healthier - more comfortable public spaces and support sustainable urban development.

RESEARCH OBJECTIVES

The objective of this study is to assess the feasibility of Lahore Metro Bus Corridor in becoming a green urban spine for ecological sustainability, biodiversity conservation, and enhancing the urban livability in Lahore. The study reviews the current environmental and spatial situation of the corridor to look for potential of incorporating green infrastructure to enhance ecological connectivity in the urban fabric of Lahore. One important goal is to investigate planning and design approaches that can help improve ecological connectivity, promote movement of species and minimise ecological fragmentation along the transit corridor to enhance biodiversity. The study aims at identifying context-specific recommendations for biodiversity-friendly transport infrastructure based on international best practices and local urban conditions. Additionally, the study explores how green infrastructure can contribute to overall environmental quality and public health, including better air quality, decreased urban heat island, increased greenness, and more aesthetically pleasing and thermally comfortable public spaces. Special focus is given to the knowledge of how strategically integrated green corridors can facilitate the commuter's experience and contribute to the overall sustainability objectives. In conclusion, the research seeks to develop a roadmap for the Lahore Metro Bus Corridor to become a multi-functional green

infrastructure network that will simultaneously support ecological resilience, environmental performance, sustainable mobility and healthier urban environments.

RESEARCH SIGNIFICANCE

This study is significant in environmental, social, planning and policy aspects. The study adds to the body of evidence on urban biodiversity conservation and ecological connectivity in increasingly urbanized cities from an environmental point of view. The study identifies innovative opportunities for restoring ecological functions in existing transportation infrastructure by examining the potential of the Lahore Metro Bus Corridor as a green urban spine. The results could inform city-wide strategies to mitigate the effects of the urban heat island, air pollution problems, ecosystem benefits and climate resilience in Lahore.

Socially, the use of green infrastructure can enhance the commuter experience by making transit systems more comfortable, beautiful and healthy. Greater vegetation and better environmental quality can have beneficial effects on the physical and mental health of urban people, and therefore improve their quality of life. The study also reinforces the notion of equitable access to green infrastructure, using existing public transportation corridors as accessible green infrastructure assets.

The research is relevant in terms of urban planning and policy, as it contributes to understanding how transportation infrastructure can be linked to environmental planning objectives. The proposed strategies are consistent with sustainable urban development principles, and are consistent with the global agenda on NBS and climate responsive cities. Moreover, the Study can be a template for future interventions in other transportation corridors of Lahore and other mega cities in Pakistan and the Global South. Finally, the study aims to prove that transportation infrastructure can contribute significantly to the ecological sustainability and urban resilience. The study presents a

vision of the Lahore Metro Bus Corridor as a 'green urban spine' and addresses the ongoing debates on multifunctional infrastructure, environmental flows and sustainable mobility in cities.

LIMITATIONS OF RESEARCH

Lahore Metro Bus Corridor is part of this study, which has the potential to become a green urban spine contributing to biodiversity connectivity, environmental quality and public well-being with its key points from Shahdara to Gajjumata. The research examines conceptual planning and design approaches to incorporate the green infrastructure in the transit corridor to enhance ecological connectivity and support urban sustainability. This study, however, does not involve detailed engineering design, structural analysis or cost estimation, but rather strategic and conceptual suggestions. The investigation does not cover long-term ecological monitoring or quantitative evaluation of environmental performance, although these are integral aspects of biodiversity enhancement and ecological connectivity. Likewise the long-term consequences of the interventions foreseen are not assessed, since a long-term monitoring after the interventions is necessary for this purpose. In spite of these constraints, the research provides a useful framework for future research and practice to build multifunctional ecological corridors and to move towards sustainable urban development and climate resilience.

LITERATURE REVIEW

Concept of Green Urban Spine

The green urban spine has become an important planning and design concept in the modern sustainable urban development discussion. The green urban spine is a linear green corridor, traversing urban environments, that acts as an ecological, social and spatial connector (Ahmed et al., 2024). Green urban spines create continuous green corridors that connect parks, open spaces, ecological habitats, public spaces and recreation areas throughout the urban area

(Nadeem et al. 2021). Such corridors can help maintain ecological connectivity, allowing species to migrate from one habitat to another even when the area is heavily built up, helping to conserve biodiversity and ecosystem resilience (Hussain and Nadeem 2021).

In addition to their environmental benefits, green urban spines also have aesthetic, environmental and health impacts. Vegetation, landscape features, and public spaces are introduced into these corridors, improving visual quality, mitigating environmental damage, and providing recreational and social opportunities (Muhammad et al. 2025). The aim is to enhance accessibility and multi-functionality in many modern cities by incorporating green urban spines into the urban transport network, water systems, pedestrian townscape and bikeway systems (Khan et al., 2023). This integration demonstrates the evolving understanding that urban infrastructure needs to have many functions, including mobility, environmental and social functions and utility, all within one framework. Green urban spines are seen as pivotal elements in resilient and sustainable urban systems as cities globally face challenges due to urbanization, climate change and environmental degradation.

The urban greenery and ecological corridors.

Green infrastructure is a key element of sustainable urban development because it provides many environmental, social, and economic benefits. Green infrastructure is an interconnected system of natural or semi-natural features, such as parks, urban forests, greenscapes, street trees, green roofs, wetlands and vegetated corridors, that deliver ecosystem services in urban areas through strategic planning (Rafique et al. 2022). Green infrastructure is a natural approach to addressing urban issues and increasing ecological resilience, in contrast to grey infrastructure which is more about engineering solutions.

Ecological corridors are a key aspect of green infrastructure. Ecological corridors -

continuous or connected landscape features that connect or link fragmented habitats to increase species population gene-flow and reduce habitat isolation (Nadeem, Matsuyuki, and Tanaka 2023). Habitat fragmentation is common in fast-growing cities, caused by urban expansion, land use and infrastructure development. Restoring landscape connectivity through ecological corridors is one way to reduce these impacts and facilitate movement of species through urban areas (Nadeem and Matsuyuki 2025).

Studies have shown that ongoing green network can play an important role in biodiversity protection, and also enhance the environmental quality of the city (Staniewska 2022). These networks improve air quality by absorbing pollutants, help control urban microclimates by lowering ambient temperatures, enable stormwater management by way of natural infiltration process, and help boost ecosystem functioning. The incorporation of green infrastructure and ecological corridors thus is becoming seen as an integral part of the process of sustainable and climate-resilient urban development (Lestari and Favurita 2024).

Conveyance infrastructure and biodiversity connectivity

Transportation infrastructure is a key enabler of urban development, mobility, economic growth and regional connectivity. Transportation networks, however, can have substantial ecological impacts as well, especially on habitat fragmentation and biodiversity loss (Lacanna and Wagenaar 2018). Roads, highways, railways and transit systems are common physical and ecological barriers that fragment natural habitats and limit wildlife movement. These barriers could lead to the fragmentation of species populations, loss of habitat and adversely impact ecological processes that preserve biodiversity (Paraskevopoulou et al., 2020).

In the modern planning and environmental study, the transportation infrastructure has become an increasing concern due to its

impacts to the environment (Shah et al., 2023). Research has shown that traditional forms of transportation can impede ecological connectivity, change species' lives and lead to wildlife deaths. Planners and designers have thus started to consider ways of incorporating biodiversity into transport infrastructure projects (Shah et al., 2023a).

Landscaped medians, vegetated buffers, bioswales (Iqbal et al., 2025), green walls and vertical greenery systems are all green infrastructure interventions that are effective for minimizing ecological impacts of transportation corridors. They can benefit habitat quality and enhance ecological connectivity, and offer stepping stone habitats for birds, pollinators and other urban wildlife. But more important, recent research indicates that ecological connectors can be created within transit corridors by applying principles of biodiversity sensitive planning. The transportation infrastructure can be designed to become more than barriers, and instead serve as ecological assets, by integrating continuous vegetation networks and habitat supporting elements.

Well-Being, Access to Green Spaces (PWA)

The effects of green spaces on human well-being are well documented in the literature of environmental psychology, public health and urban planning (Mujtaba et al. 2025). It has been found that access to green space is linked to a range of physical, psychological and social health benefits which have a positive impact on the quality of life and the urban environment (Zahid et al., 2025). Green spaces help to create better and more sustainable communities by offering opportunities for recreation, relaxation, physical activity and social interaction in increasingly dense urban areas.

In terms of psychology, spending time in nature has been found to lower stress levels, decrease anxiety, alleviate mental fatigue, boost cognitive function and improve emotional health. Natural environments can be beneficial to psychological restoration and mental health, as per theories like Attention

Restoration Theory and Stress Reduction Theory (Shah et al., 2025). Likewise, urban greenery can help to foster social cohesion by providing opportunities for people to connect with one another, participate in activities, and feel a sense of belonging.

Green infrastructure can have a substantial positive impact in transportation settings. Provide vegetated corridors, shaded walkways along transit facilities and landscaped transit stations to improve thermal comfort through heat exposure reduction and protection from harsh climatic conditions (Shakeel et al., 2025). Further, greenery helps to reduce noise, improve air quality and enhance the visual appeal, making transit environments more pleasant and comfortable. Thus, well-designed green spaces and green transit corridors are increasingly perceived as key elements of inclusive, healthy and resilient cities.

International Case Studies

Curitiba BRT Green Corridors

Pioneered by the city of Curitiba in Brazil, the idea of linking transportation planning with environmental sustainability is a global phenomenon. Curitiba's Bus Rapid Transit (BRT) is often lauded as one of the most successful sustainable urban mobility schemes in existence. One of the reasons for its success is the incorporation of green spaces, linear parks, and landscaped pathways with transportation networks. In contrast, Curitiba addressed issues of transportation and environmental planning as a whole, taking into account mobility, ecological preservation and urban development goals.

The use of linear green corridors in the BRT system has helped to improve the environmental quality, beautify the city and boost public acceptance of public transit. These green corridors also help to manage stormwater, protect biodiversity and adapt to climate change. The experience of Curitiba provides a good example of how transport can be a catalyst for enhancing the environment and social conditions in a city, an example to consider when planning sustainable

transportation-oriented development.

Seoul Cheonggyecheon Restoration

River restoration and infrastructure transformation is one of the most significant examples in urban ecology, which is the Cheonggyecheon Restoration Project in Seoul, South Korea. The project also included the demolition of a highway that crossed over the city and the restoration of an old urban stream, forming a lively green axis in the heart of the city. The transformation had a significant positive impact on the environment, the restoration of ecological functions and the public access to open spaces.

The project has resulted in significant gains in biodiversity, urban climate regulation and the use of public space after the restoration. The corridor is now home to a variety of plant and animal species and serves a variety of recreational and cultural uses to residents and visitors. The restored stream also provides ecological benefits, such as cooling and enhancing air quality in the urban environment, showcasing the ecological value of rethinking traditional infrastructure. The Cheonggyecheon project is a prime example of how infrastructure redevelopment can bring substantial environmental and social benefits, and can improve urban sustainability and resilience.

Local context: Urban Green Spaces and Transit systems in the City of Lahore.

With the surge in urbanization, population growth and infrastructure development, Lahore, being one of the major metropolitan areas in Pakistan, is facing a growing number of environmental problems. The city is famous for its gardens and green landscapes, but in recent years the availability of green spaces has significantly decreased because of uncontrolled urban growth and land-use change. Areas of green space tend to be unevenly distributed in the city, with uneven access to environmental amenities and ecological resources.

Further ecological fragmentation and environmental pressures have been caused by

expanding transportation infrastructure. Although projects like the Lahore metro bus corridor have enhanced urban mobility, they have been geared towards the efficiency of transport with a limited consideration of environmental and ecological issues. The corridor is currently not continuous in green connectivity, and there are few opportunities to support biodiversity or improve the ecological resilience.

However, the straightness of the Metro Bus Corridor is a special opportunity to integrate green infrastructure. The corridor can be designed to include strategic placement of vegetation, ecological corridors, and design interventions that support biodiversity, creating a green corridor that links disconnected green spaces and enhances the environment and commuter experience. This is in line with the international trends of sustainable transportation planning and climate smart city building.

Research Gap

Although there has been a rising global interest in the inclusion of green infrastructure in transportation, little research has been done in this context in Lahore or other cities in south Asia. Previous research in the field of urban green infrastructure in Pakistan has largely been conducted on park and urban forest systems and on single green spaces, while relatively little research has been done on the ecological value of transit corridors. As a result, there are limited understandings about the role of the transportation infrastructure in promoting biodiversity conservation and ecological connectivity in a highly urbanized context.

In addition, there is limited local research on biodiversity connectivity as it relates to transportation corridors, specifically as a transportation corridor. Though there is increasing evidence that the presence of urban greenery is associated with better physical and mental health, the connection between green transit infrastructure and public health has not been the focus of much research. The gap indicates the need for localized research

indicative of the potential for green urban spines to complement already established transportation infrastructure systems and address planning, social and environmental concerns specific to Lahore.

Therefore, the present study aims to fill these gaps of knowledge and investigate the potential of the Lahore Metro Bus Corridor as a green urban spine for providing biodiversity connectivity, environmental quality enhancement and thereby public health improvement. The research for sustainable urban development in Lahore will contribute to the academic knowledge and practical policy recommendations with the development of contextually relevant planning and design strategies.

RESEARCH METHODOLOGY

Design research and methods.

This study uses a mixed-method research approach for a holistic study of the potential of the Lahore Metro Bus Corridor (LMB) to improve biodiversity connectivity, environmental quality and the well-being of citizens. The mixed-methods framework is chosen because the research problem is complex and multidisciplinary, including spatial, ecological, environmental and social aspects. The study will use a qualitative and quantitative research methods approach to develop a comprehensive understanding of the current state and future potential for the integration of green infrastructure in transit corridors.

The qualitative part of the research is related to understanding of spatial characteristics, design challenges, spatial qualities and experiences with the corridor. This enables a detailed examination of the interactions between the urban infrastructure, landscape and the people that inhabit the area of study. Qualitative observations also help to determine contextual issues associated with ecological fragmentation, visual quality, accessibility and environmental comfort.

The quantitative data helps complement the qualitative data and provide data on spatial patterns, land use distribution, vegetation

cover, and potential connectivity. Quantitative analysis involves mapping, measuring and spatial assessments to objectively evaluate ecological conditions and environmental performance. Combining both methods increases the confidence and validity of the research results, by enabling data triangulation and a holistic analysis of ecological and social aspects. Thus, a combined approach of both methods is deemed most suitable for the research goals and as a basis for proposing context specific recommendations for sustainable development of transit corridors.

Study Area Description

The study is limited to Lahore Metro Bus Corridor (Lahore-MBC) which runs from Shahdara (North) to Gajjumata (South) of Lahore. The Metro Bus Corridor is one of the most important public transit system in Pakistan which is a key urban mobility route linked to different residential, commercial, institutional and mixed-use neighbourhoods. The corridor passes through some of the densest areas of Lahore and serves as an important transit route for thousands of people who commute to and from the city every day.

This corridor was chosen for the study because of a number of significant factors. It is in its extensive linear nature that it offers a unique opportunity to explore the potential of transportation infrastructure as a continuous ecological and environmental corridor, while also serving as a cultural and social connector. In its extensive linear configuration, it offers a unique opportunity to explore the potential of transportation infrastructure as a continuous ecological and environmental corridor; as a cultural and social connector. Second, its intermediate place in the metropolitan area makes it subject to a host of urban factors - different land uses, densities, contexts etc. Thirdly, the corridor shows poor integration of the green infrastructure despite the high spatial demand, which would be an opportunity for ecological improvements and environmental

improvements.

In addition, the study area is an appropriate case with which to research the topic of biodiversity connectivity, ecological fragmentation, and public health in an urbanizing metropolis. The corridor's uninterrupted continuity and strategic urban location make it an ideal place to look at the potential of reimagining transportation infrastructure as a green, multifunctional urban infrastructure spine for mobility, environmental and social benefits.

Data Collection Methods

The study uses several data collection methods to capture the environmental, spatial and social features of the corridor in an all-encompassing way. This can involve site observations, Geographic Information System (GIS) mapping and spatial analysis, and surveys and interviews if applicable.

Site Observations

One of the key data collection methods is site observations, which are intended to capture the current physical circumstances of the Metro Bus Corridor. Field visits are carried out to evaluate spatial configuration, environmental aspects and total environmental quality of the corridor environment. Specific focus is placed on identifying current vegetational patches, landscape, open space, ecological assets, and physical impediments that could potentially affect the movement of biodiversity, environmental performance. Data gathered from observation also help to assess pedestrian conditions, shading availability, visual quality and opportunities for green infrastructure interventions. Data collected from the site observations will be useful for understanding the current condition of the corridor and where ecological and environmental improvements are needed.

GIS Mapping and Spatial Analysis

Geographic Information System (GIS) tools are used to assist with spatial analysis and mapping of the study area. GIS based methods enable a systematic analysis of land-use patterns, distribution of green space,

vegetation cover, transportation network and ecological connectivity. Spatial data is collected and analysed to detect current green space and how connected it is in the corridor. Further, GIS mapping can be used to identify gaps in the ecosystem, broken up habitats and linkage opportunities that could facilitate the movement of biodiversity. GIS can improve the accuracy and reliability of spatial assessments through visualizations and quantitative measurements of environmental conditions. These analyses are useful for understanding the potential for strategic planning of green infrastructure interventions within the corridor to enhance ecological continuity and environmental performance.

Surveys and Interviews

When applicable, surveys and interviews are used to collect data on the public perception of environmental quality, green infrastructure and commuter experiences along the Metro Bus Corridor. These approaches offer useful information regarding user preferences, perceptions of comfort, satisfaction levels and the attitudes towards the integration of green space. Survey items aim to capture information about thermal comfort, visual quality, accessibility and overall experience of the environment in the corridor. Interviews also could be held with relevant stakeholders to better understand environmental concerns and opportunities for corridor enhancement, such as landscape professionals, planners, local residents, and commuters. The integration of stakeholders' voices ensures that planning and design recommendations proposed are informed by user needs and local contextual realities.

Data Analysis Techniques

Collected data are analyzed through a combination of spatial, environmental and social assessment techniques, which will meet the research goals effectively.

Spatial Analysis

Spatial analysis is done to assess the continuity, fragmentation and connectivity of green spaces along the Metro Bus Corridor. The distribution of vegetation has been

analysed using a GIS-based approach, ecological barriers have been identified and opportunities for establishing continuous green networks have been assessed. There is a focus on recognising how current spatial conditions affect biodiversity movement and ecological connectivity. The results of the spatial analysis are used to identify priority areas for green infrastructure interventions and to develop strategies to enhance ecological connections across the corridor.

Environmental and Social Indicators

The corridor's performance to ecological quality and user experience is assessed using environmental and social indicators. Environmental indicators include such things as vegetation cover, shading availability, landscape quality, and opportunities for improved biodiversity. These indicators help to determine the ability of the corridor to offer ecosystem services like regulating the temperature and supporting habitat, as well as improving the environment. Social indicators concentrate on measuring commuter comfort, visual quality, accessibility, and overall user satisfaction. The evaluation of these indicators will help to tell the story of what green infrastructure integration can do to advance the public good and enhance urban livability. The study uses both environmental and social analysis to create a holistic picture of the corridor's condition and its potential to become a green urban spine.

Ethical Considerations

Ethical issues are of paramount importance in the integrity, transparency and credibility of the research process. The study follows the accepted ethical standards for human participants in academic research and the assessment of the environment. The participation in surveys and interviews is voluntary, and all the participants are told the aims, nature and processes of the studies before the data is gathered. Permission to participate is sought from all participants and they are informed about the research process so that they can participate in the research with an understanding of the process.

Confidentiality and privacy is preserved during the study. All personal information, responses and opinions gathered from the participants are treated with confidentiality and kept only for academic and research purposes. Research data is kept safely and only shared with the authorized researchers. In addition, the study guarantees that the participants will not suffer harm physically, psychologically or socially in the process of the study. Beyond the ethical aspects of the study, which are human-centred, environmental responsibilities are also taken into account. Research activities are carried out in a way that doesn't disrupt the wildlife, vegetation and ecological systems in the study area. Field investigations and observational activities are conducted with care for environmental sustainability and ecological conservation principles. The study aims to uphold academic rigor through adherence to these ethical standards and also encourage responsible and ethical research practices.

RESULTS AND DISCUSSION

Current situation of Lahore Metro Bus Corridor

Land Use Patterns

It is important to comprehend the current urban landscape around the Lahore Metro Bus Corridor to assess its potential as a green urban spine. The corridor cuts across a variety of land use types from Shahdara in the north to Gajjumata in the south passing through some of the densest residential, commercial, institutional and hybrid areas in Lahore. The spatial arrangement of these land uses has a critical impact on the environmental quality, accessibility and ecological elements of the corridor.

The study of the land use shows that there is significant variation in the urban density of the route. The high-density urban development, dense commercial activities and scarcity of open spaces are features of areas like Shahdara, MAO College, Azadi Chowk, Mozang, Kalma Chowk and Model Town. Peripheral areas like Township and Gajjumata have comparatively low urban

density, hence offer more chances for landscape improvement and ecological interventions. Land use data and the amount of green space available shows that highly urbanized areas tend to have smaller and fewer areas of continuous green space, which leads to less ecological continuity and environmental quality.

The prevalence of built-up ground, roadways and impervious materials is a major factor in degrading environmental conditions along the corridor. Large concrete areas enhance heat absorption, contribute to the urban heat island effect, reduce rainwater percolation and opportunities for biodiversity to occupy the area. Therefore, existing urban fabric poses challenges and opportunities to incorporate GI within the Metro Bus Corridor. This spatial pattern understanding helps define suitable spatial areas for ecological enhancement and environmental improvement.

Review and evaluation of vegetation and biodiversity.

The evaluation of the vegetation and biodiversity along the Metro Bus Corridor shows that the current green features are mainly scattered and there is significant variation in terms of quantity, quality and continuity. The predominant vegetation is roadside plantations, landscaped medians, ornamental shrubs and single trees within a few metres of stations and chosen corridor sections. These components have positive impacts on visual quality and the corridor's environmental aesthetics, but are typically not sufficient to create meaningful ecological connectivity along the corridor.

Based on field observations both native and exotic plant species are recognized. There is a greater ecological value to native vegetation because it can help to support local biodiversity, offer habitat resources, and adjust well to local climatic conditions. Many parts of the corridor, however, are dependent on a large number of ornamental and exotics that have minimal ecological value. The continuity of vegetation is not consistent,

leaving there many gaps that hinder the corridor to play the role of an ecological network.

Common bird species, pollinators and insects are observed in areas with vegetation in the corridor. The results indicate that small green infrastructure projects can offer important habitat opportunities in the urban landscape. Biodiversity activity generally falls off sharply in areas that are heavily influenced by the presence of extensive hardscape and infrastructure. In addition, changes in vegetation health, maintenance and species variety influence the ecological success of various segments of corridors. In general, the assessment outlines the need for a more integrated and continuous approach to the green infrastructure which will cater for the movement of biodiversity and ecological resilience.

Green Gaps and Ecological Barriers.

An essential part of analysis is to identify the green gaps and ecological barriers that are currently blocking the environmental connectivity along the Metro Bus Corridor. The spatial structure and field observations indicate many gaps in the current patchwork of vegetation that would not allow the creation of an ecological corridor. These gaps exist especially in very urbanized areas where the provision of the green spaces has been severely contracted as a consequence of infrastructure development.

There are multiple physical barriers that cause ecological fragmentation. Development such as major roads, flyovers, intersections, concrete medians and extensive paved surfaces impede the continuity of habitat and movement for birds, pollinators and other small species of the city. In many places green spaces are fragmented and do not have enough structural links to promote their ecological interactions. This fragmentation makes habitat more inaccessible and limits opportunities for dispersal of biodiversity across the urban landscape.

Specific site(s) for ecological enhancement opportunities are also identified during the

analysis. Stations, median strips, road verges, underused open spaces, and empty urban parcels have significant potential for interventions in the field of Green Infrastructure. The sites may serve as ecological stepping-stones to reconnect fragmented habitats and enhance biodiversity connectivity. These opportunities give a scientific basis for the creation of a comprehensive green urban spine framework that can be used to improve the environmental performance and preserve the functionality of the transportation network.

Case Study Analysis

Metro Bus Green Integration (Shahdara-Gajjumata)

Selected nodes such as Shahdara, MAO College/Azadi Chowk, Mozang, Kalma Chowk, Model Town, Township and Gajjumata were selected for the analysis of the corridor. The sites reflect diverse urban situations and give an indication of the advantages and disadvantages of the current corridor infrastructure in ecological and environmental terms.

The extent of green integration along the corridor varies, based on the existing state of plantation and landscape elements. Some areas have high quality mature roadside trees and landscaped medians that have a positive impact on environmental quality, and other areas are dominated by hard infrastructure and have few trees and plants. At the station level, there are also gaps in greenery provision and shading, and the quality of landscapes. A few stations offer some of the landscape features, but most don't have enough vegetation to enhance thermal comfort or make the station a welcoming public space.

Also, there are large variations in pedestrian access and comfort, depending on the corridor segment. The higher the vegetation cover the better the walking environment and the better visual will be provided. On the other hand, areas with a high concrete ratio and low shading tend to have high temperatures and low user comfort. The results show that although there are isolated

instances of green integration, the corridor is missing a holistic ecological and environmental plan that can help maintain ecological and environmental continuity and the quality of life for users. This is achieved by comparing with International Best Practices.

The study of international case studies offers important lessons about the key role that transportation infrastructure can play in facilitating ecological connectivity, environmental sustainability and good health. The examples below are some well-known ones that could be emulated in Lahore.

The city of Medellín, Colombia.

The city of Medellín in Colombia, Latin America.

One of the most positive experiences of integrating ecological infrastructure with the public transportation system is the Green Corridors project in Medellín. The project created green networks that are interconnected with each other and with Bus Rapid Transit (BRT), pedestrian and cycling networks. The resulting corridors improved the environmental quality, lowered urban temperatures, promoted biodiversity and promoted sustainable mobility. The project illustrates how transportation infrastructure can be used as an effective tool for ecological restoration and urban regeneration.

Singapore Park Connector Network

The Park Connector Network in Singapore is a prime example of how parks and nature reserves can be seamlessly integrated into the fabric of local communities and transportation infrastructure, creating continuous green corridors that connect people and places. The network supports biodiversity conservation and active mobility, recreational opportunities. The project emphasizes the need for the creation of continuous green spaces that can have ecological and social value.

Seoul Cheonggyecheon Restoration Project

The Cheonggyecheon Restoration Project is a testament to the potential of an ecological corridor in the context of a conventional transportation infrastructure. The restoration

of the urban stream resulted in a massive improvement in biodiversity, environmental quality, and accessibility of public space as well as providing urban cooling. The project offers valuable experiences on how to retrofit infrastructure and restore the ecology in high density urban areas.

High Line Linear Park.

The High Line demonstrates how the reuse of infrastructure is being presented as an ecological and recreational resource. The project integrated native vegetation, public spaces and biodiversity-friendly design elements to make the most of an abandoned railway line and turn it into a celebrated urban green corridor. The project demonstrates the ability of linear infrastructure to facilitate multiple ecological, public and urban regeneration functions.

Path of the Green Corridor in Skopje

The results of the Skopje research show the ecological value of vegetated urban boulevards as linear biodiversity corridors. The study highlights the importance of linking together vegetation systems, pedestrian infrastructure, and ecological functions to create a more connected and quality urban environment. The results are especially relevant to the Lahore Metro Bus Corridor because of the similarities of the linear urban conditions.

These international precedents highlight the need for ecological connectivity, biodiversity development, active mobility and environmental sustainability to be part of transportation infrastructure planning.

Proposed Green Urban Spine Framework

After reviewing the landscape, ecological barriers and best practices from around the world, a Green Urban Spine Framework has been suggested for the Lahore Metro Bus Corridor. The vision of the framework is to turn the corridor from a transportation system into a multi-functional ecological and social network, to support sustainable urban development.

Continuous Vegetation Networks and Green Belts

One of the key pieces of the plan is the

creation of green belts that will be continuous along the corridor. These green strips would involve plants that are locally available and can sustain Lahore's climate and would also benefit the life of the local flora and fauna. The vegetation along this corridor would create a continuous vegetational network which would help with ecological connectivity, visual quality, reduce urban heat island effects and increase the resilience of the ecosystems along the corridor.

Vertical Greenery and Station-Level Plantations.

The concept suggests introducing vertical greenery systems at stations and its surrounding facilities to optimize the ecological function of the station in the limited space. Climbing plants, vertical planting systems and green walls may be incorporated into the stations, adjacent built elements and boundary walls. More plantation works should be implemented at the entrance sites and waiting areas of stations and pedestrian areas to enhance thermal comfort, lower surface temperatures and to make public areas more attractive. These measures would have a substantial impact on the regulation of microclimate and further improve the commuter experience.

Pedestrian and bicycle access and connections.

The framework also puts into focus the development of integrated transportation infrastructure, including shaded pedestrian walkways and separate bike paths. These facilities would link Metro Bus stations to nearby parks, residential areas, commercial centres, and public spaces, thus forming continuous green mobility corridors. This helps to encourage healthy lifestyles, help limit the private vehicle use and promote environmentally-friendly transportation options.

Eco-location and ecological connections

This proposed framework is based on the concept that Metro Bus stations are ecological nodes attached by continuous green links.

Vegetated corridors provide connections between biodiversity-supporting nodes (parks/ open spaces/ landscaped areas). This network-based approach will improve ecological connectivity, help to conserve biodiversity and improve environmental quality throughout the urban landscape. In conclusion, the proposed Green Urban Spine Framework shows how the transportation infrastructure can be linked with Green Infrastructure systems to enable multifunctional urban systems that can support biodiversity connectivity, public health, environmental comfort and sustainable urban development. The Lahore Metro Bus Corridor development is a practical and context-sensitive approach to promoting urban sustainability and climate resilience in Lahore, turning it into a continuous ecological corridor.

DISCUSSION

The results of this study provide an insight that the Lahore Metro Bus Corridor has potential to be a green urban spine that can provide ecological connectivity, environmental improvement, and better public health. The analysis identified that while there are different types of vegetation and landscape elements present along the corridor, they are not present in a continuous ecological network and are not sufficiently connected. Much of the current plantation area is located within medians, selected station areas and roadside areas, creating fragmented or discontinuous green infrastructure, which reduces ecological effectiveness.

Spatial analysis also revealed distinct green gaps within the critical areas of the corridor, such as pedestrian zones, intersections, areas of high urbanization, and station precincts. These discontinuities limit the ecological connectivity and further diminish the corridor's value as a meaningful environmental asset in the urban landscape. The study also showed a lot of potential for specific measures that can enhance the connectivity of the existing green spaces and

make the corridor a multifunctional ecological system.

The results suggest that the strategic incorporation of green infrastructure such as vegetated corridors, landscaping on stations, green buffers and pedestrianized green spaces can significantly enhance the environmental quality of the corridor. The interventions would improve biodiversity support, for thermal comfort, for visual quality, and for the overall urban sustainability. The outcomes align with global publications highlighting the importance of GTCs for ecological resilience, climate adaptation and sustainable urban development. This study thus ensures that transportation infrastructure can have applications that transcend its role as a mobility tool and that it can be used to achieve important environmental and social goals when planned within an integrated and ecological perspective.

The results of the research include one of the most important that the corridor can contribute to urban biodiversity connectivity. The detrimental impact of urban sprawl on urban biodiversity, especially in fast-growing cities, is well known, and habitat fragmentation is cited as one of the main threats. Results of this analysis indicate that continuous plantation systems along the Metro Bus Corridor may be an important way to decrease habitat fragmentation and increase ecological connectivity throughout the urban landscape.

Vegetated buffers, roadside plantations and green medians can serve as ecological connectors, allowing birds, insects, pollinators and other urban wildlife species to move. The linear nature of these elements creates ecological habitat resources, shelter and movement corridors that link up isolated ecological patches across the city. Moreover, the planting of greenery at the station level provides ecological stepping-stones, which enhance species movement between larger habitat patches and thus improve the ecological connectivity of the urban biogeographic network.

It is especially important to use native plant species to increase biodiversity resilience. Native plants not only create ideal habitat for local wildlife, but also offer a variety of other habitat needs, such as food, that may not be present in non-native ornamental plantings. Adding species that are climate tolerant and endemic to the region, would then enhance the quality of the habitat and would make landscape interventions more sustainable over time.

Improved ecological connectivity is not only a biodiversity conservation concern, it is also a concern for the overall stability and resilience of the ecosystem. Green corridors can enhance ecological balance by allowing the movement of species and building up habitat networks, which can help urban ecosystems to better cope with environmental pressures. Thus, the proposed green urban spine can act as one of the environmental infrastructure systems that play a crucial role in Lahore's increasingly urban context.

The results also show that Green Infrastructure integration can have a substantial impact on the public health and quality of life of the urban environment along the Metro Bus Corridor. Urban greenery is increasingly acknowledged as a very important element to healthy and sustainable cities, directly or indirectly benefitting the urban population. The proposed improvements to the corridor by adding more vegetation would enhance the visual quality and would result in better urban environments for commuters, pedestrians, and the surrounding communities.

The enhancement of thermal comfort is one of the most apparent improvements that can be achieved by adding more green. Lahore has a long summer season and hot nights in summer can impact the comfort of commuters and reduce outdoor activity. Shaded walkways, tree-lined corridors and green station environments would help to mitigate heat stress through the reduction of surface temperature and filtering of direct solar radiation. The interventions are

particularly significant in a transit context where users often wait, walk and change modes of transport.

The psychological advantages of urban greenery are also very high. Many studies have shown that the benefits of access to green space include lower levels of stress, psychological and emotional health, and a better overall well being. The greening of the environment creates the possibility of a visual relief, a regeneration of the environment and a social interaction that enhances the quality of urban life. Consequently, the rehabilitation of the Metro Bus Corridor to a green urban spine would help make the city a better urban environment for its citizens and commuters.

Better environment may also lead to an increase in public transport usage. The creation of a comfortable, attractive and environmentally responsive transit environment can have a positive impact on how users perceive the transportation system and thus contribute to public acceptance of sustainable transportation systems. Therefore, the development of green corridors can contribute to greater sustainability of cities by fostering greater uptake of public transport, but also help to improve environmental performance and social well-being.

SUMMARY OF FINDINGS

The study explored the potential of the Lahore Metro Bus Corridor as a green urban spine for improving the connectivity of biodiversity, environmental quality and public health. Results of the analysis showed that the current available green spaces in the corridor are discontinuous and disconnected from each other and they lack connectivity for meaningful ecological functions. Vegetation is present in limited areas of selected medians, roadside lands and station precincts, but these are not continuous enough to allow the corridor to function as an ecological network. Spatial analysis revealed many ecological gaps and physical barriers that block movement of biodiversity and connectivity. The results have shown that present plantings are not sufficient to enrich the environment for

corridor users' or to contribute to urban biodiversity. The study also found that there were significant opportunities to implement

green infrastructure strategies to meet these gaps.

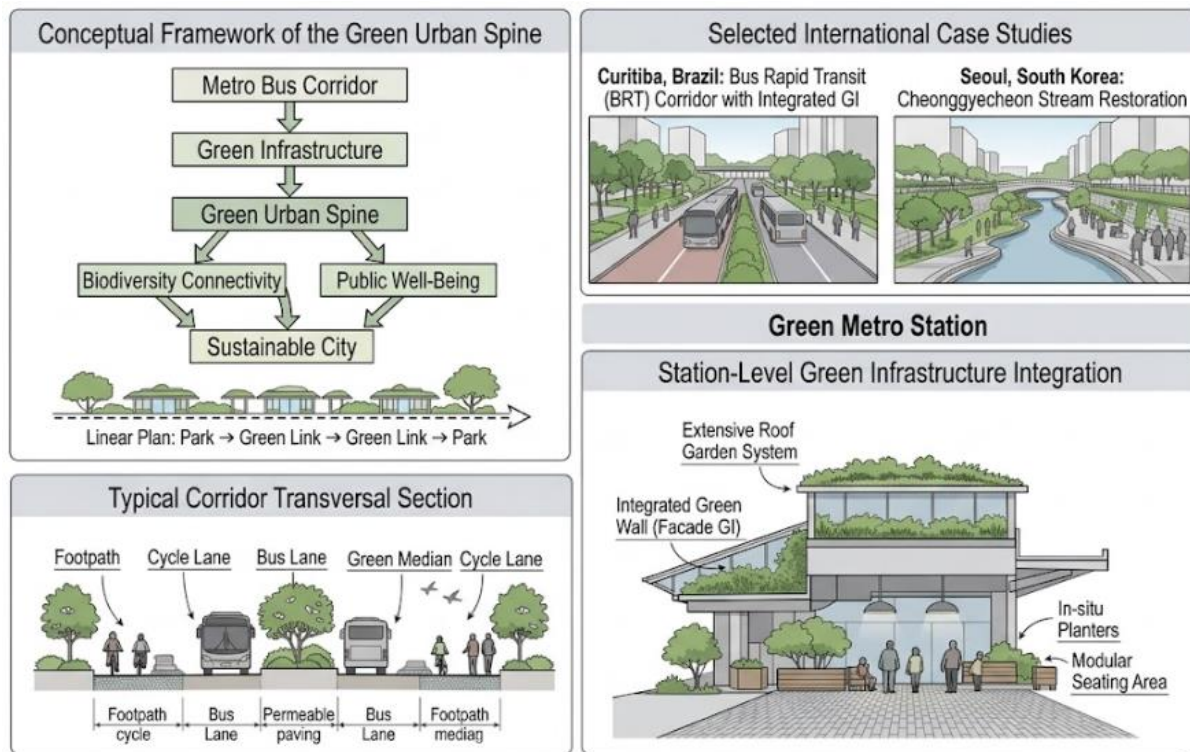


Fig. 1. Multiscalar Academic Framework for Green Urban Spine Integration

The study of international practices, such as Curitiba's BRT Green Corridors and the Cheonggyecheon Restoration Project in Seoul, showed that integrating ecological systems into transportation infrastructure were effective. The examples show how the landscape can be integrated strategically into transport sectors and how, as a result, traditional transport corridors can become multi-functional ecological resources. The conceptual framework is a vision for further development that builds on these lessons, suggesting how the Lahore Metro Bus Corridor can be transformed into a green, living, urban spine that contributes to environmental sustainability and urban living.

CONCLUSIONS

The study concludes that there is a huge potential to transform the Lahore Metro Bus Corridor into a multifunctional green spine which can accommodate all the transportation, ecological, and public space

functions within a single urban system. The corridor can serve a biodiversity, environmental enhancement, and public health goal in addition to its core transportation function by strategically implementing green infrastructure. The study proves that green corridors are important for moving biodiversity, decreasing ecological fragmentation and enhancing urban ecosystem resilience. At the same time, green infrastructure interventions benefit the city's quality of life through their visual impact, their effect on thermal comfort, and their positive impacts on the environment of the commuters and their communities. Other station-level features that can provide especially good opportunities for enhancing the microclimatic performance and user experience include green walls, roof gardens, vertical planting systems, and landscaped waiting areas. Moreover, the connectivity of walking and cycling facilities in a seamless green network contributes to the goal of

sustainable mobility by fostering active transport and decreasing reliance on private cars. Overall, the proposed green urban spine is a comprehensive strategy for urban sustainability, addressing ecological restoration, climate adaptation, and urban development that prioritizes people.

RECOMMENDATIONS & FUTURE DIRECTIONS

The study's results led to a number of design and policy recommendations for supporting the development of the Metro Bus Corridor as a green urban spine. Green infrastructure should be formally integrated as a priority during the planning stages of corridor development, zoning and urban planning policies. Stations in Metro, parks, open spaces and surrounding neighborhoods should be connected with each other through continuous green links that would form an inter-connected ecological network. It is important to use native and climate-smart plant species to enhance biodiversity benefits where possible and sustainable. The design of

the Metro station should be redesigned as green urban nodes with the introduction of landscape components like planters, vertical greenery systems, roof gardens and shaded seating areas. Landscaped medians, roadside vegetation, bioswales and ecological buffers should be added to existing transportation infrastructure. Such actions would result in better environmental performance, as well as better comfort and visual quality for users. Creating pedestrian pathways with shade and bike lanes for increased sustainable transportation and enhanced station-to-community connectivity should also be considered. Local governments also should create long-term maintenance plans and ecological monitoring programs to make environmental investments in green infrastructure effective and sustainable. Community participation programmes to promote public ownership and support for corridor greening programmes should be encouraged.



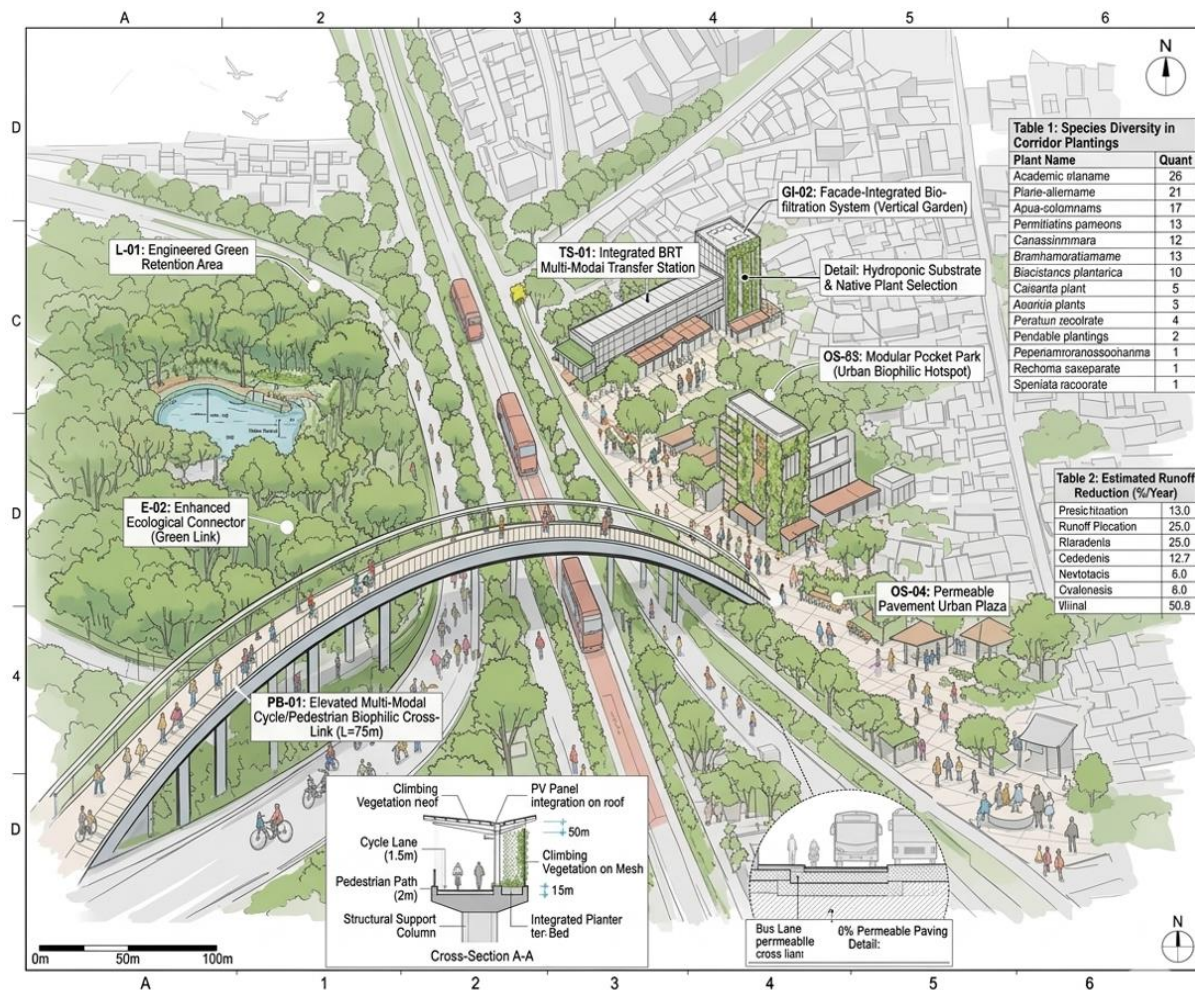


FIGURE 2: INTEGRATED MULTI-SCALAR GREEN URBAN SPINE SCHEMATIC FOR LAHORE METRO BUS CORRIDOR
Author/Year Based on Field Survey and Design Document

The present study offers a conceptual framework for the development of green corridors, but there are still several aspects that need to be investigated. Future studies should explore the long-term (i.e. long-term) ecological effects of corridor greening projects via ecosystem performance and biodiversity monitoring. These would be useful pieces of evidence to inform the effectiveness of green infrastructure interventions for supporting urban wildlife and ecological resilience. Further studies are warranted to investigate the socio-economic effects of implementing green corridors, such as commuter behavior, public transport uptake and public perceptions of the quality of the environment. To gain an understanding of these relationships would enhance the evidence base for future planning and investment decisions. The future research could also

explore the incorporation of renewable energy, smart city systems, and digital monitoring devices in green transportation corridors. These innovations can be further exploited to improve environmental performance and operational efficiency. Last, thorough cost-benefit analyses need to be carried out to assess economic viability of green infrastructure investments and to determine the environmental, social and public health impacts of corridor greening projects. The research directions would help in the ongoing progress of sustainable transport and ecological planning in the megacity of Lahore and other fast-growing urban centers.

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