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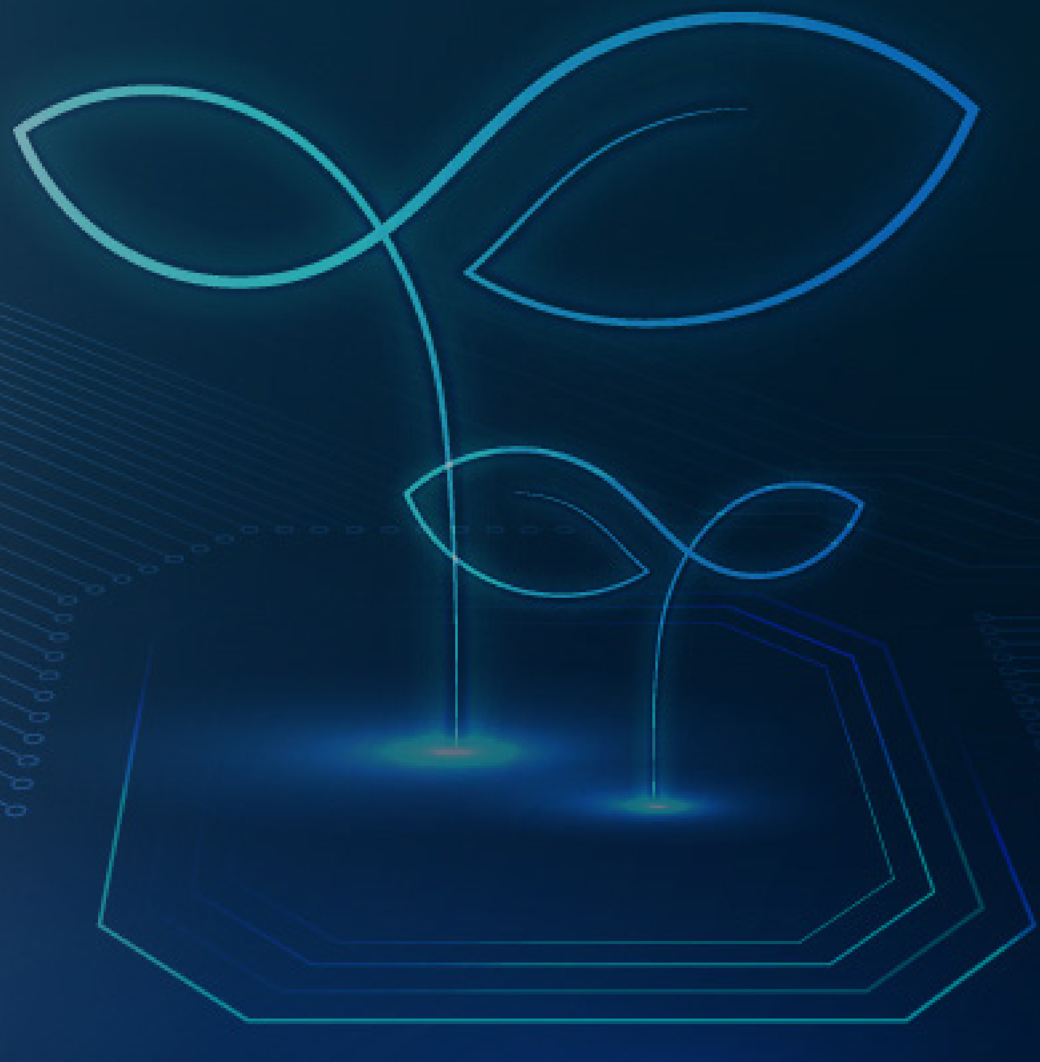

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Assessing Ecosystem Service Supply-Demand Mismatches in Urban Green Infrastructure: Evidence from Zanzibar's Urban-West Region

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ABSTRACT

This study investigates the balance between ecosystem service supply and societal demand across multiple components of urban green infrastructure (UGI) in the Urban-West Region of Zanzibar, Tanzania. The research focuses on key land-use types, including forests, allotment gardens, sports areas, agricultural land, riparian vegetation, degraded areas, and green spaces within settlements. A mixed-methods approach was employed, combining household surveys, key informant interviews, and field observations with spatial analysis of land-use data. Ecosystem services were classified into provisioning, regulating, and cultural categories following established frameworks, and assessed using a set of standardized indicators. Both supply and demand were quantified and normalized on a 0–1 scale, enabling comparative analysis across ecosystem service types and UGI categories. Descriptive statistics and supply-demand differentials were used to identify deficits and surpluses, while graphical techniques supported the interpretation of multidimensional patterns. The results indicate a widespread imbalance where ecosystem service demand exceeds supply across most urban green infrastructure types, with deficits ranging from about 19% in sports areas to over 45% in agricultural land. Regulating services show the greatest shortfalls, while provisioning services are mixed, and cultural services perform relatively better but still do not fully meet demand. These patterns, consistent with global trends, are intensified in Zanzibar by local pressures such as rapid urbanization and limited planning integration. The findings emphasize the need for improved management, spatial planning, and ecological restoration to enhance ecosystem service provision and urban sustainability..

INTRODUCTION

Urban Green Infrastructure (UGI) refers to an interconnected network of natural and semi-natural green spaces within urban environments, encompassing both extensive ecological systems and smaller green elements such as urban parks, green corridors, green roofs, and vegetated walls (Dong *et al.*, 2023). These green infrastructures play a fundamental role in sustaining urban ecosystems by providing a wide range of ecosystem services (ES) that directly and indirectly support human well-being (WB) (Hysa *et al.*, 2024). As cities continue to expand and urban populations increase, the importance of UGI has gained significant attention among researchers, planners, and policymakers due to its potential to enhance environmental quality, strengthen climate resilience, and improve the quality of urban life (Ashinze *et al.*, 2024).

Ecosystem services generated by UGI contribute substantially to achieving sustainable urban development goals, particularly those related to health, well-being, environmental sustainability, and climate adaptation. These services include the provision of essential resources, regulation of environmental processes, and delivery of cultural and recreational benefits that enhance physical, psychological, and social well-being (Das *et al.*, 2024). Although numerous studies have documented the positive influence of green infrastructure on human well-being, the mechanisms through which different ecosystem services contribute to specific well-being outcomes remain insufficiently understood (Yao *et al.*, 2025). Consequently, improving understanding of ecosystem–well-being relationships is essential for designing ecosystem-based strategies capable of enhancing urban sustainability and improving quality of life (Yao *et al.*, 2025).

The concept of ecosystem services received widespread scientific recognition following the Millennium Ecosystem Assessment (MEA), which provided a comprehensive framework linking ecosystem functioning with human well-being (Bennett *et al.*, 2026). Within this framework, ecosystem services are generally classified into four categories: provisioning, regulating, cultural, and supporting services. Human well-being, in turn, is conceptualized through five interconnected dimensions: access to basic materials for a good life, security, health, good social relations, and freedom of choice and action. Provisioning services contribute to access to food, water, fuel, raw materials, and income-generating opportunities. Regulating services support environmental stability through functions such as climate regulation, flood control, water purification, and disease regulation. Cultural services provide recreational, educational, aesthetic, spiritual, and cultural benefits that strengthen social cohesion and individual well-being. These multiple interactions illustrate the complex and multidimensional

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relationships that exist between ecological systems and human societies (Das *et al.,* 2024).

Within urban environments, different forms of UGI vary considerably in their capacity to generate ecosystem services and support human well-being. Urban forests, parks, riparian vegetation, allotment gardens, sports and recreational spaces, and neighborhood green areas each provide distinct combinations of provisioning, regulating, and cultural services. Consequently, the contribution of ecosystem services to well-being dimensions differs according to the characteristics, quality, accessibility, and management of specific green infrastructure types. For example, regulating services often exert strong influences on public health and environmental security, whereas cultural services are more closely associated with recreation, social interaction, and psychological well-being (Das *et al.,* 2024). Understanding these differences is critical for developing targeted planning and management interventions that maximize the benefits derived from urban ecosystems.

Despite increasing recognition of the value of UGI, substantial knowledge gaps remain regarding how ecosystem services are perceived by different stakeholders and how these perceptions influence assessments of human well-being. Existing studies have demonstrated positive associations between green spaces and health outcomes; however, the specific causal pathways linking different types of green infrastructure, ecosystem services, and well-being outcomes remain insufficiently explored (O'Donnell *et al.*, 2023). Furthermore, perceptions of ecosystem services vary across individuals, stakeholder groups, geographical settings, and socio-economic contexts because ecosystem benefits are often experienced differently depending on users' needs, values, knowledge, and interactions with the environment (Meli *et al.*, 2023). In many cases, ecosystem benefits are spatially and temporally uneven, benefiting certain groups more than others (Sattler *et al.*, 2022).

Addressing these challenges requires greater stakeholder participation in ecosystem service assessment and urban planning processes. Integrating local knowledge, encouraging stakeholder engagement, and strengthening science–policy interactions have been identified as critical strategies for improving environmental planning outcomes and promoting sustainable urban development (Fernanda *et al.,* 2025). Effective planning must recognize not only the ecological capacity of urban ecosystems to provide services but also the societal demand for those services. Since human well-being depends on the balance between ecosystem service supply and demand, identifying mismatches between these two dimensions is essential for developing sustainable urban management strategies (Sun *et al.*, 2024). Ecosystem services acquire practical significance only when they meet societal needs, which are themselves influenced by cultural values, perceptions, and local priorities (Thiemann *et al.*, 2022). Consequently, participatory approaches that incorporate diverse stakeholder perspectives are increasingly recognized as important tools for supporting urban ecosystem governance and sustainable management (Terribile *et al.*, 2024).

A variety of approaches have been developed to assess ecosystem services, ranging from qualitative and participatory methods to quantitative modelling techniques and spatial analyses (Hysa *et al.*, 2024). However, despite considerable methodological advancements, ecosystem services remain insufficiently integrated into urban planning and policy-making processes (Bitoun *et al.*, 2022). Moreover, many studies focus primarily on ecosystem service supply while paying comparatively little attention to societal demand (Bakare *et al.*, 2023). Understanding residents' preferences, expectations, and demands for ecosystem services is particularly important for ensuring that UGI planning reflects local priorities and contributes effectively to human well-being (Geta *et al.*, 2025). Although research examining relationships among UGI, ecosystem services, and well-being continues to expand, important questions remain regarding the magnitude and nature of ecosystem service contributions to different dimensions of well-being.

To further understand the current state of knowledge, a scoping review of literature indexed in the Web of Science identified 133 publications published between 2019 and 2025 containing the terms "urban green infrastructure," "ecosystem services," and "well-being" within titles, abstracts, keywords, or Keywords Plus. The review revealed that most studies (n = 101) primarily examined relationships between UGI and ecosystem services while discussing well-being only in general terms. These studies rarely quantified the specific contribution of ecosystem services to distinct dimensions of human well-being. In contrast, only 32 studies explicitly evaluated and quantified ecosystem service contributions to well-being using more rigorous and innovative approaches. These studies commonly employed participatory methods, social surveys, questionnaires, direct observation, experimental designs, and fuzzy cognitive mapping techniques (Chen *et al.*, 2025; Das & Liu, 2025). Other studies relied on objective approaches such as GIS, remote sensing, land-use analysis, landscape metrics, statistical modelling, and systematic reviews (Cunha *et al.*, 2025). A smaller group of studies integrated subjective and objective approaches to provide more comprehensive assessments of ecosystem service–well-being relationships (Rüger *et al.*, 2023).

Against this background, the present study develops a stakeholder-based framework for assessing ecosystem service supply and demand across different forms of urban green infrastructure in Zanzibar's Urban-West Region. Drawing upon the conceptual relationships between ecosystem services and human well-being established by the Millennium Ecosystem Assessment (Zhou *et al.*, 2025), the study translates qualitative ecosystem–well-being linkages into a quantitative assessment framework capable of evaluating the potential contributions of urban green infrastructure to human well-being.

The study was guided by three specific objectives:

1. To identify and evaluate stakeholders' perceptions of ecosystem services and their relationships with different types of urban green infrastructure in the Urban-West Region;
2. To compare ecosystem service supply with societal demand across major categories of urban green infrastructure; and
3. To generate evidence capable of supporting the integration of ecosystem service concepts into formal urban spatial planning and policy processes.

The significance of this study extends beyond conventional ecosystem service assessments. While many previous studies have focused exclusively on ecosystem service supply and demand, this research explicitly links ecosystem service provision to multiple dimensions of human well-being. Furthermore, the study provides a context-specific assessment for Unguja Island, a rapidly urbanizing small-island environment that remains underrepresented in urban ecosystem service research. By examining multiple UGI typologies, including urban forests, parks, allotment gardens, riparian vegetation, sports areas, agricultural land, and green spaces within settlements, the study offers a comprehensive understanding of how different urban ecosystems contribute to provisioning, regulating, and cultural services. Importantly, it identifies critical mismatches between ecosystem service supply and societal demand, thereby generating practical evidence to support urban planning, ecosystem restoration, environmental management, and policy development aimed at enhancing urban sustainability and human well-being in Zanzibar.

Theoretical Approach

The analytical framework shown in Figure 1 is used to understand the relationship between ecosystem service (ES) supply, urban green infrastructure (UGI), and human well-being (WB). The framework describes how several UGI elements serve as the main sources of ecosystem services, which in turn affect many aspects of human well-being. According to this method, UGI is viewed as a network of interconnected natural and semi-natural green spaces that support both human needs and ecological processes in urban settings. Forests, public parks, sports and recreation areas, allotment gardens, riparian vegetation, and green spaces within residential settlements are the six main forms of urban green infrastructure identified by the framework. These categories were chosen due to their pervasiveness and functional significance in urban and peri-urban environments, as well as their immediate connection to sustainable development, environmental management, and urban planning. Depending on its size, location, management, and ecological features, each category makes a unique contribution to the supply of ecosystem services. The three main categories of ecosystem services that come from UGI are supplying, regulatory, and cultural services. Material benefits like food, fuel, water, raw materials, biochemical products, and genetic resources are examples of provisioning services. Water quality and quantity regulation, disease and pest control, and climate regulation are all examples of environmental processes that are moderated by regulating services. Non-material advantages, including spiritual and religious values, leisure and travel, education, and cultural heritage are all included in cultural services. The Millennium Ecosystem Assessment (MEA) framework, which offers a generally acknowledged foundation for comprehending and evaluating human interactions with ecosystems, is the source of this classification.

Within the approach, the contribution of ecological services to human well-being is evaluated qualitatively. Key characteristics of human well-being include health, security, social relationships, freedom of choice and action, and availability to necessities for a decent existence.

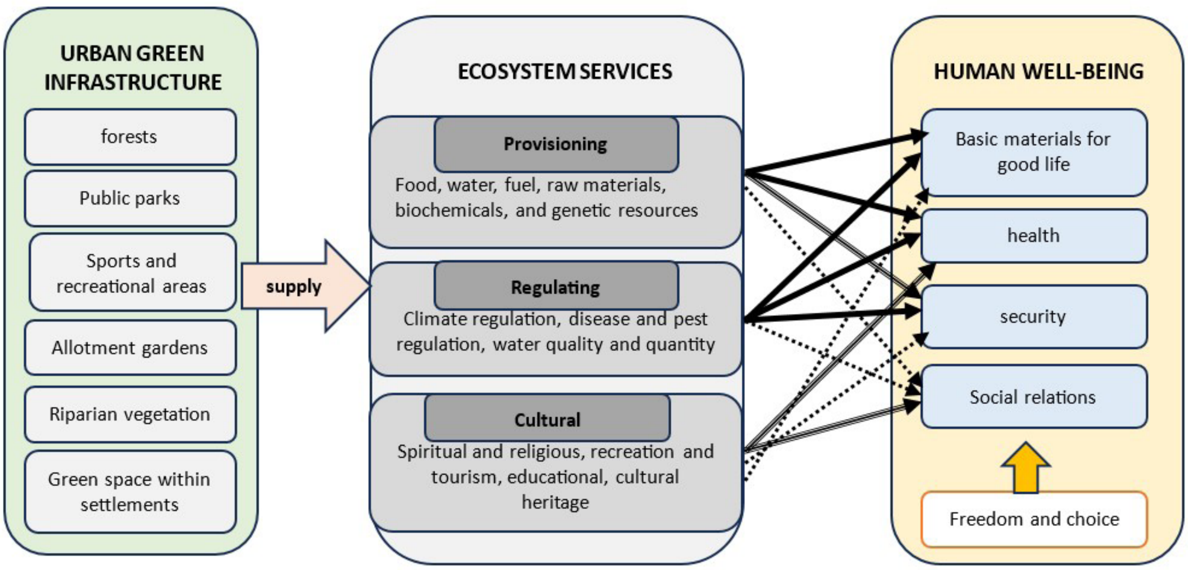

Figure 1: Linkage between ecosystem services of urban green infrastructure and human well-being, adapted from MEA (2005)

The paradigm makes the assumption that UGI-generated ecosystem services have a direct or indirect impact on these parameters. The strength of ES contributions to human well-being is assessed as strong, moderate, or weak in accordance with the MEA approach, reflecting differences in the degree and efficacy of service delivery across various forms of green infrastructure.

A relative influence technique developed from the Millennium Ecosystem Assessment (MEA) was used to evaluate the degree of interaction between ecosystem services (ES) and human well-being (WB), and it was further refined using data from the literature. To enable quantitative understanding of the otherwise qualitative links, relationships were divided into low, medium, and high influence levels and given numerical values (low = 1, medium = 2, high = 3). The contribution of various urban green infrastructure (UGI) types to distinct WB aspects may be stated in a standardized numerical form thanks to this scoring system. Table 1 summarizes the influence scores used to depict the connections between the supplying, regulating, and cultural ecosystem service categories and specific aspects of human well-being. The assigned influence levels are based on the MEA framework, but they are also supported by findings from earlier research, which show that because regulating services play a crucial role in maintaining environmental quality and general human well-being, urban ecosystem service assessments typically place more emphasis on them than on provisioning services.

The contribution of urban green infrastructure (UGI) to human well-being (WB) is quantified through a composite measure that integrates stakeholder perceptions of ecosystem services (ES) with their relative importance for well-being. Specifically, the estimation involves aggregating the products of (i) the number of ecosystem services identified within each ES category and (ii) the corresponding weighting factors assigned to WB dimensions. This aggregated value is subsequently normalized by the total number of respondents and by the cumulative weighted ES scores, as formalized in Equations (1)–(4). Furthermore, the demand-oriented contribution of UGI to human well-being is derived by adjusting the calculated UGI–WB contribution using a demand ratio. This ratio is computed as the weighted sum of demanded ecosystem services divided by the product of the total number of respondents and the overall weighted ES scores. Through this formulation, the analysis captures not only the supply-side contributions of ecosystem services but also the extent to which these services align with societal needs. An illustrative application of this procedure, focusing on the well-being dimension of security demand, is presented in Equation (5).

Table 1: Relationship between ecosystem service categories and dimensions of human well-being based on relative influence scores

Ecosystem Service Category	Materials for Livelihood	Physical & Mental Health	Safety & Stability	Social Interaction
Provisioning Services (NP = 6)	fs (3)	fs (3)	fm (2)	fw (1)
Regulating Services (MR = 4)	fs (3)	fs (3)	fs (3)	fw (1)
Cultural Services (NC = 6)	fw (2)	fm (2)	fw (1)	fs (3)

Note: Scores represent the relative strength of influence between ecosystem service categories and human well-being dimensions, where 3 = high influence, 2 = moderate influence, and 1 = low influence. n indicates the number of ecosystem services considered within each category

WB security provision = $((X_p f_m + X_R f_s + X_c f_w)/N(n_p f_m + N_R f_s + N_C f_w))/100$

WB basic material provision = $((X_P f_s + X_R f_s + X_C f_w)/N(N_P fs + N_R f_s + N_C f_w))/100$

WB health provision = $((X_P f_s + X_R f_s + X_C f_m)/N(N_p fs + N_R f_s + N_C f_m))/100$

WB social relations provision = $((X_P f_w + XRf_w + X_C f_m)/N(N_p f_w + N_R f_w + N_C f_m))/100$

WB security demand = WB security provision + $((Y_P f_m + Y_R f_s + Y_C fw)/N(N_P f_m + N_R f_s + N_C f_w))/100$

where

X_P = number of perceived provided provisioning ES

X_R = number of perceived provided regulating ES

X_C = number of perceived provided cultural ES

F_w = weak linkage between ES group and WB component

f_m = medium linkage between ES group and WB component

f_s = strong linkage between ES group and WB component

N = number of respondents

N_P = number of provisioning ES

N_R = number of regulating ES

N_C = number of cultural ES

Y_P = number of demanded provisioning ES

Y_R = number of demanded regulating ES

Y_C = number of demanded cultural ES

The methodology used in this study is especially important because many similar studies are restricted to evaluating the supply and demand of ecosystem services (ES) without taking well-being (WB) and its component characteristics into account. Additionally, current research frequently focuses on a small number of urban green infrastructure (UGI) types or only one or two ES categories (Shen *et al.*, 2023). Furthermore, WB is often regarded as a single, aggregated construct without differentiating between its numerous components, or the research is limited to particular dimensions, most typically mental and physical health. On the other hand, the current study follows the methodology of Watson *et al.* (2024) and looks at individual WB components. It goes beyond this concept, though, by assessing the relative contribution of ES to WB using a differential weighting mechanism. This is an improvement over Zhao *et al.*'s (2021) approach, which makes the assumption that all WB components are equally weighted.

MATERIALS AND METHODS

Study Site

The research area is situated in the Urban-West Region of Unguja Island, Zanzibar, which is a part of the United Republic of Tanzania's semi-autonomous Zanzibar archipelago. The research region is located on the western side of Unguja Island between around 39°10'E and 39°20'E longitude and 6°00'S and 6°20'S latitude, as shown in Figure 2. The Indian Ocean borders the Urban-West Region's central-western coastline location, which extends inland into the island's center. Due to its advantageous location, the neighborhood is situated in Zanzibar's most urbanized and economically active zone, which includes Zanzibar City and the nearby communities. Its proximity to the shore has a major impact on ecosystem dynamics and land use patterns, especially when it comes to elements of urban green infrastructure including riparian zones, coastal vegetation, and settlement green spaces.

The tropical marine climate of urban Zanzibar is marked by high temperatures, high humidity, and bimodal rainfall patterns. Because of its equatorial location, average yearly temperatures are between 25°C and 30°C, with little seasonal change. The long rains (Masika) from March to May and the short rains (Vuli) from October to December are the two primary seasons for rainfall, with an average annual precipitation of 1,200 to 1,800 mm (Mohamed *et al.*, 2024). Additionally, the coastal location leads to moderate sea breezes that affect local microclimates and high humidity levels, frequently surpassing 70%. Although rising urbanization and climate unpredictability may have an impact on the resilience of urban green infrastructure, these climatic circumstances are generally beneficial for vegetation growth and ecosystem service provision (Mohamed *et al.*, 2023).

The Urban-West Region's geography is primarily low-lying and gently undulating, with altitudes typically falling below 50 meters above sea level. The terrain is made up of coastal plains with little ridges and depressions scattered throughout, which affect riparian system distribution and drainage patterns. The relatively flat terrain in some places, particularly along the shore, makes them ideal for urban development but also increases their susceptibility to flooding and waterlogging, especially during periods of intense rainfall. The functionality of urban green infrastructure is significantly influenced by this geographical environment, particularly with regard to drainage services and water regulation (Mohamed *et al.*, 2024).

Although the research area's soil qualities are varied, sandy soils, coral rag soils, and alluvial deposits typically predominate. Many areas of Unguja have shallow, stony, low-fertility coral rag soils, which can restrict vegetation density and agricultural production (Mohamed *et al.*, 2023). Low water retention capacity is a characteristic of sandy soils, which are common in coastal areas. On the other hand, riparian and low-lying regions have more fertile alluvial soils that promote vegetation development and cultivation (Mohamed *et al.*, 2024). However, urbanization and unsustainable land use practices have led to an increase in reports of soil degradation, erosion, and nutrient depletion, which can have a detrimental impact on the provision of ecosystem services (Mohamed *et al.*, 2024). With a sizable share of the island's population, the Urban-West Region is Zanzibar's most densely populated district. Recent estimates place Zanzibar's population at over 1.8 million, with a significant portion of the population living in Unguja's urban and peri-urban districts, especially in the Urban-West Region (National

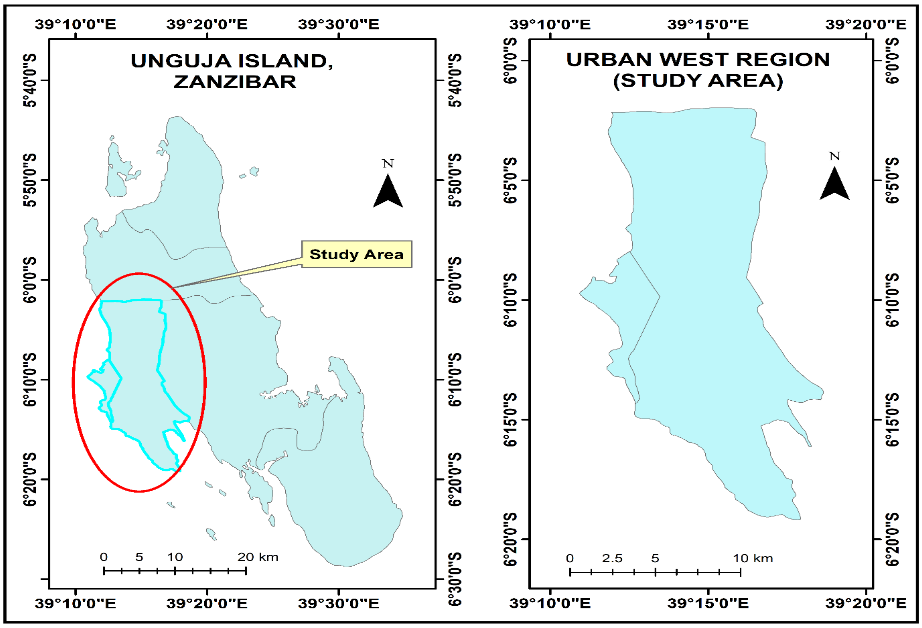

Figure 2: Study Area

Bureau of Statistics, 2022).

Urban green infrastructure is under a lot of strain due to the growing demand for land, housing, and ecosystem services brought on by rapid population expansion and urbanization (Mohamed, M.K., 2025). As growing settlements encroach on forests, agricultural land, riparian zones, and other green spaces, this demographic trend plays a major role in the observed imbalance between ecosystem service supply and demand.

Stakeholder Engagement

In the setting of Zanzibar Town, a structured participatory method was used to identify and choose stakeholders to jointly investigate the connections between ecosystem services (ES), urban green infrastructure (UGI), and well-being (WB). Several workshops and stakeholder mapping methods were used in this process, along with tools from the urban learning lab like mind mapping activities and matrices. The methods for identifying and engaging stakeholders adhere to recognized methodological frameworks described in earlier research (e.g., Khalilzadeh, M., 2021; Lepre *et al.*, 2021). A diverse range of players, including representatives from the corporate sector, local government agencies, non-governmental organizations, research bodies, and youth/students, many of whom had no prior exposure to the ES concept, were represented in the final cohort of participants (N = 42).

It is crucial to remember that this sample does not reflect a statistically representative cross-section of Zanzibar Town's population. Instead, it depicts a purposefully chosen group involved in a collaborative learning process centered on UGI growth and planning in an urban setting. Stakeholder involvement was carried out as a multi-year, assisted approach that included focus groups, seminars, consultative sessions, and cooperative learning exercises. The goal of these interactions was to promote a shared knowledge of UGI, the ES that goes along with it, and how these factors affect urban well-being. As a result, Zanzibar Town's planning procedures, governance systems, and policy debates pertaining to UGI and WB were actively shaped by stakeholders.

To operationalize the research strategy, a special one-day workshop was arranged as part of this participatory framework. The theoretical underpinnings of ES and their linkages to UGI and WB were first explained to the participants. They then had to connect particular ES to different UGI categories. Participants distinguished ES according to their roles in supply and demand during the last phase. According to the conceptualization put forth by Castellar *et al.* (2021), ES supply was defined as an area's ability to provide ecosystem goods and services over a certain time period, whilst ES demand was defined as the quantity of ecosystem goods and services used within that same context. During the exercise, ES were divided into provision and demand functions for clarity and ease of comprehension. Equations (1)–(5) were used in the quantitative study that followed after the workshop facilitators collated and methodically categorized the ES that stakeholders had recognized into providing, regulating, and cultural categories (Banela *et al.*, 2024).

RESULTS AND DISCUSSION

Parks

Ecosystem service supply (red) and society demand (purple) are contrasted in the spider diagram below on a normalized scale from 0 to 1 (Figure 3). The findings demonstrate distinct quantitative discrepancies between cultural services (CS), provisioning (PS), and regulating (RS), with demand typically outpacing supply. There is a shortfall of roughly 0.15 (≈43% higher demand than supply) for food, with supply being about 0.35 and demand being higher at about 0.50. Fuel shows a greater disparity, with supply at about 0.25 and demand at 0.60, or a difference of 0.35 (≈140% higher demand). Fresh water has a shortfall of 0.15 (about 50% higher demand) with a supply of about 0.30 and a demand of about 0.45. In a similar vein, raw materials show a disparity of 0.35 (≈175% higher demand) between supply of approximately 0.20 and demand near 0.55. On the other hand, biochemicals (supply ≈0.20, demand ≈0.25) and

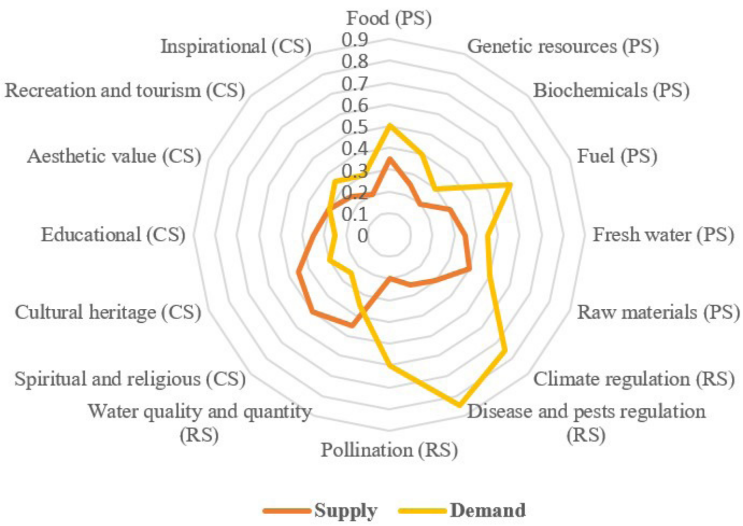

Figure 3: Radar (Spider) Diagram of Ecosystem Service Supply and Societal Demand in Urban Parks within Urban Green Infrastructure

genetic resources (supply ≈0.25, demand ≈0.30) exhibit comparatively tiny discrepancies of 0.05, indicating near balance albeit at generally low levels.

According to climate regulation, supply is approximately 0.25 and demand is approximately 0.65, with a 0.40 discrepancy ("160% higher demand). Regulation of disease and pests has a supply ratio of 0.20 compared to demand ≈0.70, with the biggest difference at 0.50 ("250% higher demand). Additionally, there is a noticeable mismatch in pollination, with supply ≈0.15 and demand ≈0.60, resulting in a differential of 0.45 (≈300% higher demand). The water quality regulation, on the other hand, shows a minor excess of 0.05 (about 20% higher supply) with supply around 0.30 and demand ≈0.25. Overall disparities are less pronounced in cultural services. Spiritual values reveal a surplus of 0.15 (≈60% higher supply) with supply ≈0.40 and demand ≈0.25. Cultural heritage similarly exhibits a surplus of 0.15 (supply ≈0.35, demand ≈0.20). With supply ≈0.30 and demand ≈0.20 (difference 0.10), educational value is moderately balanced. The aesthetic value is almost comparable (gap 0.05, supply ≈0.25, and demand ≈0.30). On the other hand, demand for recreational and inspirational services is marginally higher than supply (≈0.35 vs. 0.30, gap 0.05).

Forest

A comparison of the supply and demand for ecosystem services obtained from forest ecosystems within urban green infrastructure (UGI) is shown in Figure 4. The results are presented on a normalized scale from 0 to 1, making it possible to compare various ecosystem service indicators consistently. Overall, the findings show a continuous trend where demand outpaces supply in the majority of ecosystem service categories, pointing to a pervasive shortfall in ecosystem services within urban forest systems. Quantitatively, supply values are typically below 0.6, indicating a significant mismatch between a society's demands and the biological capacity of urban woods. Demand values typically vary between around 0.8 and 1.0 (and occasionally slightly above). There is a clear discrepancy in all parameters within the Cultural Services (CS) category offered by Urban Woods. Inspirational value, recreation, and tourism, for instance, show demand levels of roughly 1.1 and supply levels close to 0.5, indicating a shortfall of more than 50%. Similar to this, demand values for educational services and aesthetic value are near 1.0, while supply is still between 0.3 and 0.4. The greatest significant disparity is found in spiritual and religious services, where supply is roughly 0.2, and demand is roughly 0.5, meaning there is a shortage of more than 60%.

The disparity is also important for Regulating Services (RS), which are important roles of urban forests within green infrastructure. Pollination services and water quality and quantity regulation both show demand values between 1.1 and 1.2, while supply is restricted to about 0.5, suggesting deficits of greater than 50%. Furthermore, climate regulation shows a supply of around 0.4 compared to demand of around 1.0, while disease and pest regulation show a supply of roughly 0.3 versus demand of roughly 0.9. The results in the Provisioning Services (PS) category are conflicting. Significantly, food provision shows a surplus, with supply reaching roughly 1.6 and demand exceedingly roughly 1.0, indicating that urban forest systems may make a substantial contribution to resources connected to food. Other provisioning services, including fuel, exhibit a shortfall of around 55%, with demand at roughly 1.1 and supply at about 0.5. While fresh water is still somewhat closer to balance, it still shows a modest deficit (supply = 0.4, demand ≈ 0.6). Biochemicals also show a significant disparity, with supply roughly 0.2 and demand roughly 0.8. This suggests that urban woods perform unevenly when it comes to

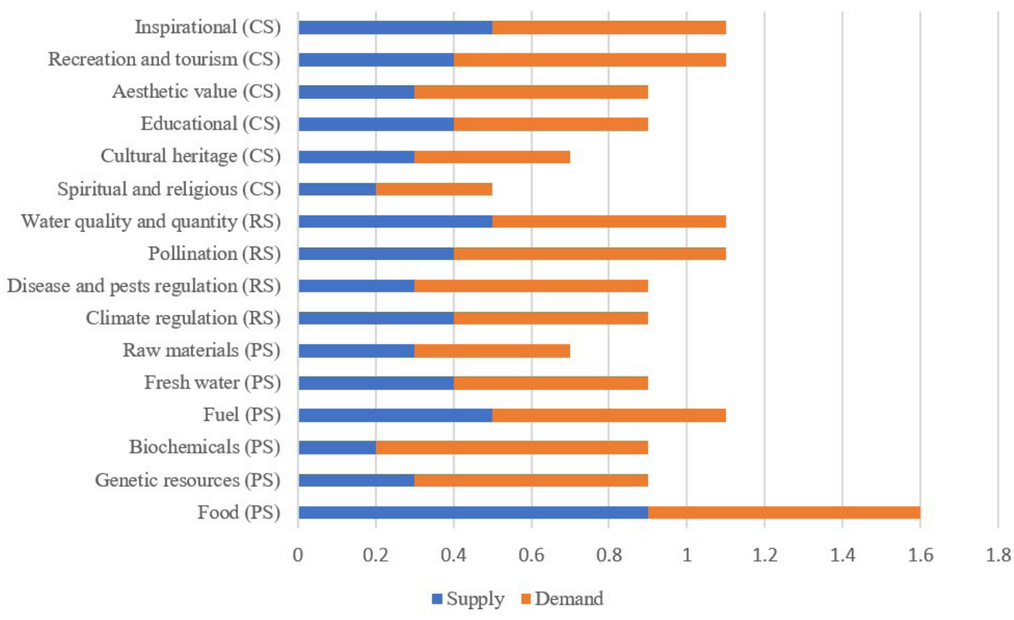

Figure 4: Supply and demand derived from forest ecosystems within urban green infrastructure

providing material resources.

Allotment Garden

The scatter plot presented in Figure 5 illustrates the relationship between ecosystem service supply and demand across 16 indicators, focusing on forest-related services provided by allotment gardens within urban green infrastructure. Values are standardized on a scale ranging from 0 to 1. The overall distribution indicates that demand consistently exceeds supply across all indicators, pointing to a sustained shortfall in ecosystem service provision within these systems. Supply values generally fall between approximately 0.45 and 0.75, whereas demand values are notably higher, ranging from about 0.65 to 0.90. On average, supply is estimated at around 0.61, while demand reaches approximately 0.78, yielding a mean gap of about 0.17 (roughly 22%).

A more detailed inspection of the individual indicators reveals that the lowest levels of supply are associated with indicators 3 and 6 (approximately 0.45–0.50), while comparatively higher supply values are recorded for indicators 12, 15, and 16 (around 0.70–0.75). This pattern suggests some degree of variation, although overall service provision remains relatively limited. In contrast, demand displays less fluctuation but consistently higher values, reaching a maximum of about 0.90 (indicator 7) and remaining above 0.70 across all indicators. The most pronounced mismatches between supply and demand occur at indicators 6 and 7, where deficits are estimated at roughly 0.25–0.30, corresponding to discrepancies exceeding 30%. By comparison, smaller gaps (approximately 0.05–0.10) are observed for indicators such as 12, 15, and 16, indicating cases where ecosystem service provision in allotment gardens more closely aligns with user demand.

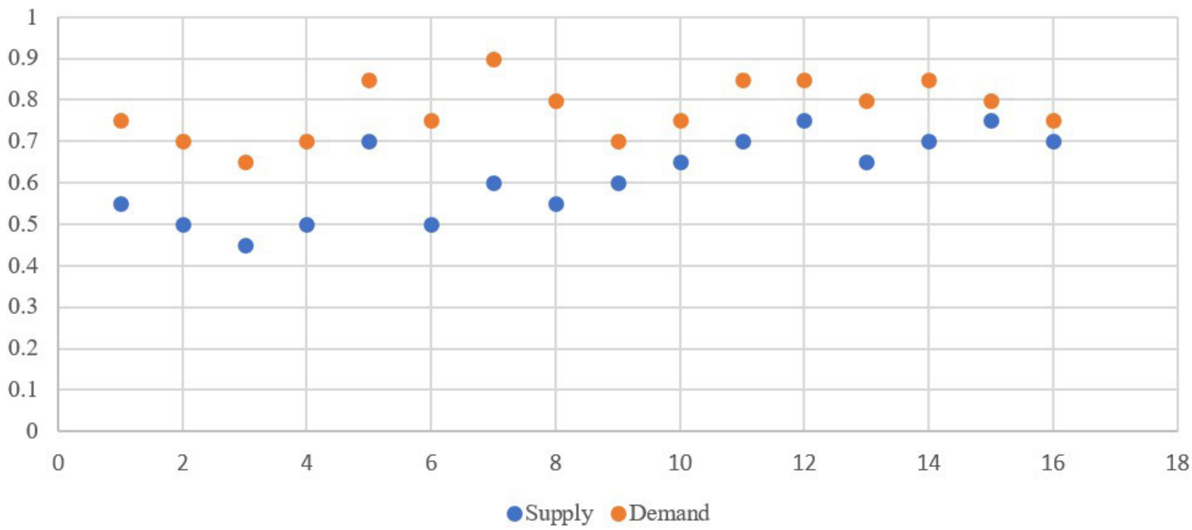

Figure 5: Scatter Plot of Ecosystem Service Supply and Demand in Allotment Gardens within Urban Green Infrastructure

Sports Areas

The line graph (Figure 6) presents ecosystem service supply and demand in sports areas within urban green infrastructure across provisioning (PS), regulating (RS), and cultural services (CS), with all values normalized between 0 and 1. The results indicate variations between supply and demand across the different service categories. Supply values range approximately from 0.20 to 0.50, whereas demand values span from about 0.20 to 0.80. The mean supply is estimated at around 0.33, while the mean demand is approximately 0.41, resulting in an average deficit of about 0.08 (≈19%). Sports facilities have comparatively low capacity within the Provisioning Services (PS) category. For instance, there is a 20% gap in food provision, with a supply of about 0.40 and a demand of about 0.50. In a similar vein, biochemicals and genetic resources show low supply levels (~ 0.20–0.30) compared to demand (≈ 0.30–0.40), indicating deficiencies in the range of 25–35%. Similar patterns can be seen in other services like gasoline, fresh water, and raw materials, where supply values are constantly lower than demand.

The Regulating Services (RS) group, on the other hand, shows more noticeable differences. While disease and pest regulation indicates a significant disparity, with demand reaching almost 0.70 compared to a supply of 0.30, climate regulation shows a demand of roughly 0.50 against a supply of 0.35. The most significant mismatch is seen in pollination services, where supply is low at roughly 0.25 and demand peaks at about 0.80, indicating a deficit that is close to 70%.

It's interesting to note that the only regulating service where supply (≈ 0.40) surpasses demand (≈ 0.30) is water quality and quantity control. Sports facilities do rather well for Cultural Services (CS), frequently with supply outpacing demand. Religious and spiritual qualities show a surplus of more than 150%, with a supply of about 0.50 and a demand of 0.20. In a similar vein, supply values for cultural assets and educational services range from 0.45 to 0.50, surpassing demand levels of 0.20 to 0.25.

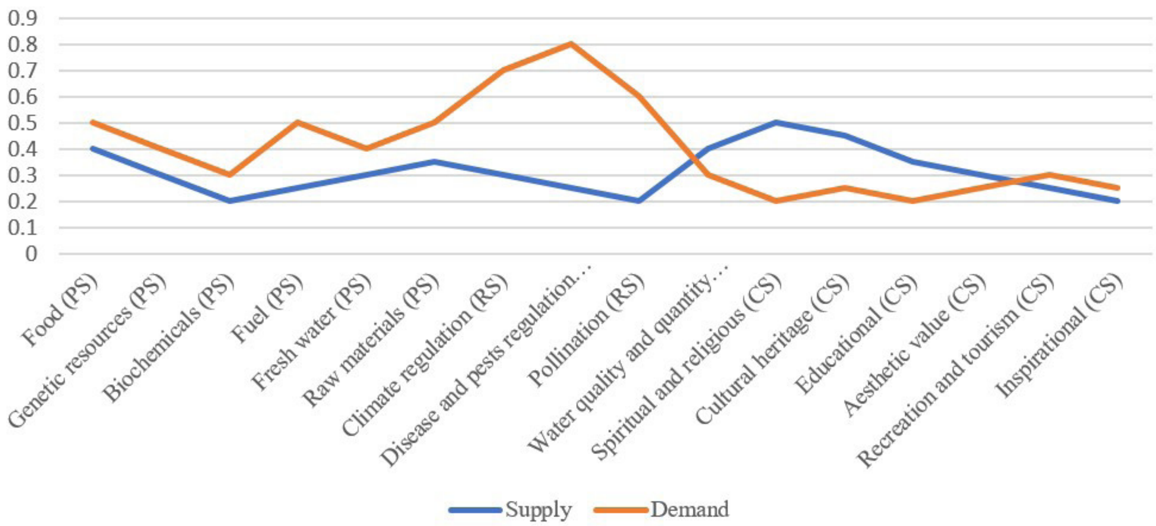

Figure 6: Comparative Analysis of Ecosystem Service Supply–Demand in Urban Sports Areas

Services like recreation, tourism, and aesthetic value are more evenly distributed, with supply and demand falling between 0.25 and 0.30.

Agricultural Land

The multidimensional performance of provisioning (PS), regulating (RS), and cultural services (CS) is depicted in the radar chart of ecosystem service supply and demand in agricultural land within urban green infrastructure (Figure 7). All values are expressed on a normalized scale ranging from 0 to 1. Overall, the findings show that demand consistently outpaces supply in almost every category of ecosystem services, indicating a structural shortfall in the provision of ecosystem services on agricultural land. Demand values range from roughly 0.20 to 0.60, whereas supply values are typically lower, ranging from roughly 0.05 to 0.35. The average deficit is about 0.15 (≈45–50%), indicating the inadequate ecological capacity of agricultural land to meet urban ecosystem service needs. The mean supply is estimated to be between 0.15 and 0.18, whereas the mean demand is between 0.30 and 0.35. Agricultural land contributes very little to the Provisioning Services (PS) category. Food supply and genetic resources, for example, show supply values of roughly 0.10–0.15 and demand levels of roughly 0.20–0.30, implying deficits of nearly 30–50%. Fuel has the biggest disparity in this category, with a shortfall of around 70% as supply stays close to 0.15 while demand approaches 0.50. Fresh water and raw materials also exhibit low supply values (~ 0.10–0.15) in comparison to demand (≈ 0.20–0.30). These results align with the functional design of agricultural land, which limits its provisioning capability by prioritizing recreation above resource production.

The gap between supply and demand is especially noticeable in the Regulating Services (RS) sector. Water quality and quantity regulation reveals a deficit of almost 75% due to the highest demand (≈ 0.60) and comparatively low supply (≈ 0.15). Additionally, pollination services show a disparity of more than 60%, with strong demand (≈ 0.40–0.45) compared to the supply of about 0.15.

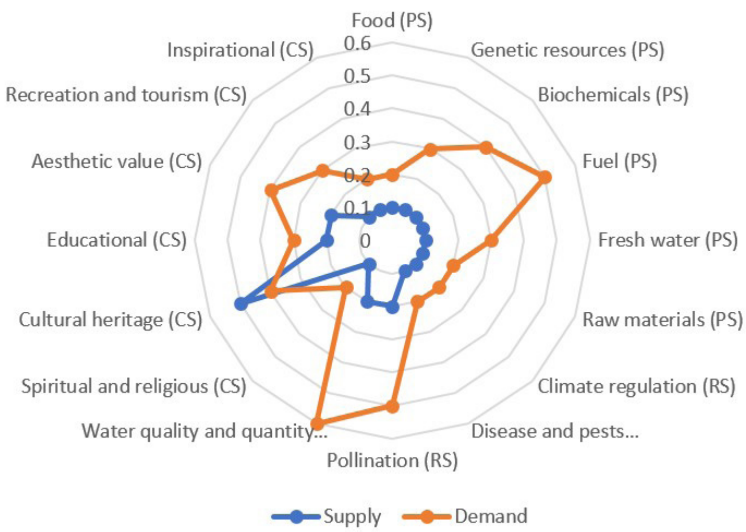

Figure 7: Radar Chart of Ecosystem Service Supply and Demand in Agricultural Land within Urban Green Infrastructure

Furthermore, supply levels (≈ 0.10–0.20) for temperature regulation and disease and pest control are minimal in comparison to demand values of 0.20–0.30.

While demand still typically outpaces supply, the picture for Cultural Services (CS) is quite varied. Within this category, cultural heritage exhibits the largest supply (≈ 0.35), surpassing demand (≈ 0.25), suggesting a localized surplus. However, services like recreational and tourism, inspirational value, and aesthetic value show demand levels of roughly 0.30–0.40 compared to supply values of only 0.10–0.20, indicating deficits of 40–60%. Similar trends are seen in educational services, where demand (≈ 0.25) exceeds supply (≈ 0.15). These results imply that although agricultural land is intended for recreational purposes, its potential to provide larger cultural ecosystem services has not yet been fully realized.

Degraded Areas

With values expressed on a normalized scale ranging from 0 to 1 (and occasionally slightly above for demand), the bar chart of ecosystem service supply and demand in degraded areas within urban green infrastructure provides a comparative assessment across provisioning (PS), regulating (RS), and cultural services (CS) (Figure 8). Overall, the results show that demand consistently and clearly outpaces supply in every category of ecosystem services, pointing to a significant ecosystem service deficit in deteriorated urban environments. Demand levels are higher, ranging from roughly 0.60 to 1.00, but supply values are roughly between 0.30 and 0.85. The decreased ecological functionality of degraded areas is shown by the mean deficit of around 0.23 (≈30%), which results from an average supply of about 0.54 and an average demand of about 0.77.

Within the provisioning services (PS) category, degraded areas demonstrate moderate yet inadequate levels of ecosystem service supply relative to demand. For example, food provision records a supply of approximately 0.60 compared to a demand of 0.80, corresponding to a shortfall of about 25%. Similarly, genetic resources and biochemicals exhibit supply levels of around 0.55 and 0.50, respectively, while demand reaches approximately 0.75 and 0.70, indicating deficits in the range of 20–30%. Fresh water shows the highest level of supply within this category (about 0.85); however, demand still surpasses this value at roughly 1.00, leaving a remaining gap of about 15%. In the case of raw materials, supply is estimated at around 0.45 against a demand of 0.70, representing a discrepancy exceeding 35%.

The differences between supply and demand are especially noticeable in the Regulating Services (RS) category, which is indicative of impaired ecological processes. Climate control reveals a deficit of roughly 38% with a supply of roughly 0.40 and a demand of 0.65. The regulation of disease and pests shows a lower but still significant discrepancy, with supply close to 0.50 and demand at 0.60. With both supply and demand at roughly 0.70, pollination services seem to be fairly balanced, indicating localized resilience in this function. The control of water quality and quantity, however, shows a notable mismatch, with supply close to 0.35 and demand around 0.60, indicating a deficit of more than 40%. These results show that the ability of degraded areas to successfully control environmental conditions is very limited.

Although supply levels are comparatively greater than those of other service categories, the pattern for Cultural Services (CS) continues to show that demand consistently exceeds supply. Spiritual and religious values show one of the biggest deficits (≈ 60%), with a supply of about 0.30 and a demand of 0.80. While educational services and aesthetic value exhibit supply values of roughly 0.55–0.60 compared to a demand of 0.75–0.80, indicating shortfalls of 25–35%, cultural heritage indicates a supply of 0.60 against a demand of 0.85. Similar patterns may be seen in recreation, tourism, and inspirational value, where supply is between 0.60 and 0.65, and demand is

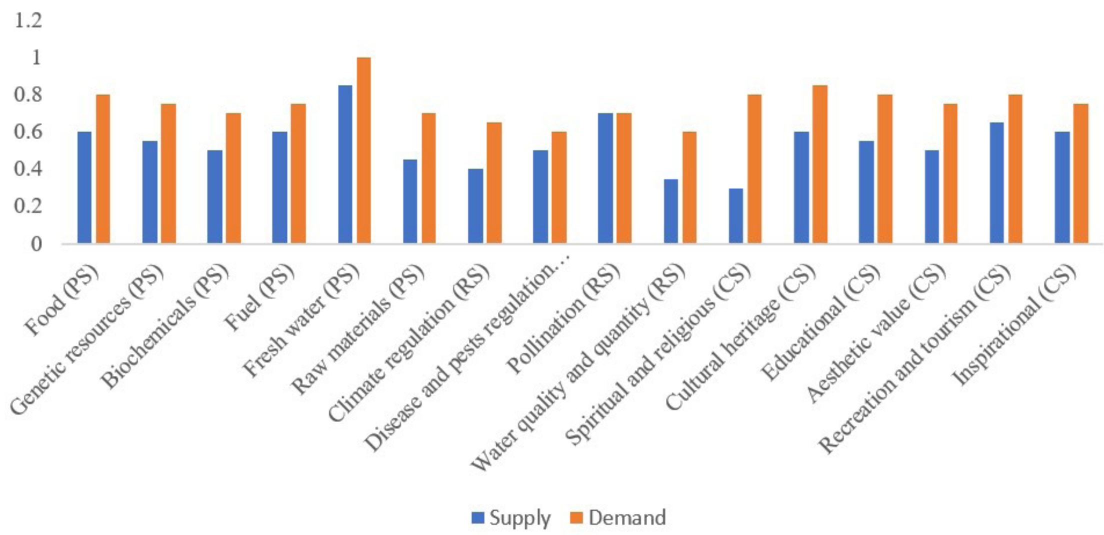

Figure 8: Ecosystem Service Supply and Demand in Degraded Areas within Urban Green Infrastructure

between 0.75 and 0.80. These findings imply that, despite deterioration, these spaces nevertheless offer certain cultural advantages, even though they don't fully satisfy user demands and expectations.

Riparian Vegetation

The stacked bar chart (Figure 9) illustrates the relative proportions of ecosystem service supply and demand associated with riparian vegetation within urban green infrastructure, disaggregated into provisioning (PS), regulating (RS), and cultural services (CS). All values are presented as percentages summing to 100%. The results show that demand consistently exceeds supply across all service categories, indicating a sustained shortfall in the ability of riparian vegetation to satisfy urban ecosystem service requirements. Supply shares generally fall within the range of approximately 20% to 45%, whereas demand occupies a larger proportion, typically between 55% and 80%. On average, supply contributes about 33–38%, compared to demand at roughly 62–67%, yielding an overall gap of approximately 25–30 percentage points and underscoring the increasing pressure on riparian ecosystems in urban settings.

Riparian vegetation exhibits moderate but inadequate supply levels under the Provisioning Services (PS) category. Food provision reveals a significant imbalance of about 40–45 percentage points, with supply of about 25–30% and demand of 70–75%. In a similar vein, supply contributions for genetic resources and biochemicals are between 25–35%, whereas demand is between 65 and 75%. Fresh water and fuel have slightly greater supply levels (≈ 35–40%), but demand still predominates at 60–65%, indicating ongoing shortages. This pattern is also seen in raw resources, where supply is close to 40%, and demand is at 60%. These results show that although riparian vegetation helps supply services, its capacity is still restricted in comparison to urban demand.

Within the regulating services (RS) category, disparities between supply and demand remain pronounced, although certain services exhibit comparatively higher levels of provision. Regulation of water quality and quantity shows a supply of roughly 30% against a demand of about 70%, indicating a gap of approximately 40 percentage points. Pollination services record the lowest supply in this category (around 20–25%), while demand reaches 75–80%, representing one of the most substantial mismatches. Disease and pest regulation appears relatively more balanced, with supply estimated at 30% compared to a demand of 70%, and a similar pattern is observed for climate regulation.

Riparian vegetation has comparatively better supply levels for Cultural Services (CS) than other categories, but demand still prevails. Cultural heritage and educational services have narrower shortfalls of 10–20 percentage points, with supply values of roughly 40–45% and matching demand levels of 55–60%. Additionally, aesthetic value shows a comparatively high supply (≈ 40%) relative to demand (≈ 60%). Recreation, tourism, and inspirational value, on the other hand, have lower supply (≈ 30–35%) compared to demand (65–70%), indicating larger disparities. Similar trends may be seen in spiritual and religious services, where supply is about 35% and demand is about 65%. These results imply that riparian vegetation is especially valued for its cultural and experiential benefits, even though societal expectations are still not met by its availability.

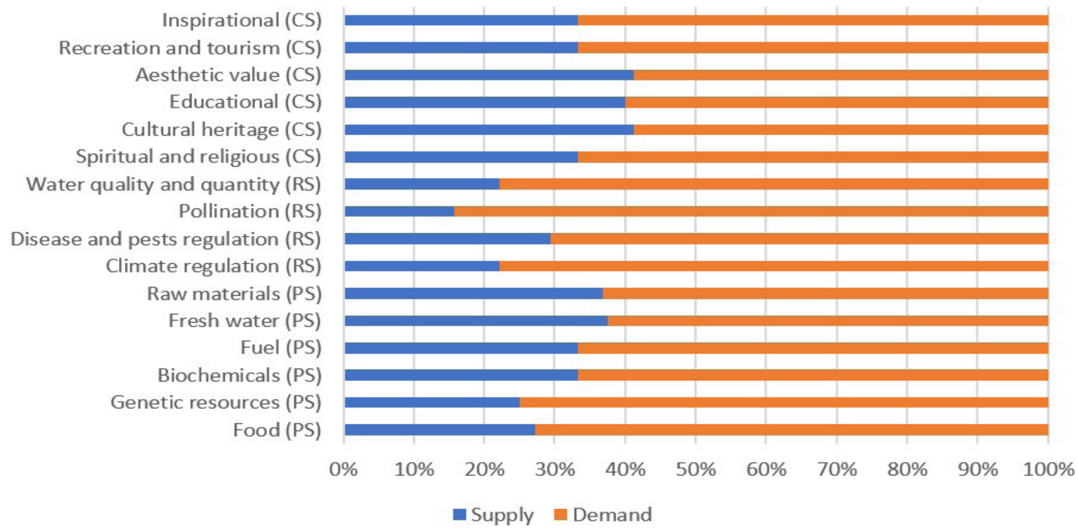

Figure 9: Stacked Bar Chart of Ecosystem Service Supply and Demand in Riparian Vegetation within Urban Green Infrastructure

Green Areas within Settlements

With values stated on a normalized scale ranging from 0 to 1, the bar chart of ecosystem service supply and demand in green spaces within settlements in urban green infrastructure provides a comparative evaluation across provisioning (PS), regulating (RS), and cultural services (CS) (Figure 10). Overall, the results show that demand consistently outpaces supply in almost every category of ecosystem services, indicating a pervasive lack of ecosystem services in settlement-based green spaces. Demand numbers are often greater, ranging from roughly 0.40 to just above 1.00, whereas supply values are roughly between 0.20 and 0. 95. There is an average shortfall of about 0.25 (≈35–40%) because the mean supply is expected to be between 0.40 and 0.45 and the mean demand is between 0.65 and 0.70.

The results indicate a moderate but inconsistent performance within the Provisioning Services (PS) category. Food provision has the highest supply (≈ 0.95) and demand (≈ 1.00), with a comparatively minor deficit of roughly 5%. This suggests that settlement green spaces may significantly influence local food provision. Other provisioning services, however, show significant gaps. For example, shortfalls approach 50% in biochemicals (supply ≈ 0.20, demand ≈ 0.60) and genetic resources (supply ≈ 0.30, demand ≈ 0.70). Fuel, fresh water, and raw materials show shortfalls ranging from 25% to 40%, with supply levels between 0.30 and 0.45 and demand levels between 0.50 and 0.65.

The disparity between supply and demand is more noticeable in the Regulating Services (RS) sector. Climate control reveals a 50% gap with a supply of roughly 0.30 and a demand of roughly 0.60. A similar pattern may be seen in the regulation of disease and pests, where deficits exceeding 50% are reflected in supply near 0.20–0.25 and demand around 0.50. Pollination services show a discrepancy of almost 40%, with a supply of roughly 0.30 and a demand of 0.70. A deficit of almost 20% is indicated by the water quality and quantity control, which displays a somewhat higher supply (≈ 0.40) but still falls short of demand (≈ 0.60).

Although demand still typically outpaces supply, green spaces within settlements perform relatively better for Cultural Services (CS). Cultural legacy demonstrates a localized excess of almost 20%, with supply of roughly 0.60 exceeding demand (≈ 0.50). The ratio between spiritual and religious values is also fairly balanced (supply = 0.50, demand ≈ 0.40). However, there are shortfalls of roughly 15–30% in other cultural services, such as educational, aesthetic value, recreational and tourism, and inspiring services, where supply values vary from 0.40 to 0.55 and demand varies from 0.55 to 0.70.

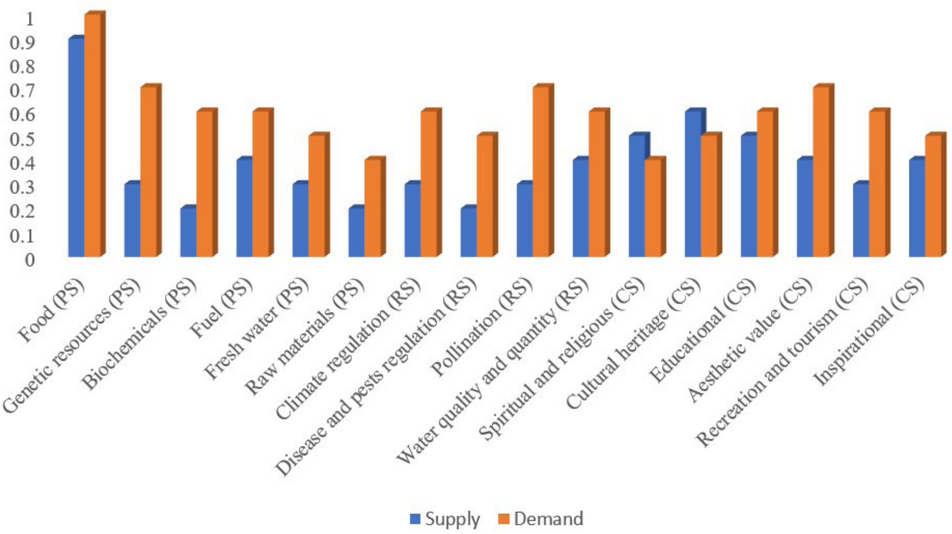

Figure 10: Ecosystem Service Supply and Demand in Green Areas within Settlements in Urban Green Infrastructure

Discussion

Parks

The results from Zanzibar's Urban-West Region show a glaring and statistically significant mismatch between the supply and demand of ecosystem services, especially when it comes to delivering and regulating services. Although the extent of the shortfalls found in this study is noticeably greater in numerous instances, this pattern is consistent with both local (African) and worldwide studies, particularly those that concentrate on urban parks and green infrastructure. International research on urban parks regularly demonstrates that, mostly as a result of urbanization pressures, demand for ecosystem services, particularly cultural and regulating services, tends to outpace supply. Research on urban parks in China, for instance, revealed that locals have high demands for services like recreation and air purification, frequently beyond what parks can offer, resulting in trade-offs among ecosystem services (Wu *et al.*, 2026). Similarly, research conducted in Bangkok shows that although parks provide services like carbon sequestration and air pollution removal, their ability to do so is mostly dependent on vegetation density and management, and it is frequently insufficient in the absence of ecological enhancement (Singkran *et al.*, 2022). These results are consistent with the study's findings, especially the deficiencies in pollination ("300% higher demand) and climate regulation (≈160% higher demand), which confirm that regulating services are usually the most limited in urban systems.

More precisely, there is a high correlation between the pollination deficits found in this study and findings from around the world. Urbanization dramatically changes pollinator diversity and decreases pollination services, particularly in densely populated areas, according to a systematic assessment by Harrison and Winfree (2015).

According to Liu *et al.* (2025), research suggests that well-managed urban parks may be able to somewhat offset this shortfall by supporting relatively high pollinator richness when the flora is structurally complex and diverse. In comparison to better-managed parks in other areas, this disparity raises the possibility that Zanzibar's substantial pollination gap is caused by either a lack of vegetation or a lack of ecological diversity in urban green spaces.

International park-based research also provides substantial support for the high demand for cultural offerings found in this study. According to studies, urban dwellers frequently place a higher demand on recreation, social interaction, and aesthetic pleasures in parks than ecological systems can sustainably supply (Li *et al.*, 2024). This is in line with the study's findings, which indicate that demand for recreational and inspirational services is somewhat higher than supply. Zanzibar's surpluses in spiritual and cultural heritage services, however, deviate slightly from worldwide patterns, where demand usually outpaces supply. Zanzibar's strong cultural identity and historical ties to landscapes, which improve the perceived and actual provision of these services even in the face of ecological stress, can account for this discrepancy.

From a local standpoint, Zanzibar's inadequacies seem to be more serious than those seen in many international case studies. Due to growing urbanization and reliance on natural resources, studies conducted in cities in Sub-Saharan Africa have revealed comparable service deficits (Li *et al.*, 2025). However, structural dependency on environmental resources and limited alternatives—which is especially severe in tiny island urban systems like Zanzibar—is reflected in the extraordinarily high relative gaps found in this study (e.g., ≈175% for raw materials and ≈140% for fuel). The results indicate that the system under study performs below the ecological potential usually seen in well-managed parks when compared specifically to urban parks as a component of urban green infrastructure. According to research, when properly planned and managed, urban parks can serve as important suppliers of ecosystem services and hotspots for biodiversity (Pandey & Ghosh, 2023). Therefore, there is a gap between the current state of affairs and the potential contribution that improved park systems and green infrastructure may make to the delivery of ecosystem services, as evidenced by the deficiencies found in Zanzibar, particularly in regulating services.

Forests

The results from Zanzibar's Urban-West Region show a distinct and systematic imbalance between the supply and demand of ecosystem services in forest-based urban green infrastructure; this pattern is well-supported in both domestic and foreign research. Similar to these findings, research conducted worldwide consistently shows that urban forests are unable to satisfy the growing demands of society, especially for cultural and regulatory functions, as a result of land-use pressure and rising urbanization (Russo & Cirella, 2024). In contrast to many other contexts, Zanzibar's urban forest ecosystems appear to be under more pressure due to the size of the deficits found in this study, particularly when demand approaches 0.8–1.2 while supply stays below 0.6.

The significant gaps in Cultural Services (CS) found in this study (such as deficiencies of more than 50–60% in recreation, aesthetic, and spiritual services) are in line with results from urban forest studies conducted worldwide. According to research, metropolitan populations frequently surpass the biological supply of woods due to their high demand for recreation, mental health, and aesthetic experiences (Crean *et al.*, 2024). The greater deficits seen in Zanzibar, however, point to restricted accessibility, inadequate forest covering, or poor urban forest infrastructure, whereas many overseas studies show generally balanced or mildly deficit circumstances because of well-developed park systems. There is a management and planning gap between Zanzibar and more established urban systems, as research conducted in European cities show that well-managed urban forests may provide a significant amount of recreational demand (Kumar *et al.*, 2023).

International data significantly supports the substantial discrepancies shown in this study for Regulating Services (RS), especially in pollination (demand ≈1.1–1.2 vs. supply ≈0.5), climate regulation (≈1.0 vs. 0.4), and disease regulation (≈0.9 vs. 0.3). Urbanization dramatically diminishes forests' ability to maintain biological processes, support biodiversity, and regulate the temperature, according to studies (Huang *et al.*, 2025). However, Zanzibar's deficits are significantly greater than those of cities with vast and interconnected urban trees, where regulating services can be partially maintained. This implies that ecological functionality may be limited by urban forest fragmentation, degradation, or low vegetation density. Similar issues have been documented in Africa, where fuelwood exploitation and land conversion frequently cause urban forests to deteriorate (Ale *et al.*, 2025), supporting the trends found in our study.

The results in the Provisioning Services (PS) category exhibit a mixed trend, which is likewise consistent with the literature. In contrast to numerous worldwide studies, where urban forests usually have a limited role in food production, there is an observed excess in food provision (supply ≈1.6 surpassing demand ≈1.0) (Jensen *et al.*, 2021). This implies that urban woods in Zanzibar may be used more directly for informal food production or sustenance, reflecting the socioeconomic circumstances and reliance on natural resources of the area. However, the fuel (≈55%) and biochemicals (≈75%) shortages are in line with research from Sub-Saharan Africa, where urban populations rely significantly on forest resources for materials and energy, frequently surpassing sustainable supply limits (Ale *et al.*, 2025). The Zanzibar scenario illustrates increased reliance and susceptibility in contrast to global settings where other energy sources lessen the strain on forests.

The findings imply that forests in Zanzibar's urban green infrastructure are not performing to their full potential when compared specifically to urban parks and managed forest systems. According to studies, when supported by appropriate design and biodiversity protection, well-managed urban parks and forests can greatly improve the provision of ecosystem services, especially for regulating and cultural services (Jamean *et al.*, 2023). Therefore, the greater deficiencies found in this study indicate a discrepancy between the existing state of affairs and the possible advantages that could be attained by better management, restoration, and growth of urban forest cover.

Allotment Garden

The results from Zanzibar's Urban-West Region show a systematic mismatch between the supply and demand of ecosystem services in allotment gardens; this trend is in line with both domestic and foreign research on urban green infrastructure. The observed mean deficit of roughly 0.17 (≈22%), where demand (≈0.78) surpasses supply (≈0.61), is consistent with studies from around the world indicating that while allotment gardens are multipurpose systems, their ecological capacity frequently lags rising urban demand (Kwartnik-Pruc & Droj, 2023). However, the deficits seen in Zanzibar appear somewhat higher than in studies conducted in European cities, where allotment gardens frequently achieve more balanced supply–demand relationships because of structured management and policy support. This suggests context-specific limitations like land scarcity, management constraints, and a greater reliance on ecosystem services.

Allotment gardens are well known globally for their role in supporting biodiversity, providing food, and providing cultural ecosystem services. Allotment gardens can provide comparatively high levels of provisioning and cultural services, frequently eliminating supply–demand gaps through rigorous management and community engagement, according to studies conducted in places like Stockholm and Berlin (Haase & Gaeva, 2023). The Zanzibar data, on the other hand, demonstrate that supply continually falls short of demand across all parameters, even while it reaches moderate levels (≈0.45–0.75). Even in cases where ecosystem service provision is quite strong, user demand quickly matches or surpasses it, as indicated by the biggest shortfalls (≈30%) found in indicators 6 and 7. This is consistent with research from other fast-urbanizing areas, where overuse of small-scale green spaces is driven by growing population pressure (Kwartnik-Pruc & Droj, 2023).

International literature also supports the positive co-variation between supply and demand found in this study. According to research, successful allotment gardens typically draw more visitors and more demand, which puts additional strain on ecosystem services (Flores *et al.*, 2026). Your results clearly show this dynamic, especially for indicators 10–16, where higher supply (≈0.70–0.75) corresponds with higher demand (≈0.80–0.90). This illustrates the appeal and versatility of allotment gardens, but it also points to a self-reinforcing cycle of demand that, if improperly managed, may restrict sustainability. Similar patterns have been observed in urban agriculture systems around the world, where increased accessibility and productivity result in increased consumption and resource pressure (Mishra, H., 2025).

The findings are in line with research demonstrating that urban agriculture systems, such as allotment gardens, are essential for livelihoods but function under severe ecological and spatial restrictions from a local and Sub-Saharan African viewpoint (Mhlanga *et al.*, 2025). However, because of its island setting, where land is scarce and reliance on local ecosystem services is greater, the Zanzibar instance probably faces more pressure than mainland towns. This could be the reason that even very high supply levels (≈0.70–0.75) do not result in demand equilibrium. Zanzibar's allotment gardens are more dependent on local ecological processes, which makes them more susceptible to abuse than in some international contexts where external resource inputs can replenish ecosystem services.

Sports Areas

Sports spaces within urban green infrastructure show a moderate but continuous mismatch between ecosystem service supply and demand, with an average shortfall of about 0.08 (≈19%), according to research from Zanzibar's Urban-West Region. While sports areas contribute to the provision of ecosystem services, their ecological usefulness is frequently secondary to their primary recreational role, according to both local and international studies (Remme *et al.*, 2021). This pattern is mostly consistent with these findings. However, the deficiencies found in Zanzibar indicate insufficient ecological optimization and increased pressure on multifunctional land use when compared to more carefully managed urban green areas in developed regions.

The comparatively low supply levels (≈0.20–0.40) in the Provisioning Services (PS) category in comparison to demand (≈0.30–0.50) are consistent with worldwide findings that sports areas are not built to deliver material resources like food, fuel, or raw materials (Zbiljić & Isaković, 2025). Recreational green spaces, which are usually characterized by controlled lawns and sparse productive plants, have been found to contribute very little to provisioning in European and Asian cities (Remme *et al.*, 2021). However, Zanzibar's somewhat higher demand is indicative of a larger reliance on local ecosystem services; this tendency has also been noted in cities in Sub-Saharan Africa, where urban inhabitants depend increasingly directly on adjacent green spaces for a variety of needs (Mohamed, M. K., 2025). In resource-constrained urban environments, where even unproductive spaces are expected to contribute to service providing, this difference emphasizes the context-specific importance of sports areas.

International literature clearly supports the significant deficits shown in this study for Regulating Services (RS), especially in pollination (≈70% deficit), disease and pest regulation (≈57% deficit), and climate regulation (≈30%). According to research, sporting grounds have a limited capacity to support biodiversity and ecological processes since they are frequently dominated by monoculture grass and have low flora diversity (Cunninghame & Stanley, 2024). This accounts for the observed low supply levels (≈0.25–0.35) in contrast to the higher demand (≈0.50–0.80). However, research showing that open green spaces can improve stormwater infiltration and reduce runoff even when biodiversity is low are consistent with the result that water quality and quantity control shows a modest surplus (supply ≈0.40 vs. demand ≈0.30) (Mohamed, M. K., 2025). The Zanzibar results indicate partial functionality but overall underperformance when compared to international situations where green infrastructure is purposefully constructed to optimize regulating functions. This is probably because ecological design concepts were not fully integrated.

On the other hand, both local and international data support the excellent performance of Cultural Services (CS), which includes notable surpluses in spiritual, cultural heritage, and educational services. Research indicates that recreational green spaces and sports areas are highly appreciated for social contact, physical activity, and psychological well-being, and they frequently provide significant levels of cultural ecosystem services (Feng *et al.*, 2025). The socio-cultural setting of Zanzibar, where open spaces frequently serve many societal and cultural activities beyond formal recreation, may have a specific impact on the observed excess in spiritual and religious values (≈150% higher supply than demand). Nonetheless, the comparatively balanced circumstances for recreation and aesthetic value (≈0.25–0.30) indicate that rising urban demand is starting to equal available supply, a pattern also seen in densely populated cities across the globe.

Agricultural Land

With an average deficit of roughly 0.15 (≈45–50%), the results from Zanzibar's Urban-West Region show a significant and systematic mismatch between ecosystem service supply and demand in agricultural land under urban green infrastructure. This tendency is in line with research from both domestic and foreign sources, which demonstrate that urban and peri-urban agricultural systems frequently experience significant demand pressures while functioning within limited ecological capacity (Fantini, A., 2023). However, the size of the shortfall found in this study is rather large, indicating that Zanzibar's agricultural land is not functioning to its full potential. This is probably because of land constraints, management techniques, and conflicting urban land uses. In contrast to many international studies, where agricultural land is usually the primary contributor to food and material production within urban green infrastructure, the Provisioning Services (PS) category's relatively low supply values (≈0.10–0.15) compared to demand (≈0.20–0.30) (Evans *et al.*, 2022). The observed shortages of 30–50% for food supply and up to 70% for fuel indicate that Zanzibar's agricultural land is either not managed intensively for production or is limited by urban pressures such soil degradation and land fragmentation. Similar trends have been shown in Sub-Saharan Africa, where urban agriculture greatly boosts livelihoods but frequently falls short of demand because of insufficient inputs, water scarcity, and unstable land tenure (Vidal Merino *et al.*, 2021). This is in contrast to research from cities in Europe and Asia, where urban agriculture systems are more productive as a result of policy assistance and technical inputs, leading to fewer supply-demand mismatches.

International literature also provides substantial support for the Regulating Services (RS) deficits found in this study, namely in water regulation (≈75% deficit), pollination (≈60% deficit), and climate regulation. Research indicates that urban agricultural land with low vegetation diversity and monoculture methods frequently has a poor ability to provide regulating services (Evans *et al.*, 2022). The extremely low supply values (≈0.10–0.20) compared to demand (≈0.20–0.60) suggest that Zanzibar's agricultural landscapes are more like simplified production systems with less ecological complexity than multifunctional ecosystems. The Zanzibar case illustrates limited integration of biodiversity-friendly practices, thereby limiting ecosystem service delivery, in contrast to agroecological systems in some global contexts where practices like crop diversification and agroforestry enhance regulating services (Rapiya *et al.*, 2024).

The study's mixed trend for Cultural Services (CS) is also in line with more general conclusions. Agricultural land in Zanzibar appears to have cultural and historical significance, as indicated by the localized surplus in cultural heritage (supply ≈0.35 vs. demand ≈0.25). This is also reported in other African and Asian contexts where farming landscapes are closely linked to identity and tradition (Omar, H. M., 2020). In contrast to many worldwide situations where urban agriculture is integrated with recreation and tourism, these landscapes are not optimized for multifunctional usage, as evidenced by the shortages in aesthetic, recreational, and inspiring services (≈40–60%) (Hassan *et al.*, 2022). This disparity implies that although Zanzibar's agricultural land still has cultural significance, its wider social and recreational potential is still underdeveloped.

Degraded Areas

The results from Zanzibar's Urban-West Region show that there are significant ecosystem service deficits in degraded regions of urban green infrastructure, with an average gap of roughly 0.23 (≈30%), where demand (≈0.77) often outpaces supply (≈0.54). Degraded urban landscapes generally experience lower ecological functionality and diminished potential to deliver ecosystem services, according to both local and international studies, which substantially confirm this pattern (Pandey & Ghosh, 2023). However, the deficits seen in Zanzibar are still comparatively severe when compared to several situations around the world where restoration measures have improved service provision; this suggests limited rehabilitation and ongoing ecological pressure.

The moderate but insufficient supply levels (≈0.45–0.85) in the Provisioning Services (PS) category are consistent with findings that degraded lands may still have residual productive capacity, especially for fundamental resources like water and biomass (MEA, 2005). Localized ecosystem resilience is suggested by the comparatively high fresh water supply (≈0.85) in comparison to other services. This has also been observed in certain degraded environments where hydrological functions continue despite ecological deterioration (Granata & Di Nunno, 2026). However, the persistent shortages in all provisioning services, especially in food (≈25%) and raw materials (≈35%), show that these systems cannot meet the increasing urban demand. This trend is also seen in cities in Sub-Saharan Africa, where degraded land is frequently overused for subsistence needs (Tefera *et al.*, 2024). The Zanzibar scenario indicates ongoing pressure without enough restoration inputs, in contrast to international situations where degraded lands are occasionally restored for productive use.

According to research from around the world, the deficiencies in Regulating Services (RS) are very large and represent impaired ecological processes. According to studies, land degradation results in decreased biodiversity, decreased soil fertility, and loss of vegetation cover, all of which hinder ecosystem regulating processes like pollination, water regulation, and climate control (Ekka *et al.*, 2023). The deficiencies in water regulation (≈40%) and climate regulation (≈38%) found in this study are similar to those found in degraded urban settings across the globe. However, given that most research record significant pollination losses in degraded habitats, the somewhat balanced condition for pollination services (≈0.70 supply and demand) is quite unusual (Cardoso *et al.*, 2026). This could point to remnant vegetation areas or specific ecological niches in Zanzibar that continue to sustain pollinator activity. However, the general pattern indicates that the ability of degraded regions to control environmental conditions is severely limited, especially when compared to intact ecosystems or well-managed urban green spaces.

The results show that while demand for Cultural Services (CS) is still much higher, these regions continue to offer reasonable levels of cultural benefits despite decline. This is in line with global research that demonstrates the social and cultural significance of even damaged landscapes, especially in highly populated urban areas with limited access to green space (Ahn & Juraev, 2023). The significant gaps in cultural heritage and aesthetic value (≈25–35%) and the significant deficiency in spiritual and religious services (≈60%) indicate that although these places are still used, their quality and user expectations are not met. By contrast, research from Europe and Asia shows that well-managed or restored green areas can greatly improve cultural ecosystem services and lessen these deficiencies (Dinca *et al.*, 2026). The Zanzibar case illustrates how environmental deterioration affects both the perceived and real quality of cultural offerings.

Riparian Vegetation

The results from Zanzibar's Urban-West Region show that riparian vegetation in urban green infrastructure is under a lot of stress, with demand continuously outpacing supply in every category of ecosystem services. The observed mean deficit of roughly 25–30 percentage points indicates a significant imbalance, which is in line with global data demonstrating that urban riparian systems are frequently in high demand but ecologically limited as a result of land-use change and urban encroachment (Napoletano *et al.*, 2025). However, the Zanzibar data indicate lower ecological performance, probably due to degradation, fragmentation, and insufficient buffer protection, in contrast to well-protected riparian corridors in certain developed countries, where supply can approach or even meet demand.

The Provisioning Services (PS) category's moderate supply levels (≈20–45%) in comparison to high demand (≈55–80%) are consistent with worldwide findings that riparian zones produce crucial but frequently supplemental resources such raw materials, fuelwood, and water (MEA, 2005). In contrast to agricultural or allotment systems, riparian systems in urban areas are rarely managed for intense production, which is compatible with the considerable deficiencies seen for food provision (≈40–45 percentage points) and biochemicals (Napoletano *et al.*, 2025). Similar patterns have been observed in Sub-Saharan Africa, where riparian vegetation is used for subsistence but is still insufficient to supply rising urban demand because of land pressure and overexploitation (Nyambo *et al.*, 2024). The Zanzibar setting shows a larger reliance on these ecosystems without comparable management support when compared to international situations where riparian buffers are protected and regulated.

Given that riparian ecosystems are generally acknowledged as essential providers of regulating functions, such as water purification, flood control, and habitat connectivity, the deficits found in this study, particularly in water regulation (≈40 percentage points) and pollination (≈50–55 percentage points), are particularly significant for Regulating Services (RS) (Dinca & Lupoae, 2025). Riparian zones are frequently highlighted in international studies as ecological "hotspots" that, when intact, can provide high amounts of regulating functions. As a result, Zanzibar's comparatively low supply levels (≈20–30%) point to deteriorated ecological circumstances, such as pollution, plant clearance, or hydrological modification. This is in contrast to research from areas where restored riparian buffers greatly improve biodiversity and water quality, closing supply-demand gaps (Majumdar & Avishek, 2025). Therefore, rather than systemic constraints, the Zanzibar data suggest underused ecological potential.

The comparatively greater supply levels (≈30–45%)

and smaller shortages (≈10–30 percentage points) in the Cultural Services (CS) category align with global trends indicating that riparian habitats are highly valued for recreation, aesthetics, and cultural identity (Downey *et al*., 2022). Even in the face of ecological stress, these landscapes appear to preserve social and experiential significance, as evidenced by the smaller gaps in cultural heritage and educational services. However, it appears that growing urban demand is outpacing these organizations' capacity to deliver high-quality experiences, as evidenced by the larger shortcomings in recreational and inspirational offerings. The Zanzibar case indicates limited infrastructure and planning integration, which limits the realization of full cultural benefits, in contrast to international examples where riparian corridors are integrated into urban park systems and greenways, improving accessibility and functionality (Juma, 2020).

Green Areas within Settlements

With an average ecosystem service deficit of roughly 0.25 (≈35–40%), the results from Zanzibar's Urban-West Region demonstrate that green spaces within settlements serve as crucial yet overworked components of urban green infrastructure. This tendency is in line with research conducted both domestically and internationally, which shows that residential areas' small, scattered green spaces are heavily used yet have limited ecological potential (Wei *et al*., 2025). The Zanzibar results, however, point to a more noticeable imbalance when compared to planned residential green systems in many major cities. This imbalance is probably caused by higher population density, informal land-use patterns, and limited spatial allocation for green infrastructure.

The comparatively good performance of food provision (≈0.95 supply vs. ≈1.00 demand) in the Provisioning Services (PS) category contrasts with other worldwide studies where settlement green spaces usually contribute very little to food production (Walsh *et al*., 2022). This suggests that household green spaces in Zanzibar are actively utilized for sustenance, reflecting the socioeconomic circumstances and dependence on local resources. Similar trends have been seen in Sub-Saharan African cities, where urban agriculture at the family level is crucial to food security (Sangwan & Tasciotti, 2023). In contrast to more diverse urban green systems documented in international contexts, the significant deficiencies in other provisioning services, especially genetic resources and biochemicals (>50%), imply that these spaces are functionally limited and lack ecological diversity (Semeraro *et al*., 2021).

The biological constraints of settlement-based green spaces are further highlighted by the Regulating Services (RS) deficiencies found in this study. The notable deficiencies in disease regulation (>50%), pollination (≈40%), and climate regulation (≈50%) align with worldwide observations that tiny and dispersed green spaces are less able to sustain biological processes and biodiversity (Kowe *et al*., 2021). On the other hand, cities with more complex vegetation and integrated green networks frequently claim better regulating service delivery (Caldarelli *et al*., 2025). According to studies on urban ecosystems, even a little amount of green cover can help reduce runoff and stormwater infiltration (Kowe *et al*., 2021). This is confirmed by the comparatively smaller shortfall in water control (≈20%). Overall, the Zanzibar data indicate a system in which the quality and connection of green spaces, in addition to their size, limit ecological functionality.

The results suggest that settlement green spaces have a disproportionately significant social and cultural significance in the Cultural Services (CS) category, with some services exhibiting balance or even surplus. The integration of green spaces into daily social and cultural practices is reflected in the near balance of spiritual services and the surplus of cultural heritage (≈20%), both of which are frequently observed in African urban environments (Melaku & Pastor Ivars, 2024). However, user expectations are increasing more quickly than advances in the quality and accessibility of green spaces, as seen by the continuous deficiencies in recreation, aesthetic, and educational services (≈15–30%). In contrast, research from around the world indicates that when infrastructure, upkeep, and inclusive planning are provided, well-designed residential green spaces can provide significant levels of cultural services (Ashinze *et al*., 2024). The story of Zanzibar illustrates a situation in which planning and investment fall behind demand despite a high level of cultural dependency.

CONCLUSION

The study's findings show that, in the Urban-West Region of Zanzibar, ecosystem service supply and societal demand are consistently out of balance across all forms of urban green infrastructure (UGI), with demand typically outpacing supply. This mismatch is especially noticeable in regulating services, such as pollination, disease management, and climate regulation, suggesting a limited ecological capacity to maintain environmental functions under growing urban demand. The performance of provisioning services is uneven, with ongoing shortages of fuel, raw materials, and biochemicals but comparatively robust food provision in other areas, such as settlement green spaces and allotment gardens. With some instances of balance or surplus, especially in spiritual and heritage values, cultural services perform relatively better, underscoring the critical role that urban green areas play in promoting social well-being. Even in this category, though, demand frequently outpaces supply due to increasing population pressure and increased utilization of the green places that are available. These results are in line with worldwide patterns seen in quickly urbanizing areas, where ecological degradation, land-use change, and urban growth limit ecosystems' ability to provide services while demand keeps rising. However, the extent of deficiencies found in Zanzibar points to context-specific issues, such as little land, dispersed green areas, and inadequate UGI inclusion into urban planning frameworks. Differences in land-use types also show that some systems are socially desirable but biologically limited, whereas others have ecological potential but are limited by deterioration. These findings highlight the necessity of focused interventions to improve ecosystem service provision and promote sustainable urban development in coastal and small island cities, such as ecological restoration, better spatial planning, and the adoption of multifunctional green infrastructure approaches.

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