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GREEN INFRASTRUCTURE DEVELOPMENT AND ITS ROLE IN CLIMATE CHANGE ADAPTATION: EVIDENCE FROM TARCHA TOWN, SOUTHWEST ETHIOPIA

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Abstract

This study assesses the development of green infrastructure (GI) and its role in climate change adaptation in Tarcha Town, Dawuro Zone, Southwest Ethiopia. The research examined the status, institutional capacity, community perception, and climate adaptation functions of GI. Using A mixed-methods approach involving household surveys (142 respondents), key informant interviews, focus group discussions, field observation, GIS mapping, and i-Tree canopy assessment was adopted for the research. Results show that GI elements such as urban trees, green belts, parks, and watershed buffer zones are limited in coverage and poorly managed. Institutional performance is constrained by weak coordination, limited budget, lack of technical expertise, and absence of clear GI implementation strategies. Community members recognize climate-related challenges (heat stress, flooding, erosion) and acknowledge the ecological services of GI, including micro-climate regulation, soil stabilization, and storm-water control. The study concludes that GI has substantial potential for strengthening local climate resilience but requires improved planning, stronger institutional frameworks, and community participation. Policy recommendations include integrating GI into urban planning, establishing maintenance guidelines, enhancing stakeholder collaboration, and increasing investment in sustainable urban ecosystem management.

Keywords: *Green infrastructure, Climate change adaptation, Urban ecosystem, Vegetation cover*

Introduction

Rapid urban development over recent decades has led to significant loss of forests, farmland, and open spaces, contributing to declining environmental quality and reduced well-being of urban residents. These challenges are becoming more severe when combined with the growing impacts of climate change, including increased temperatures, flooding, and water scarcity. Despite these realities, there is limited local-level information on the environmental consequences of urban expansion, particularly regarding the role of green infrastructure (GI) in climate change adaptation. This study addresses this gap by assessing the status of green infrastructure development and community perceptions of its role in climate change adaptation in Tarcha Town, Southwest Ethiopia.

Globally, urbanization has intensified environmental pressures. According to United Nations (2012), more than half of the world's population now resides in urban areas, with the fastest growth occurring in developing countries. Urban expansion not only changes landscape configurations but also drives increased ecological footprints (Zhang, 2025). Urbanization is closely linked with climate change as it increases pressures on housing, transportation, sanitation, and resource consumption while simultaneously requiring cities to manage climate-induced risks such as heat waves, droughts, and extreme rainfall events (Clark, 2009). African cities, in particular, are highly vulnerable to urban flooding, drought, and water scarcity, making climate-resilient urban planning essential.

Urban green infrastructure elements — such as parks, urban forests, and wetlands — have been shown to provide a wide range of ecosystem services, including temperature regulation, flood mitigation, air purification, biodiversity support, and recreational opportunities (Sokolova, 2024). However, many African cities have experienced rapid loss of green resources due to unplanned development and weak land-use control (Marie, 2014). In Ethiopia, urbanization has been associated with numerous environmental problems, including urban sprawl, solid and liquid waste pollution, illegal settlements, and degradation of green and open spaces (Thomas, 2013). These pressures have reduced the ecological, social, and economic functions of urban green areas, contributing to rising urban temperatures and declining air and water quality.

Tarcha Town, the administrative center of Dawuro Zone, is an example of a rapidly urbanizing secondary town facing these environmental challenges. With a growing population and expanding built-up areas, the town has experienced significant loss of green spaces and increasing exposure to climate-related hazards such as flooding and heat stress. Ayichew (2014) determined that, although town development plans allocate land for green and open spaces, these areas are increasingly converted to other land uses, affected by erosion, or used as informal waste disposal sites. Furthermore, the town lacks adequate recreational areas and public green spaces.

The relevance of this study lies in its contribution to sustainable urban development and climate resilience planning. By assessing the status of green infrastructure, institutional capacity, stakeholder involvement, and community perceptions, the research provides evidence to support improved urban planning and environmental management. The study's scope focuses on Tarcha Town, covering an area of 1,032 hectares with 2,270 households across two kebeles and fourteen sub-kebeles. The findings are intended to support planners, policymakers, and development practitioners in integrating green infrastructure into urban development strategies to enhance climate change adaptation and improve urban living conditions.

Description of the Study Area

Tarcha Town is the administrative capital of Dawuro Zone in the Southwest Ethiopia Peoples Regional State. It was established in 2000 and obtained municipal status in 2005, later becoming one of the region's reform towns in 2006. The town is located about 550 km southwest of Addis Ababa and 360 km west of Hawassa City, at approximately 7°14′ N latitude and 37°05′ E longitude, covering a total area of 1,032 hectares (DZUDHD, 2016). The town lies within the tropical (Kolla) agro-climatic zone, at elevations ranging from 1,200 to 1,450 meters above sea level. It experiences relatively high temperatures, with mean annual temperatures between 25.1 °C and 27.5 °C, and receives an average annual rainfall of about 2,271.6 mm (Tarcha Town Administration, 2014).

According to the 2007 national census, Tarcha Town had a projected population of 22,717 people living in 2,270 households, with a relatively young and productive population structure (DZUDHD, 2016). The local economy is predominantly mixed, with trade, small-scale manufacturing, agriculture, and livestock rearing as major activities. The town also serves as a political, administrative, educational, health, and tourism center, supporting regional governance, social services, and development.

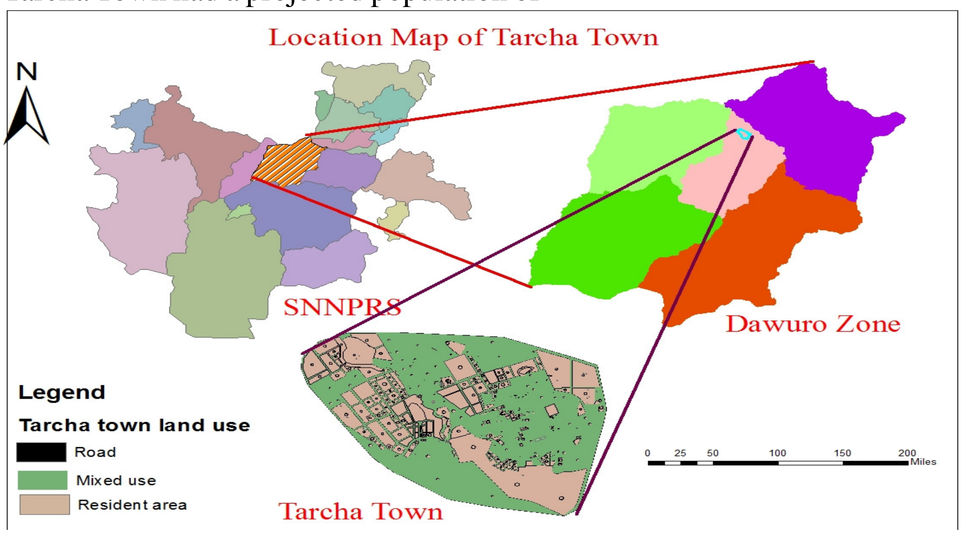

Fig. 1: Location map of Tarcha town

Methodology

This study adopted a comprehensive research methodology designed to assess the status of green infrastructure (GI) development in Tarcha Town and examine its contribution to climate change adaptation (CCA). The methodology combines both qualitative and quantitative approaches to generate a multidimensional understanding of GI distribution, institutional performance, stakeholder engagement, and community perceptions.

Research Approach

Research problems related to environmental systems and community perceptions require a methodological approach that integrates numerical evidence with human experience. For this reason, a mixed research approach was employed, incorporating both quantitative and qualitative methods. The quantitative component provided measurable data on land cover, vegetation distribution, and GI status using Geo-spatial tools, while the qualitative component captured insights from institutions, experts, and local residents regarding GI management and its climate adaptation role.

A survey strategy formed the core of the approach, as it is widely used in social and environmental studies to collect data from a representative population sample. The survey strategy helped answer the research questions by enabling generalization from the sampled households to the broader urban population. This approach is particularly appropriate for examining perceptions, participation levels, and institutional practices related to GI in the study area.

A descriptive case study design was employed, focusing specifically on Tarcha Town. This method enabled an in-depth examination of GI development patterns and institutional arrangements in a defined urban context. As a case study, it relied on a longitudinal perspective, assessing selected indicators - such as green cover, municipal budget trends, and institutional performance - over time. The methodology aimed to describe the actual development trajectory of GI in the town, the level of stakeholder involvement, and the extent to which GI is perceived as a climate adaptation tool by the community.

This method does not attempt to cover every detail of the town's environmental system but rather focuses on key aspects related to GI status, institutional capacity, participation mechanisms, and community understanding. Such targeted analysis is necessary to generate relevant findings for planning and decision-making.

Methods of Data Collection

A variety of complementary data collection methods were used to ensure the validity and richness of the findings.

Quantitative Data Collection

Quantitative data were primarily used to assess the status and spatial distribution of GI. The following tools were employed. GIS (Geographic Information System) to analyze spatial data and generate GI distribution maps, Google Earth satellite imagery to interpret land-use features and i-Tree Canopy to statistically estimate vegetation cover, built-up areas, roads, and bare land through random point sampling. Together, these tools enabled a precise assessment of vegetation cover and land-use patterns, providing crucial data for understanding ecological change.

Qualitative Data Collection

Qualitative data were collected to examine institutional development, stakeholder involvement, and community perceptions. The following techniques were used. Questionnaires distributed to randomly selected households to gather information on participation in GI activities, perceptions of GI benefits, and awareness of climate change adaptation. Key informant interviews with government officials, environmental experts, and administrators from six key departments involved in GI development. Focus group discussions (FGDs) with community representatives, including Eder leaders, religious leaders, elders, and local residents, to obtain detailed perspectives on GI and climate adaptation. Field observation to validate land-use patterns, assess GI conditions, and observe management practices on the ground. This combination of qualitative methods strengthened the robustness of the findings and complemented the quantitative evidence.

Sample Design

Population

The study population consisted of 2,270 households in Tarcha Town, as well as experts and administrative officials responsible for urban development and environmental management. Households were chosen because they represent the fundamental social unit and are directly involved in local environmental practices. Officials and experts were selected due to their roles in planning, decision-making, and GI implementation.

Sampling Frame

The sampling frame included 1,163 household heads from seven selected sub-kebeles. These sub-kebeles were chosen because households were assumed to be homogeneously distributed. Additional sampling units included 18 experts and officials purposively selected from six GI-related offices, and 8 participants selected for FGDs.

Sampling Unit

The primary sampling units were individual household heads. Institutional units included officers from the municipal planning office, land administration, beautification and environmental development, sanitation, agricultural extension, and environmental protection offices. Community leaders served as units for qualitative inquiry.

Sampling Technique

A combination of probability and non-probability sampling was applied:

Simple random sampling was used to select household respondents for the questionnaire survey. This ensured equal chance of selection and reduced bias. Purposive sampling was used for key informants and FGD participants, targeting individuals with relevant knowledge, responsibilities, and experience in GI development. This mixed technique ensured both representativeness and depth of information.

Sample Size

The sample size for households was determined using Kothari's (2004) formula for finite population sampling. With a confidence level of 93% and a 7% margin of error, the required household sample size was calculated as:

n = 146 households

Including 13 officials and 8 FGD participants, the total number of study participants was 163.

Sources of Data

Primary data were obtained through questionnaires, interviews, FGDs, and field observation. Secondary data included municipal documents, planning reports, Google Earth images, aerial photos, and GI development guidelines. These sources provided essential background information and helped triangulate the primary findings.

Data Analysis and Interpretation

Quantitative data were coded and analyzed using SPSS, Excel, ArcGIS, and i-Tree Canopy. Descriptive statistics such as frequencies, percentages, and tables were generated. Qualitative data were analyzed through thematic classification and narrative interpretation. The i-Tree analysis involved classifying 600 randomly generated points, of which 137 represented tree or forest cover, producing an estimated 23% vegetation cover with a standard error of 0.03%.

Interpretation integrated all data sources to derive conclusions about GI development, institutional performance, and community perceptions, forming the basis for recommendations.

Results

Vegetation Cover and Land-Use Composition

Table 1: The vegetation cover and land-use composition in Tarcha Town.

Land-use / Vegetation class	Description	Area share (%)
Tree cover / Urban forest	Scattered trees, roadside trees, institutional compounds, homestead trees	18.6
Shrub and grass cover	Open grasslands, shrubs, vacant vegetated plots	21.4
Agricultural land	Urban and peri-urban cultivated land	14.8
Built-up area	Residential, commercial, public buildings, paved surfaces	34.2
Bare land	Exposed soil, construction sites, degraded open areas	9.1
Water bodies	Streams, drainage channel, ponds	1.9
Total		100

Table 2: Land-Cover Classes in Tarcha Town

Cover class	Description	For the year 2007		For the year 2017	
		Points	Percent cover	Points	Percent cover
Forest and tree	Tree canopy cover	189	31.5	137	22.8
Bare land	Open areas	326	54.3	295	49.2
Pavement	Streets and impermeable areas	31	5.2	78	13
Built up	Construction areas	54	9	90	15
		600	100	600	100

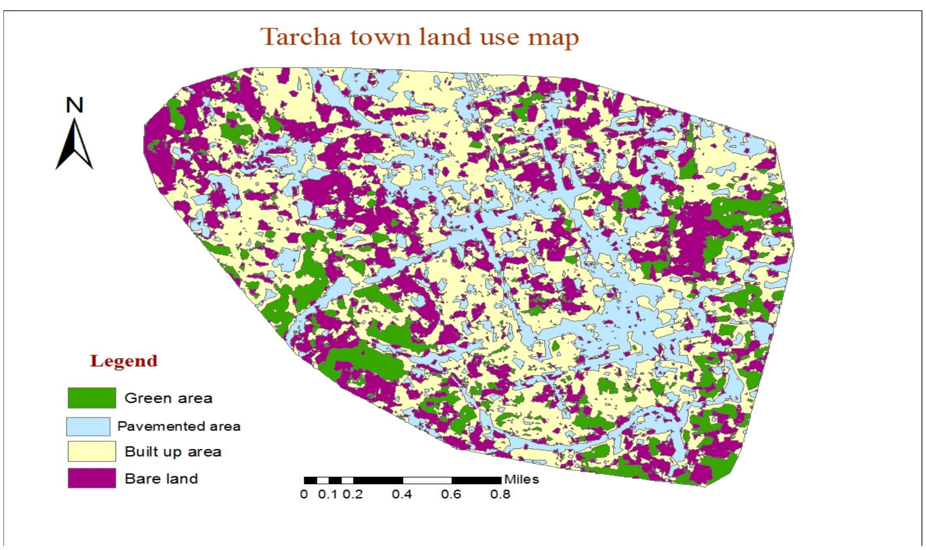

Fig. 2: Land use map of Tarcha town
Source: Google Earth satellite image 2017

Quantitative analysis using i-Tree Canopy (600 random sampling points) and GIS land-cover classification revealed a fragmented and limited distribution of green infrastructure in Tarcha Town. The land-use and vegetation cover analysis indicates that built-up areas dominate Tarcha Town, accounting for 34.2% of the total area, while total vegetated cover (tree, shrub, grass, and agricultural land) constitutes approximately 54.8% (Table 1). Tree cover alone represents only 18.6%, indicating limited green infrastructure coverage relative to rapid urban expansion. Similar spatial patterns have been documented in many rapidly urbanizing secondary cities, where built-up land increases at the expense of natural vegetation and other green land covers. For example, Adama City in Ethiopia experienced a significant increase in built-up area from approximately 6.99% to 44.05% between 1995 and 2023, while traditional vegetation and forest cover declined substantially due to expansion of urban infrastructure and settlement (Adama City study, preprint).

The 23% vegetation cover is significantly lower than international urban greening recommendations (≥30%) and lower than Ethiopia's own UGI standard. The standard error (SE = 0.03%) indicates a statistically reliable estimate. A GIS-based Land-Use/Land-Cover Map showing scattered tree patches concentrated around institutions, residential backyards, and river buffer zones, with extensive built-up expansion toward the north and west (Figure 2). Bare land is visible around newly developing neighborhoods. The results indicate an ongoing decline of natural vegetation, primarily driven by rapid construction, informal settlements, and conversion of open spaces for mixed land uses.

Status of Green Infrastructure Components

Green infrastructure components were assessed based on the Ethiopian Urban Green Infrastructure (UGI) Standard, which categorizes GI into fifteen types, including parks, street trees, riparian buffers, institutional greens, and residential vegetation.

Key findings:

Parks and recreational green areas were almost absent in both kebeles.

Street trees were poorly distributed, with some stretches showing complete absence of canopy cover.

Riparian vegetation along small rivers and streams was degraded, with evidence of erosion and waste dumping.

Institutional compounds (schools, offices) showed relatively better GI, often due to fencing and tree-planting efforts.

Residential compounds had scattered fruit and shade trees, but density was low and inconsistent.

Overall, GI development is piecemeal and not guided by a formal plan, contributing to a low adaptive capacity of the urban environment.

Table 3: Summary of GI Components Identified in Tarcha Town

GI Component	Presence	Condition	Remarks
Parks/Public Greens	Very Low	Poor	No properly planned parks
Street Trees	Low	Poor	Largely missing on major roads
Riparian Buffers	Medium	Degraded	Encroached, polluted
Institutional Greens	Medium–High	Good	Better managed
Residential Greens	Medium	Moderate	Uneven distribution
Urban Forest/Plantations	Very Low	Poor	Only small patches

Institutional Development and Capacity

Institutional assessment was based on interviews with 13 officials and experts from six offices: Urban Green Development, Land Administration, Urban Planning, Environment, Municipality Services, and Agriculture.

Key institutional gaps identified:

1. Lack of dedicated GI policy or strategy: None of the offices had a formal GI plan aligned with climate resilience.
2. Weak coordination among institutions: Responsibilities overlapped and communication among sectors was minimal.
3. Insufficient budget allocation: Annual green development budgets were unpredictable and too low for meaningful intervention.
4. Shortage of trained personnel: Most offices lacked specialized GI experts, urban foresters, or landscape planners.
5. Inadequate monitoring and enforcement: Illegal construction and encroachment onto reserved green spaces went largely unaddressed.

A table showing institutional ratings (Strong, Moderate, Weak) across five dimensions: Staffing, Budget, Coordination, Planning, and Implementation. Most categories fall under Weak. These findings highlight that institutional weakness is a major barrier to sustainable GI development.

Table 4 Institutional capacity ratings across five dimensions

Institutional dimensions	Rating	Interpretation
Staffing	1	Weak
Budget	1	Weak
Coordination	1	Weak
Planning	2	Moderate
Implementation	1	Weak

Stakeholder Participation in Green Infrastructure

Stakeholder involvement was assessed through household survey results (n=146), FGDs, and interviews.

Household Participation Levels

Only 31% of households participated in any GI activity (tree planting, cleaning campaigns) and 69% had never been involved in organized greening activities. Participation was highest during environmental ceremonies or temporary campaigns.

Table 5 Household Participation in GI Development

Participation Type	Percent (%)
Tree Planting	22
Cleaning Campaigns	9
No Participation	69

Reasons for Low Participation:

Lack of organized community programs

Low awareness of GI responsibilities

Limited seedling supply

Perception that GI is "government responsibility"

FGD participants emphasized the need for incentives, awareness, and coordinated community-based programs.

Community Perception of GI and Climate Change Adaptation

Survey data indicate that while awareness of environmental challenges is high, understanding of GI's adaptation role is limited.

Perception Highlights*:*

A total of 89% of respondents perceived temperature increases over the last decade and 76% reported increased flooding or soil erosion while 83% agreed that vegetation improves shade, cooling, and comfort. Only 35% explicitly connected GI with climate change adaptation before explanation. After clarification, over 90% recognized GI as beneficial for cooling, flood reduction, and environmental quality improvement.

A perception table illustrating high awareness of environmental hazards but moderate awareness of GI's climate adaptation benefits.

These findings show strong potential for community-driven GI development if awareness and engagement programs are improved.

Table 6 Perception table

Perception category	Percentage (%)
Perceived temperature increase	89
Perceived flooding/erosion increase	76
Belief that vegetation improves comfort	83
Initial awareness of GI role in CCA	35
Awareness of GI role in CCA after explanation	90

The Role of GI in Climate Change Adaptation (CCA)

Based on analysis of land-cover data and community responses, GI contributes to CCA in the following ways:

Mitigating urban heat through shade and evapotranspiration

Managing storm-water by enhancing infiltration and reducing runoff

Preventing erosion along streams and slopes

Improving air quality through pollutant absorption

Enhancing biodiversity in fragmented urban habitats

Providing recreational and psychological benefits that strengthen social resilience

However, the effectiveness of these ecosystem services is strongly dependent on the extent and distribution of GI. The limited vegetation cover observed in Tarcha Town - where tree cover constitutes only 18.6% of the total land - significantly reduces the potential of GI to deliver such services at scale. Similar constraints have been reported in other rapidly urbanizing African towns, where insufficient green space undermines climate adaptation efforts, especially in mitigating heat stress and managing peak storm runoff events (Kabisch *et al*., 2016; Li *et al*., 2019).

Discussion

The findings of this study reveal that green infrastructure (GI) development in Tarcha Town is limited, unevenly distributed, and constrained by weak institutional capacity. The discussion below interprets these results within the broader context of urban environmental management and climate change adaptation, drawing connections with existing literature and similar studies conducted in Ethiopia and other developing countries.

Urbanization, Land-Use Change, and Vegetation Loss

The vegetation cover of Tarcha Town, estimated at 23%, is lower than international urban greening recommendations, which often suggest a minimum of 30% canopy cover for ecological stability, climate regulation, and improved urban livability. This finding is consistent with national patterns reported by Thomas (2013), who noted widespread degradation of urban green areas in Ethiopian towns due to rapid urbanization, weak planning systems, and competition for land. The decline of natural vegetation in Tarcha—especially along riparian buffers and public open spaces—reflects a broader urban challenge where expansion of built-up areas outpaces environmental management.

The GIS and i-Tree Canopy results indicate significant fragmentation of existing green spaces, a condition known to reduce ecological functionality. Fragmented green patches fail to provide adequate habitat connectivity, weaken storm-water absorption capacity, and limit the cooling benefits provided by continuous vegetation networks. Pauleit *et al*. (2005) similarly demonstrated that declining vegetation cover increases surface runoff and urban heat island effects, reinforcing the need for planned GI systems.

Institutional Capacity and Governance Challenges

Institutional factors emerged as one of the most significant barriers to effective GI development. The lack of a dedicated GI policy or urban greening strategy in Tarcha Town reflects a systemic gap found in many Ethiopian municipalities. Urban environmental offices often have mandates for development but lack specific guidelines, budgets, and technical expertise to enforce standards. This study found weak coordination among land administration, urban planning, environmental protection, and municipal service departments, resulting in duplicated efforts, conflicting decisions, and poor integration of GI into urban planning processes.

Budget shortages were another major constraint. Without consistent funding, long-term GI initiatives such as tree planting, park development, and riparian restoration cannot be effectively implemented or maintained. The inadequacy of trained personnel, particularly professionals in urban forestry, landscaping, GIS, and ecosystem management, further limits the capacity of institutions to plan and monitor green infrastructure. These challenges support findings by Ayichew (2014), who noted similar governance and capacity barriers in Tarcha's earlier attempts at open space development.

Community Participation and Social Dimensions

Although environmental awareness is relatively high among residents—evidenced by 89% noting temperature increases and 76% perceiving greater flooding—actual participation in GI development is low. Only 31% of households reported involvement in any greening activity. This gap between awareness and practice suggests structural limitations such as inadequate community mobilization, absence of organized greening programs, and insufficient access to seedlings or incentives. These findings align with community perceptions recorded in similar studies where urban residents recognize climate threats but lack platforms or motivation for action.

The study's focus group discussions revealed that residents often perceive GI development as primarily a government responsibility. This perception limits voluntary participation and reduces community ownership of green spaces. However, once the concept of GI and its climate adaptation benefits was explained, acceptance levels rose significantly—indicating that awareness and capacity-building programs could effectively improve participation.

Green Infrastructure as a Climate Change Adaptation Strategy

The results demonstrate that GI can play an important role in enhancing urban climate resilience in Tarcha Town, but its benefits remain underutilized due to limited coverage. Vegetation provides shade, lowers localized temperatures through evapotranspiration, stabilizes soil, and improves rainfall infiltration, reducing flood risk. These functions are particularly important in towns like Tarcha, which experience high temperatures and intense seasonal rainfall.

The degradation of riparian vegetation around streams contributes to erosion and localized flooding, highlighting the missed opportunity for natural adaptation solutions. International studies emphasize that riparian buffers are among the most effective nature-based solutions for controlling erosion and enhancing water regulation in urban areas. Likewise, expanding street trees could significantly reduce surface temperatures and improve aesthetic and microclimatic conditions in dense neighborhoods.

The community's strong recognition of the environmental benefits of vegetation (83% agreement) provides a foundation for future GI interventions. Once explained, over 90% acknowledged the importance of GI for climate change adaptation, indicating substantial potential for community-driven initiatives.

Implications for Urban Planning and Sustainability

The findings indicate that Tarcha Town lacks an integrated GI approach, resulting in ad-hoc and fragmented development. Without a coherent strategy, green spaces are vulnerable to encroachment and land-use conversion, undermining sustainability efforts. Strengthening GI planning is therefore essential for achieving climate resilience.

Urban Master Plans should incorporate GI as a core land-use category, rather than treating it as residual or leftover space. This includes designating protected green corridors, developing community parks, restoring riparian zones, and enforcing zoning regulations that preserve open spaces. The town's productive population and growing institutions present an opportunity to initiate sustainable GI programs, provided institutional coordination and public engagement improve.

Summary of Interpretations

Overall, the discussion suggests that the limited extent of GI, weak institutional coordination, low participation, and rapid urbanization collectively undermine Tarcha Town's climate resilience. However, strong community awareness and the town's ecological context provide opportunities for improvement. The results underscore the need for policy development, capacity-building, and collaborative approaches to enhance GI for sustainable urban development.

Conclusion

This study concludes that the current status of green infrastructure (GI) in Tarcha Town is inadequate to meet the growing environmental and social demands of the community. Green spaces are unevenly distributed, poorly developed, and insufficiently maintained. Only a limited number of GI components are present, and many planned green areas have not been implemented due to shortages of materials, financial resources, and skilled personnel. As a result, GI delivery in the town fails to effectively support climate change adaptation and urban livability.

Institutionally, the municipality is the primary body responsible for GI development, while the urban agriculture office and the environment and forest office have supporting mandates. However, these institutions suffer from structural weaknesses, limited budget allocations, and severe shortages of qualified human resources. In practice, only one staff member is directly responsible for GI development and management, which greatly constrains effective planning and implementation.

Stakeholder involvement in GI development exists but is limited in scope and effectiveness. Although multiple actors are formally involved, including community members, government offices, NGOs, and private actors, community and private sector participation remains weak due to low awareness, unclear participatory frameworks, and weak institutional coordination. The lack of sustained, integrated, and holistic collaboration among stakeholders further undermines effective GI development.

The study also found that community awareness of climate change and the role of GI is relatively high. Residents recognize key climate change indicators, such as rising temperatures, altered rainfall patterns, and flooding, and understand the importance of GI for temperature regulation, flood control, wind protection, biodiversity conservation, and urban beautification. Areas with low green cover were perceived as more vulnerable to climate-related risks.

Recommendations

The study recommends:

1. Strengthening GI planning and implementation in line with national urban green infrastructure standards,
2. Establishing permanent nursery facilities,
3. Developing functional parks and green cemeteries,
4. Improving sports and recreational spaces, and
5. Reinforcing institutional human resource structures.

In addition, increasing financial investment and adopting participatory, multi-stakeholder approaches are essential to enhance the role of GI in climate change adaptation and sustainable urban development.

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