

Investigating and Scaling-up Effective Nature-Based Solutions for Climate Resilience in Dessie City Administration, Ethiopia

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Table of Contents

Abstract.....	4
1. Background and Rationale	6
2. Review of Related Literature.....	11
2.1 Economic Benefits of NbS	12
2.2 Sociocultural Benefits of NbS	12
2.3 Health Benefits of Urban Green Areas	13
2.4 Environmental Benefits of Urban Green Areas	14
2.5 The Role of GIS in Nature-Based Solutions, Flooding, and Hazard Vulnerability Assessment.....	15
3. Research Methodology	16
3.1 Description of the Study Area.....	16
3.2 Research Approach and Design	16
3.3 Target Population, Sampling Techniques, and Samples.....	17
3.4 Data Type, Sources, and Collection Tools.....	18
3.5 Data Analysis Techniques	20
4. Results and Discussion.....	24
4.1 Demographic Characteristics of Respondents.....	24
4.2 Participation of respondents in NbS activities and their Motives.....	26
4.3 Perception of Participants on the Perceived Benefits of NbS	29
4.4 Perception of Respondents on the Actual Benefits of NbS.....	37
4.5 Challenge in the Development of NbS.....	51
4.6 Vulnerability and Suitability Analysis	1
5. Summary, Conclusion, and Policy Recommendations.....	5
5.1 Summary of Findings	5
5.2 Conclusion.....	6
5.3 Policy Recommendations	7
References	10

Annex 1: Pairwise comparison for climate flood hazard, land slide, and urban heat vulnerability index.....	19
Annex 2: Climate Vulnerability Index.....	23
Annex 3: Survey Questionnaire Items	27
Annex 4: Interview and FGD items.....	32

Abstract

Due to its steep topography, rapid urbanization, and inadequate infrastructure, the Dessie city administration is among the most climate change-sensitive urban centers in Ethiopia where landslides and flooding have been the most catastrophic challenges. To overcome these challenges, innovative and sustainable adaptation measures are required. To that end, Nature-based Solutions (NbS) offer a promising and cost-effective solution by integrating ecological systems into urban development, thereby enhancing resilience while generating environmental and socio-economic co-benefits. Nevertheless, despite local initiatives, the effectiveness and sustainability of NbS in Dessie remain underexplored, mainly with respect to community participation and socio-ecological benefits. This study opted to investigate and scale up effective NbS for climate resilience in Dessie City using a mixed research approach. The main objective of the study was to evaluate the performance of NbS that involves community participation by establishing how people value the benefits gained with NbS; significant challenges encountered and lessons learned in scaling up; best practices, while mapping risk zones for threat reduction and suitability for implementing NbS. Data collection was undertaken using a household-based survey from 305 randomly selected households, in-depth interviews with key informants, focus group discussions, and direct field observation, which were complemented by literature review and the use of geospatial analysis. Data analysis was conducted using descriptive statistics (mean, percentage, and standard deviation), weighted mean values, and the problem confrontation index. The results indicated that although communities perceive the environmental and social benefits of NbS, such as improved air quality, flood control, and livelihood support, their involvement is restricted by a lack of financial resources, high maintenance costs, inaccessibility, safety concerns, weak institutional support, weak coordination among relevant stakeholders, and limited awareness. The GIS-based Multi-Criteria Evaluation (MCE) shows that Dessie City has a moderate risk of flooding (57.6%) and a moderate risk of landslides (34.4%). Almost one-fifth of flood-prone areas and more than 40% of landslide-prone areas are in high to extremely high-risk zones. The analysis also shows that 42.4% of the region is very good for NbS. This shows that NbS should be a part of urban development to make cities more resilient through better water management and green infrastructure. We concluded that scaling up NbS requires a holistic policy framework that incorporates allocating financial incentives and sustainable funding mechanisms, strengthening policy support and institutional collaboration, and integrating NbS into municipal development plans with priority for high-risk zones. To overcome the possible risks and scale up best practices, we recommend enhancing community engagement through inclusive planning, capacity building, and awareness campaigns; improving infrastructure for accessibility and safety; allocating financial

incentives and sustainable funding mechanisms; strengthening policy support and institutional collaboration; and prioritizing scalable NbS in vulnerable urban zones. This research contributes to narrowing the knowledge gap on the role of NbS in mitigating climate-change-induced hazards in the urban context, particularly in developing countries. Additionally, it provides actionable insights for policymakers and practitioners to foster climate-resilient urban development.

Keywords: Nature-based Solutions, Urban Resilience, Economic Benefits, Health Benefits, Sociocultural Benefits, Environmental Benefits, Vulnerability Analysis, Suitability Analysis

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1. Background and Rationale

The urbanization trend is both the cause and the effect of the worsening climate crisis. As projections around climate change grow more severe, different geographic regions experience not only spatial but also socio-economic environmental vulnerabilities as well (IPCC, 2022). Urban areas are more susceptible to exposure to extreme weather conditions, floods, landslides, air contamination, extreme heat, and haphazard loss of biodiversity (IPCC, 2022). People living in such environments who are already marginalized are the worst affected by the adverse effects of climate change, as they lack the essential resources or infrastructure to adapt to the threats posed by climate change (IPCC, 2022). The situation is further worsened by the high thermal mass of the building materials and pavements, resulting in urban areas experiencing the so-called thermal lifting known as the 'urban heat island' (IPCC, 2022; EPA, 2023), which leads to many health risks associated with heat exposure. Further climate change impacts are likely to lead to the extensive spread of disease vectors, leading to increased interaction between urban populations and diseases (WHO, 2021). The urban populations will be further physically impacted by poor air quality linked to carbon dioxide emissions from domestic waste and industry, coupled with high temperatures, which are likely to increase vulnerability to heart and respiratory diseases (EPA, 2023).

It is predicted that poor urban infrastructure, coupled with erratic rainfall, could trigger the emergence of urban landslides and flooding in cities, which in most cases can be disastrous (IPCC, 2022; EPA, 2023). Extreme climate events like flooding and heavy storms have caused large-scale devastation to the core cities' critical infrastructures, such as bridges, energy systems, and road networks (World Bank, 2020). However, urban areas, due to their high population density, inadequate waste management, inefficient transport systems, and industrialization activities, also significantly contribute to the emission of global greenhouse gases. In this regard, cities present challenges as well as opportunities to implement climate change adaptation and mitigation strategies. Among the Sustainable Development Goals, human beings need to achieve the creation of inclusive, safe, resilient, and sustainable cities and human settlements (SDG 11). As a result, there is a clear commitment to meet target 11.7 by 2030, which entails increasing the proportion of cities planned in a way that contributes towards ensuring that there is universal access to safe, inclusive, and accessible green public spaces and open spaces (UN, 2023).

Nature-based solutions (NbS) can be described as a management of the natural ecosystem processes, and together with novel ecosystem engineering and may provide an adequate response to the mentioned problems and help improve climate adaptation, ecological restoration, and urban quality of life (Ali *et al.*, 2018; Douglas *et al.*, 2019;

IPCC, 2022, Wilson and Xiao, 2023). Furthermore, investing in urban green areas has beneficial effects, including temperature reduction, tree cover, carbon sequestration, improved air quality, flow control, flood reduction, offsetting greenhouse gas emissions, stormwater control, water quality improvement, and mitigation of climate change (Oliveira et al., 2022). It was also claimed that well-preserved urban green spaces offer a variety of social advantages, including beauty and pleasure, leisure, psychological satisfaction, and good physical health, as well as the development of social networks, preservation of cultural and historical heritages, and education (Zhou and Rana, 2012). Examples of NbS include urban green spaces, tree planting, green structures, rehabilitation of wetlands, and community gardening. Beyond traditional green spaces and tree planting, the concept extends to a holistic approach that integrates ecological systems with urban infrastructure. NbS also encompasses integrated infrastructure designs such as green roofs, permeable pavements, constructed wetlands, and 'sponge city' approaches that mimic natural hydrological cycles. These urban planning innovations combine ecological engineering with climate adaptation, promoting resilient urban environments that store, filter, and reuse storm water naturally. Despite NbS being embraced for its cost-effectiveness and creation of multiple co-benefits, scaling NbS in urban areas remains complicated due to governance, space, and diverse community priorities.

Dessie city administration is in the Amhara regional state (Ethiopia), characterized by a subtropical highland climate. It is at the foot of interconnected ridges and low, shrouded mountains and hills (Figure 1) (Assefa, 2024). The town is situated in a tectonic depression along the western rift margin, characterized by a hanging valley, where landslides and flooding pose significant risks (Suryanarayana *et al.*, 2021). Dessie City has mild temperatures, with an average annual temperature of 19.82°C and an average annual rainfall of 1100 mm (Yimer and Wudu, 2020). According to the Central Statistical Authority (CSA) estimation, the city is inhabited by more than 300,000 people (CSA, 2021). Due to its location and topography, Dessie is among Ethiopia's most highly vulnerable areas to the adverse effects of climate change, mainly landslides and flooding (Figure 2). Waste disposal problem is another factor contributing to the emission of greenhouse gases in Dessie City (Assefa, 2024). Recently, the Dessie City Council has introduced projects focused on NbS to tackle landslides, flooding, and waste management problems. While these initiatives reflect a commitment to urban sustainability, they are insufficient to address the challenges faced by residents. Many communities experience similar issues, and practical strategies have been successfully implemented in comparable areas, highlighting the need for scaling these efforts. Comprehensive assessments should identify specific community problems and viable

solutions tailored to their context. Prioritizing such actions will enhance Dessie City's urban ecology and better prepare the area for the challenges of climate change.



Figure 1: Partial view of Dessie city administration along with Tossa mountain ridge

(Photo Credit: The Research Team, 2025)

In recent years, research has highlighted the importance of community engagement in ensuring the success and longevity of NbS projects. Community-based approaches enable residents to participate actively in planning, implementation, and maintenance, fostering a sense of ownership and sustainability. Engaging communities can also ensure that NbS projects are tailored to local needs and cultural contexts, making them more inclusive and impactful. However, there is little empirical evidence and gaps in understanding how community-driven models of NbS can be effectively implemented and scaled up in urban areas, particularly in ways that address environmental and social resilience. This research addresses this gap by evaluating the effectiveness of community-based NbS in urban areas and identifying best practices for scaling up these solutions to achieve broader climate adaptation and mitigation goals in cities. Additionally, geospatial tools and techniques, like GIS and Multi-Criteria Evaluation (MCE), have been used to identify high-risk zones, assess vulnerability, and prioritize areas for intervention. This report integrates socio-economic and environmental data to provide comprehensive insights into the spatial distribution of risks and the suitability of NbS.



Figure 2: Unstable area (Recommended to be a new NbS intervention area)

(Photo Credit: WU Research Team, 2025)

Research Objectives

The main objective of this research was to investigate and scale up nature-based solutions for climate resilience in the Dessie city administration of Ethiopia. Specifically, it opted to:

1. Assess the effectiveness of community-based NbS in urban settings: identify how community involvement influences the success, sustainability, and resilience outcomes of NbS in cities.
2. Identify best practices for scaling community-driven NbS: examine case studies and existing frameworks to derive scalable strategies and guidelines for local governments and organizations.
3. Assess the perceptions of the Local community towards the NbS and major problems encountered: how do local communities perceive the benefits of NbS, and what issues do they face in the implementation process
4. Identify vulnerable areas to natural hazards (flooding and landslides) and develop a suitability map for new NbS sites

Significance of the Study

Since the Dessie city administration is one of the rapidly urbanizing areas highly exposed to recurrent flooding and landslides, this study is significant in addressing the urgent need to enhance urban climate resilience through NbS. By assessing the effectiveness of community-based NbS, the study will provide empirical evidence on the role of local participation in ensuring sustainability, inclusivity, and resilience outcomes. Furthermore, identifying best practices for scaling up community-driven NbS will contribute to practical strategies and policy-relevant guidelines that can benefit local governments,

civil society organizations, and development partners in mainstreaming NbS into urban planning. The exploration of community perceptions and challenges highlights the social dimensions of NbS, ensuring that interventions are context-sensitive and responsive to local needs. By mapping vulnerable and suitable areas, the study will provide spatially explicit evidence to prioritize high-risk zones and allocate resources more effectively for decision-makers. Consequently, this empirical evidence will inform climate change adaptations in city contexts and serve as a replicable framework for other Ethiopian cities and similar contexts in the Global South. In summary, the study bridges the gap between theory and practice by integrating ecological, social, and spatial perspectives, thereby providing actionable knowledge for building resilient, sustainable, and inclusive urban systems through NbS.

Delimitation of the Study

The study was delimited to the Dessie City administration (Amhara Regional National State of Ethiopia) and primarily aimed to investigate the practices and challenges of Nature-based Solutions (NbS). It specifically focused on identifying the major NbS being practiced, role models in this practice, the perceptions of the local community, the benefits and constraints of NbS, and their management practices. The study also attempted to map the vulnerable areas for flooding and landslides, along with suitability mapping for NbS development.

Limitations of the Study

The study employed a cross-sectional research design where data were collected at a snapshot. As a result, it did not capture the dynamic situation over time. Besides, the assessment was based on the residents' perceptions of NbS's multifaceted benefits and did not employ a rigorous valuation approach. Moreover, the study is restricted to one locality, and the results must be utilized with caution, mainly for areas having different biophysical and socioeconomic contexts.

Ethical Considerations

The research involves engaging with diverse community members in urban areas. Ethical clearance was secured from Wollo University's institutional ethical research review committee (Ref. No: WU-03464-T-02/25), and informed consent was obtained from all participants during interviews, FGD, and surveys to address ethical concerns. All participants' personal information was held confidentially. The research does not impact the environment, plants, or animals. Cultural sensitivity was prioritized, ensuring that all activities respect local norms and traditions. Data privacy protocols were established to protect participants' information.

Intellectual Merit and Broader Impact

This research will advance the understanding of NbS by focusing on the community's role in project success and scalability. Unlike traditional top-down models, this project provided evidence of grassroots-driven NbS's effectiveness in urban resilience. The research outcomes have practical implications for urban planning, policy, and environmental organizations. By providing evidence-based recommendations, this project will empower cities and communities to effectively deploy NbS at a grassroots level, fostering long-term, sustainable climate resilience in urban areas. Local governments and non-governmental organizations will benefit from a replicable model emphasizing local engagement, inclusivity, and cultural relevance. The insights from this project could inform regional and national strategies on NbS, potentially influencing policy changes that prioritize community-based climate solutions. Besides, understanding the residents' perceptions and identifying major problems can be valuable for designing a sustainability plan.

2. Review of Related Literature

The contemporary urban landscape is defined by unprecedented growth and escalating environmental challenges. Urban areas are home to more than 4.2 billion of the world's population, and an additional 2.5 billion people are expected to be living in urban areas by 2050 (Dodman *et al.*, 2022). This rapid urbanization, characterized by expanding urban footprints and often at the expense of natural ecosystems, inherently creates heightened exposure and vulnerability (Dodman *et al.*, 2022), compromising green infrastructure as well as the ecosystem services, reducing adaptive capacity, and increasing risk in urban areas (Egerer *et al.*, 2024). Besides, as noted in Dodman *et al.* (2022), climate impacts are felt disproportionately in urban communities, where economically and socially marginalized individuals are being most affected by climate change-induced risks and effects. To overcome those complex and interconnected challenges, scholars recommend NbS as a viable mainstream urban adaptation option (Dodman *et al.*, 2022; Gashu and Gebre-Egziabher, 2019).

In response to these complex and interconnected challenges, NbS are increasingly advocated as viable and mainstream options for urban adaptation and indispensable components of resilient urban development. NbS encompasses a broad spectrum of natural and semi-natural areas within cities, including forested and vegetated lands, recreational fields, community gardens, playgrounds, and urban squares (Ali *et al.*, 2018). According to the World Health Organization (WHO), NbS may include places with 'natural surfaces' or 'natural settings' but may also include specific types of urban greenery like street trees. The importance of NbS has been recognized in international

frameworks, such as the United Nations Sustainable Development Goal (SDG) 11.7, which prioritizes improving access to Urban Green Spaces (UGS) and ensuring universal access to safe, inclusive, and accessible green and public spaces by 2030, with a particular focus on women, children, older persons, and persons with disabilities (Wilson and Xiao, 2023). According to Ali *et al.* (2018), NbS play essential social, economic, cultural, environmental, ecological, and health-related roles which are vital for sustainable development through increasing property value due to amenity, improving water quality, improving quality of life and air quality, enhancing carbon sequestration, providing aesthetic services, and reducing the energy cost of cooling buildings. For this research, economic, sociocultural, health and environmental benefits of NbS are discussed hereunder in consultation to various related literature.

2.1 Economic Benefits of NbS

NbS offers a variety of economic contributions. One of the well-documented benefits of NbS is its contribution to creating job opportunities (Wang *et al.*, 2014). NbS contributes to job creation and economic development through the planning, construction, and maintenance of green infrastructure; and being as stimulates of tourism activities and local businesses (Wang *et al.*, 2014; Ali *et al.*, 2021; Bizuneh, 2021; Ali *et al.*, 2021). Since areas closer to NbS are perceived as more desirable places to live, properties adjacent to well-maintained green spaces often have higher market values (Douglas *et al.*, 2019). According to Kasim *et al.* (2019), average property premiums increased by 2.6% to 12% whenever the property is found near well-managed green spaces. Besides, NbS also reduces healthcare costs by promoting physical activity and by mitigating air pollution, which lowers the prevalence of chronic diseases (Nowak *et al.*, 2018). NbS could improve mental health, which has significant economic implications. Individuals living in areas with more green space will have lower levels of stress and depression, which in turn leads to fewer sick days and higher workplace productivity (Semeraro *et al.*, 2021).

2.2 Sociocultural Benefits of NbS

The presence of NbS encourages positive social interactions that cultivate social cohesion, which in turn enhances well-being and health (Zhou and Rana, 2012; Jennings and Bamkole, 2019); creates a venue for recreational and cultural meetings, and enhances civil society involvement (Oliveira *et al.*, 2022). Some of the social benefits of NbS include aesthetic enjoyment, improving psychological well-being, enhancing social ties, providing recreational opportunities, and offering educational opportunities (Zhou and Rana, 2012; Jennings *et al.*, 2016; Kasim *et al.*, 2019; Semeraro *et al.*, 2021). Well-managed NbS help to preserve cultural heritage, which is integral to local identities and empowers local communities while promoting sustainable land stewardship (Raymond *et al.*, 2017). Kasim *et al.* (2019) discovered that interactions with nature significantly

contribute to spiritual well-being, fostering feelings of awe, gratitude, and a sense of interconnectedness among individuals. In a related study, Heft and Chawla (2006) emphasized the crucial role that green spaces play in the spiritual development of children, offering environments that cultivate wonder and curiosity about the natural world. NbS provide opportunities for cultural transmission and intergenerational learning, fostering a sense of continuity and shared identity (Semeraro *et al.*, 2021). A study by Krasny and Tidball (2009) found that community gardening projects promoted intergenerational learning and strengthened family and community bonds. Research outputs revealed that parks, community gardens, and urban forests serve as vital gathering spaces that enhance social cohesion and intercultural exchange (Rishbeth *et al.*, 2019), which also host cultural events, festivals, and traditional practices, helping to maintain local identities and intergenerational knowledge (Elands *et al.*, 2019). Similarly, UGS often hosts cultural events, festivals, and storytelling sessions that celebrate local traditions and histories. These activities provide opportunities for younger generations to learn about their cultural heritage and for older generations to share their knowledge and experiences. A study by Rishbeth *et al.* (2019) highlighted the role of urban green spaces in facilitating cultural exchange and dialogue, particularly in multicultural cities. Studies also highlight how green spaces reduce crime rates and enhance perceived neighborhood safety, contributing to more substantial social capital (Kondo *et al.*, 2015).

2.3 Health Benefits of Urban Green Areas

The development and enhancement of NbS is vital in improving the well-being and health of urban populations (WHO, 2017; Semeraro *et al.*, 2021; Wilson and Xiao, 2023; Edeigba *et al.*, 2024). NbS provides myriad health and well-being-related benefits. Frequent exposure to such areas is linked to positive physical and mental health outcomes; NbS can mitigate harmful impacts from air pollutants (leading contributors to respiratory, cardiac, and lung cancer-related mortality), heat, noise, and climate-related health risks; improved mood, and enhanced cognitive function (Kabisch *et al.*, 2017). According to WHO (2016), physical inactivity is the fourth leading risk factor for global mortality. The presence of NbS has been demonstrated to significantly stimulate resident engagement in physical activity, which in turn can protect people against a range of diseases and adverse health outcomes, like diabetes, cancer, cardiovascular disease, hypertension, obesity, depression, osteoporosis, and premature death (Raymond *et al.*, 2017; WHO, 2017; Kasim *et al.*, 2019; Wilson and Xiao, 2023). Furthermore, spending more time in UGS has been associated with notable psychological and emotional benefits, including stress reduction and enhanced levels of happiness and life satisfaction (Wilson and Xiao, 2023; Edeigba *et al.*, 2024). In a systematic review conducted by Kondo *et al.* (2015), a robust negative association was identified between exposure to NbS and adverse health indicators such as mortality rates, heart rate, and incidents of

violence. A study in Scotland (Thompson *et al.*, 2012) found that cortisol levels decreased by 15% after having a 30-minute stay in green spaces. A study in the United Kingdom (Sarkar *et al.*, 2018) reported a reduction of depression up to 25% due to exposure to NbS.

Urban green spaces, by absorbing pollutants and particulate matter, help to mitigate air pollution, thereby reducing respiratory illnesses (Nowak *et al.*, 2018). A study in Beijing (Yin *et al.*, 2011) reported an 8% reduction in respiratory disease due to having NbS in adjacent neighborhoods. Cogent to this, a study in Barcelona (Nieuwenhuijsen *et al.*, 2017) estimated that, by improving air quality and promoting physical activity, NbS helped to prevent 1,868 premature deaths annually. A study conducted by Coombes *et al.* (2010) found a positive correlation between access to urban green spaces and increased levels of physical activity among residents. This enhanced physical activity not only contributes to individual well-being but also plays a significant role in improving overall air quality, thereby benefiting respiratory health (Semeraro *et al.*, 2021). NbS also fosters community well-being and social cohesion, which are essential for mental and emotional health. A study by Jennings & Bamkole (2019) found that individuals exposed to NbS reported fewer feelings of loneliness and greater social support. These findings collectively emphasize the critical role of UGS in promoting public health and well-being, highlighting their potential as a vital component of urban planning and health policy interventions.

2.4 Environmental Benefits of Urban Green Areas

Urban green areas play a crucial ecological and environmental role in improving quality of life and air quality (Rakhshandehroo *et al.*, 2015), enhancing carbon sequestration (Rakhshandehroo *et al.*, 2015; Kasim *et al.*, 2019; Edeigba *et al.*, 2024), effectively reduce noise pollution from urban areas (Rakhshandehroo *et al.*, 2015), protecting air pollution and flooding (Rakhshandehroo *et al.*, 2015; Kasim *et al.*, 2019; Oliveira *et al.*, 2022; Edeigba *et al.*, 2024), and offsetting carbon emission (Chen, 2015). A study in Berlin (Strohbach *et al.*, 2012) reported that UGS were found to store 1.2 million tons of carbon, equivalent to 10% of the city's annual emissions, highlighting their potential for climate mitigation. They also served to stabilize the urban thermal island situation (Rakhshandehroo *et al.*, 2015; Kasim *et al.*, 2019; Semeraro *et al.*, 2021; Edeigba *et al.*, 2024). Saaroni *et al.* (2018) found that urban areas are 1.5 to 3.5°C warmer than their surrounding areas due to urban thermal island effects, and the presence of green spaces can mitigate this effect. A study conducted in Peru on the impact of green corridors in reducing the urban heat island (UHI) effect revealed that maximum temperatures in areas lacking green corridors were up to 5.4 °C higher than those within corridor zones (Molina-Barrenechea *et al.*, 2025). NbS also reduces noise pollution from traffic,

construction, and other urban activities (Fang and Ling, 2003). By providing habitats and wildlife corridors, NbS enhances flora and fauna biodiversity in urban areas, contributing to ecosystem stability (Edeigba *et al.*, 2024). NbS also plays a significant role in sustainable storm water management and water cycle restoration through rainfall interception, facilitating infiltration, and water storage in the underlying soil (Marrazzo and Raimond, 2025).

2.5 The Role of GIS in Nature-Based Solutions, Flooding, and Hazard Vulnerability Assessment

Geographic Information Systems are increasingly becoming integral in monitoring and assessing environmental challenges, such as drought, flooding, and hazard susceptibility. NbS, which leverage the natural environment to address societal challenges, have gained attention in addressing environmental problems. GIS provides robust tools for mapping and analyzing floods and other environmental risks. Friedrich *et al.* (2016) elucidated the significance of GIS to create detailed floodplain maps that inform urban planners and disaster response strategy implementers. The integration of GIS with remote sensing data enables near-real-time monitoring of flood events and assessment of vulnerable areas. Disaster risk management is not possible without vulnerability assessment in the first place. The indispensable role of spatial data in understanding the socio-economic factors that contribute to vulnerability assessment is boldly addressed by several authors (Schröter *et al.* 2014). GIS provides the opportunity to overlay demographic data with environmental hazards, which enables planners to identify at-risk populations and accordingly tailor intervention strategies.

GIS offers computationally effective and timely analysis techniques that pave the road for the implementation of NbS. Optimal locations for Nbs implementation, such as green roofs or riparian buffers, can be easily identified with the help of GIS partial data analysis techniques (Seddaiu *et al.* 2018). Thus, the spatial decision-making process in GIS is crucial for maximizing the effectiveness and efficacy of NbS in curbing the impact of anthropogenic and natural disasters. However, NbS strategies demand the involvement of multiple stakeholders, effective communication, and collaboration, which can be challenging (Barton *et al.*, 2020). The way forward is the integration of GIS and nature-based solutions for managing environmental disasters and reducing vulnerability. Since climate change exacerbates environmental and man-made challenges, it is crucial to use GIS in facilitating informed decision-making and effective implementation of NbS. The focus of Future research should be on enhancing data availability, developing user-friendly GIS tools, and fostering collaborative frameworks among stakeholders to maximize the impact of NbS in environmental hazard and risk management.

3. Research Methodology

3.1 Description of the Study Area

Dessie city administration is in the Amhara regional state (Ethiopia) at 11°8'North latitude and 39°38'East longitude (Figure 3), with an elevation between 2470 and 3200 meters above mean sea level, characterized by a subtropical highland climate. It is at the foot of interconnected ridges and low, shrouded mountains and hills. The town is situated in a tectonic depression along the western margin of the Great East African Rift Valley. This location, characterized as graben land, is sandwiched between the rift rim and the Tossa Ridge, making the city particularly susceptible to landslides and flooding. Dessie City has mild temperatures, with the average temperature of the town being 19.82°C. Its average yearly rainfall is about 1100 mm. According to the 2024 estimation of the Central Statistical Authority of Ethiopia, the city is inhabited by more than 500,000 people. Due to its location and topography, Dessie is among Ethiopia's most highly vulnerable cities to the adverse effects of climate change, mainly landslides and flooding.

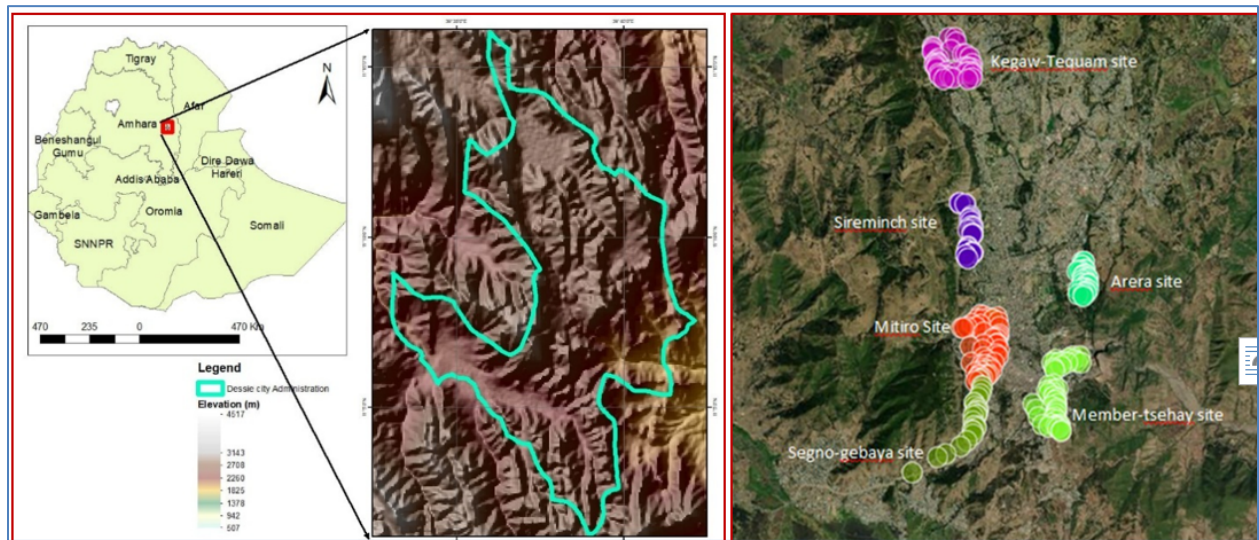


Figure 3: Study Area Map and Specific Sample Sites

3.2 Research Approach and Design

A sequential mixed-methods approach, which integrates both qualitative and quantitative data collection and analysis, was employed to address the objectives of the research effectively. This methodological framework facilitated a comprehensive understanding of how NbS can be effectively implemented, assessed, and scaled within urban contexts. To achieve the study's goals, a combination of cross-sectional surveys

and case study research designs and Geospatial data analysis designs were employed. This strategic selection of research designs ensured a robust exploration of the intended research objectives, allowing for a multifaceted examination of the dynamics at play in the urban implementation of NbS.

3.3 Target Population, Sampling Techniques, and Samples

The target population for this study comprises residents living in proximity to the NbS resource, experts from sub-cities and municipalities engaged in NbS-related works, elders, religious leaders, NGO leaders, and representatives of youth and women groups. A multi-stage sampling technique was employed to select representative samples for the survey study. Four sub-cities were considered to choose representative samples, and in consultation with experts from Dessie municipalities and Dessie city natural resource conservation office, six sites (see Figure 3), namely *Kegaw-tequam*, *Sireminch*, *Mitiro*, *Segno-Gebaya*, *Membe-tsehay*, and *Arera* site, based on their demonstrated better performance in NbS implementation and susceptibility to hazards. A proportionate systematic random sampling technique was applied to select 305 samples (out of 12600 target population) using the formula proposed by Yehuala *et al.* (2021) (Equ.1). Based on the formula, the estimated total sample size was 193. However, an additional 5% ($n = 10$) was incorporated to account for potential attrition and non-responses, as recommended by Israel (2012). Consequently, this adjustment yielded a preliminary sample size of 203 households. This initial sample size was further modified to account for the design effect inherent in the employed sampling technique. Specifically, the computed sample size was multiplied by a design effect factor of $D=1.5$. This adjustment resulted in a total of 305 individuals for the survey.

$$n = \frac{z^2 p \cdot q \cdot N}{e^2 (N - 1) + z^2 \cdot p \cdot q} \quad 1$$

where n is the desired sample size, N is the total number of individuals, z is the value of the standard variant at a 95% confidence level and to be worked out from a table showing the area under the normal curve ($z = 1.96$), e is the level of precision = 0.05, p is the proportion of sample size ($p = 50\%$), and $q = (1-p)$. The selection of participants for the Focus Group Discussion (FGD) was conducted by selecting appropriate individuals from the respective sub-cities, the municipality office, and community-based Organizations based on their relevant experience regarding NbS. Thus, a total of 15 experts (organized in three separate groups) participated in FGD. A Key Informant Interview (KII) was conducted with 22 purposively selected community representatives of elders, religious leaders, youth, and women to gather detailed insights. Survey data collection was conducted by five trained data enumerators under the supervision of the research teams, while the FGD and KII were facilitated directly by the researchers.

3.4 Data Type, Sources, and Collection Tools

To attain the intended objective of the research, diverse data sources and data gathering techniques were employed.

3.4.1. Literature Review and Theoretical Framework Development

We conducted reviews of articles, case studies, and reports from urban areas of the world to build a theoretical framework on the effectiveness of NbS, the role of community engagement in urban climate solutions, and identify current best practices, challenges, and gaps in knowledge. The literature review also established a basis for assessing how community-driven approaches can enhance NbS outcomes in urban areas.

3.4.2 Case Study Analysis

Four case studies from the sub-cities in Dessie city administration with established community-based NbS initiatives were assessed to provide in-depth insights into the successes and limitations of NbS implementations.

3.4.3 Community and Stakeholder Engagement Workshops

To gain additional qualitative insights, workshops were organized in selected urban areas, bringing together community members, city officials, environmental organizations, and other relevant actors. These workshops focused on identifying community priorities in implementing NbS, understanding the perceived benefits and barriers of NbS in the community, and exploring potential solutions to overcome challenges for sustainable and effective NbS projects.

3.4.4 Survey, Interview, FGD, and Field observation

A household survey was conducted utilizing a structured questionnaire (Annex 3) administered to 305 randomly selected household heads across four sub-cities with the help of Kobo Toolbox. Trained data enumerators surveyed under the supervision of the research team. This survey aimed to assess residents' perceptions of NbS and the challenges encountered during implementation. Interviews and FGD were also undertaken to substantiate the survey result using interview guidelines (Figure 4 and Annex 4). Additionally, direct field observations were conducted to evaluate the existing status of NbS in the area.



Figure 4: Photo showing the Research Team in the Reconnaissance field visit, survey interview, FGD, and Participatory Mapping (partial)

(Photo Credit: The Research Team, 2025)

3.4.5 Vulnerability Assessment and Suitability Mapping

Both primary and secondary environmental and socio-economic data were utilized for vulnerability and suitability analysis. Digital Elevation Models (DEMs) data derived from the Shuttle Radar Topography Mission (SRTM) were acquired from the USGS portal and analyzed to compute elevation, slopes, aspect, curvature, and drainage patterns, which are the basis for understanding water flow in the area. Additionally, we obtained the 10m spatial resolution Sentinel-2 satellite imagery from the Copernicus data hub. We utilized it to classify current and past land use/cover of the study area to investigate land cover change in the last 10 years. Soil and geological data were obtained from the Ethiopian Geological Survey, while historical and projected climate data, including rainfall and temperature, were taken from meteorological stations and climate models. Another dataset required for vulnerability assessment is socio-economic data. Parallel to environmental data, understanding the community is equally essential in vulnerability assessment. Therefore, socio-economic data, including demographic information such as age distribution, employment status, education level, housing conditions, and income levels, were collected through surveys and questionnaires from the community. We also

gathered information on access to resources and services, such as healthcare access, road and drainage infrastructure, and transportation, from the CSA and local records.

3.5 Data Analysis Techniques

The qualitative data gathered from interviews, workshops, and case studies were analyzed using thematic analysis to identify common themes, challenges, and success factors across the different urban contexts. Quantitative data, perception towards NbS, and problems encountered were analyzed using the perception model and Problem Confrontation Index (PCI). Data analysis was undertaken using SPSS vr. 27 software. Vulnerability and suitability analysis were conducted using geospatial technologies. The details are given below.

3.5.1 Problem Confrontation Index

To identify the most critical problems faced by the local community while implementing NBS, the Problem Confrontation Index (PCI) was applied (Uddin *et al.*, 2014) using the following formula:

$$PCI = [Ph \times 3 + Pm \times 2 + Pl \times 1 + Pn \times 0] / 6 \dots\dots\dots 2$$

Where,

PCI = Problem Confrontation Index

Ph = Number of respondents expressed problem as “high”

Pm = Number of respondents expressed problem as “medium”

Pl = Number of respondents expressed problem as “low”

Pn = Number of respondents expressed problem as “not at all”

3.5.2 Perception of the benefits of nature-based solutions and their effectiveness

Perceived benefits of different NbS and their actual effectiveness were measured using five-level Likert-scale items. The perception was assessed using the weighted mean index as presented below:

$$(\text{Number of respondents rated strongly agree} \times 5) + (\text{Number of respondents rated agree} \times 4) + (\text{Number of respondents rated neutral} \times 3) + (\text{Number of respondents rated disagree} \times 2) + (\text{Number of respondents rated strongly disagree} \times 1) / \text{Total Number of respondents}$$

3.5.3 Vulnerability Assessment

Vulnerability of the city to the adverse impacts of climate-change induced hazards like flooding and landslides has been detected using the following producers and techniques.

Key indicators identification: key indicators such as exposure to climate hazards (flood risk or proximity to water bodies and historical flood data), landslide susceptibility (areas with steep slopes or loose soil), and extreme heat events (urban areas with poor vegetation cover) were used to develop a Climate Vulnerability Index (CVI) that enables assessing vulnerability. Socio-economic factors such as the percentage of households below the poverty line, health status (the proportion of residents with chronic illnesses), and dependence on vulnerable sectors, like communities reliant on rain-fed agriculture, have been used to examine community sensitivity to climate impacts. Adaptive capacity to climate change has been considered, including access to resources (availability of financial resources and infrastructure), education and awareness (community participation in climate training programs), and community networks (the strength of local organizations and social networks).

Normalize indicators: Data for each indicator gathered from various sources were standardized to a common scale (0 to 1) to ensure comparability. The standardization process was achieved using the min-max normalization technique, which rescales the data to a range between 0 and 1. Equ gives the formula for this normalization. 3:

$$X' = \frac{X - X_{min}}{X_{max} - X_{min}} \quad (\text{Grus, 2015}) \text{-----}$$

3

Where: X' is the normalized value, X is the original value, X_{min} is the minimum value of the dataset, X_{max} is the maximum value of the dataset.

Assigning weight for each indicator: After assigning weights to each indicator based on its importance in contributing to overall vulnerability, where flood risk might be weighted more heavily in flood-prone areas, we calculated the CVI for different regions by combining the normalized and weighted scores of all indicators.

Calculate the CVI: GIS tools were utilized to analyze spatial relationships among the CVI indicators, including overlay analysis to combine different vulnerability layers and identify areas at high risk. Finally, vulnerability maps have been produced, depicting areas of high, moderate, and low vulnerability throughout Dessie City. These maps provide a clear understanding of where the community is most at risk. Equation 4 has been used to calculate CVI based on Grus (2015).

$$CVI = \frac{\sum(W_i X'_i)}{4}$$

Where: W_i is the weight of the i^{th} indicator, and X'_i is the normalized value of the i^{th} indicator.

3.5.4 Suitability Mapping for NbS

In the next phase, we were identifying the most suitable locations for implementing NBS. To determine suitability, we established several criteria that encompass ecological, socio-economic, and hazard mitigation factors. Ecological criteria include soil quality, vegetation cover, and ecosystem health, particularly in wetlands and forests. Socio-economic criteria focus on community needs, accessibility, and the potential for community engagement in NBS initiatives. Hazard mitigation criteria highlight areas that can effectively reduce flood and landslide risks. We were performing a Multi-Criteria Analysis (MCA) to evaluate these criteria, assigning weights based on their significance in achieving effective NBS outcomes. Utilizing GIS, we overlay suitability criteria layers, allowing us to assess cumulative suitability scores across the landscape. This analysis helps in identifying optimal sites for NBS implementation, ensuring that the selected locations have been provided with maximum ecological and social benefits.

Parameter Weighting Using AHP

The parameters were weighted using the Analytical Hierarchy Process (AHP) introduced by Saaty (2004) (see Annexes 1 and 2). Pairwise comparisons were conducted, and consistency ratios (CR) were calculated to ensure decision matrix validity ($CR < 0.1$). The geometric mean method was used to calculate eigenvector weights, allowing integration of expert judgments and biophysical rationale.

$$a_{ji} = 1/a_{ij}$$

Where (a_{ij}) is the element of row (i) and column (j) of the matrix.

$$E_{gi} = (a_{i1} \times a_{i2} \times a_{i3} \dots \times a_{in})^{1/n}$$

Where E_{gi} is the eigenvector value for the row (i) and n is the number of elements in row (i)

$$P_{ri} = E_{gi} / (\sum E_{gi})$$

Where, pri is the priority vector or normalization of eigenvector i.e., the weighted one

$$\lambda_{\max} = \sum_{j=1}^n [w_j \sum_{i=1}^m a_{ij}] \text{-----}$$

-----8

Where $\lambda_{\max}$ is the maximum eigenvalue as indicated in the formula (4), has been obtained from the summation of products between each component of the weighted eigen (w_j) and the sum of the column of the reciprocal matrix.

$$CI = (\lambda_{\max} - n) / (n - 1) \text{-----}$$

-----9

Where CI is the consistency index, n is the number of elements. Conceptually, it is the mean deviation of the components of the elements and the standard deviation of the evaluation error from the actual one.

$$CR = CI / RI \text{-----}$$

-----10

Where CR is the consistency ratio, RI is the random index value. Based on the eigen principle, a CR value of less than or equal to 0.1 is statistically significant or acceptable, and the result is consistent. In contrast, a CR value greater than 0.1 is statistically not substantial or unacceptable. Furthermore, the pairwise reciprocal comparison of criteria which the decision maker makes, has been inconsistent, indicating that the requirements should be redesigned.

Mapping and Visualization

The results of our assessments were visually represented through a series of maps. Suitability maps for NbS highlighted areas identified as optimal for implementation, guiding decision-makers in selecting sites where NbS can yield the greatest ecological and social benefits. These visual representations make complex data more accessible and actionable for stakeholders involved in urban planning and resilience building.

Validation and Ground Truthing

To ensure the accuracy of our findings, we conducted field surveys to verify the information obtained from GIS and remote sensing analyses. Engaging with local communities is essential for understanding their perceptions of vulnerability and the suitability of identified locations for NbS. We organized a participatory mapping session to discuss the mapping results, fostering a collaborative approach that allowed us to gather feedback and refine our maps based on local knowledge. This engagement

ensured that our findings are contextually relevant and reflect the needs and priorities of the community.

Integration into Planning

The final step of our methodology involved integrating our findings into actionable plans. We compiled our findings into a comprehensive report that includes detailed maps, data analyses, and recommendations for incorporating NbS into local climate adaptation and mitigation strategies. Based on our research, we provided actionable recommendations that will guide the effective deployment of NbS at a grassroots level, fostering long-term sustainability and resilience in Dessie City.

4. Results and Discussion

4.1 Demographic Characteristics of Respondents

Survey data were collected from 305 randomly selected respondents from six study sites in four sub-cities, namely Arada sub-city 49 (16.1%), Hotie sub-city 120 (39.3%), Menafesha sub-city 61 (20%), and Segno-Gebaya sub-city 75 (24.6%). The great majority of the respondents were male 63% while female respondents accounted for 37%. Regarding their marital status, 76.1% were married, while the remaining had single (12.8%), widowed (6.6%), divorced (3%), and separated (1.6%) status. Among the respondents, 34.9% engaged in self-employment occupations, while 30.5% were employed either in public or private sectors. Unemployed respondents comprised 17.4% while the remaining were retired (8.9%), students (3.3%), engaged in urban agriculture (1.6%), or other activities (3.3%). The mean age of respondents was 46.76 years (SD=14.598) with a minimum and maximum of 19 and 88 years old. The educational status of the respondents indicates that the majority (73.4%) had attained some level of formal education, whereas 8.5% reported having only informal education, defined as the ability to read and/or write without formal schooling. Approximately 17.7% of the respondents had no formal education at all. The mean grade level completed by the sample was 10.57 (SD = 3.216), with values ranging from a minimum of 2 years to a maximum of 18 years of schooling. Regarding their length of residence in the study area, 55.7% of respondents had lived there for more than ten years, while 35.1% had resided in the area for six to ten years, and 9.2% had lived there for one to five years (Table 1 and Figure 5).

Table 1: Demographic Characteristics of respondents

No	Issue/category	Responses	N	%
1	Sub-city	Arada	49	16.1

		Hotie	120	39.3
		Menafesha	61	20.0
		Segno Gebeya	75	24.6
		Total	305	100.0
2	Sex	Male	192	63.0
		Female	113	37.0
		Total	305	100.0
3	Marital Status	single	39	12.8
		Married	232	76.1
		Separated	5	1.6
		Divorced	9	3.0
		Widowed	20	6.6
		Total	305	100.0
4	Principal Occupation	Employed (Public/private sector)	93	30.6
		Self-employed (Business person)	106	34.9
		Student	10	3.3
		Unemployed	53	17.4
		Urban Agriculture	5	1.6
		Retired	27	8.9
		other	10	3.3
		Total	304	100.0
5	Educational level category	No Formal Education	54	17.8
		Informal Education	26	8.6
		Have Formal Education	224	73.7
		Total	304	100.0
6	Duration of residence in the area	1-5 years	28	9.2
		6-10 years	107	35.1
		More than 10 years	170	55.7
		Total	305	100.0
7	Frequency of visit to NbS	Daily	5	1.6
		Weekly	40	13.2
		Monthly	21	6.9
		Rarely	186	61.2
		Never	52	17.1
		Total	304	100.0

Source: Survey Output (2025)

4.2 Participation of respondents in NbS activities and their Motives

The frequency of their visit to the NbS was assessed using a rating scale. As indicated in Figure 5, around 17 percent did not have a habit of visiting such places. A great majority of respondents (61%) visited NbS rarely, while those who visited such places monthly, weekly were 7% and 13% respectively. Only a small proportion of the respondents (2%) had a habit of visiting NbS daily. Their participation in NbS-related activities and the reasons behind it were also assessed. Around 72.1% of the respondents have participated in various NbS-related activities, primarily in tree and vegetation planting (96.4%), cleaning and waste management (77.7%), NbS maintenance (55.9%), and attending community meetings about NbS (49.1%). Those who had participated in planning and designing of NbS (15%) and fundraising or donation for NbS (11.4%) were very small (see Table 2 and Figure 6). The first three major motivating factors for their participation, as depicted in Table 2 and Figure 7, were environmental concern (94.1%), ideal conditions for social interaction (62.7%), and the opportunity for incentives or rewards (49.1%).

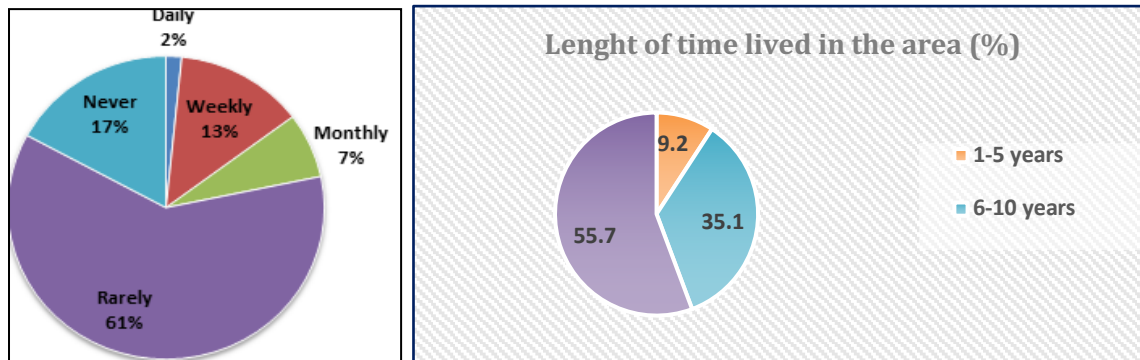


Figure 5: Respondents' Frequency of Visit to NbS and Duration of Residence in the Area

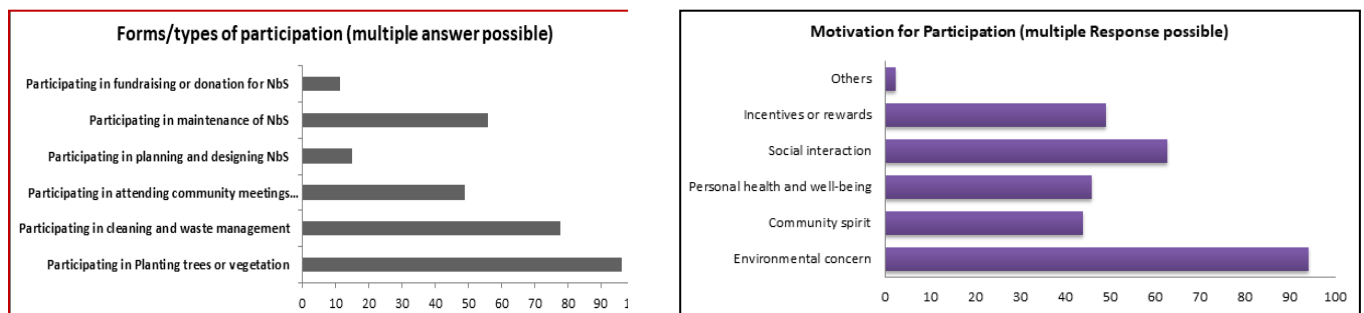


Figure 6: Forms or types of participation in NbS activities

Figure 7: Motivation for Participation in NbS activities

Table 2: Participation of respondents in NbS activities and Motives for participation

No	Item	Response	Percentage
1	Have you ever participated in activities related to the maintenance or management of NbS? (N=305)	Yes (N=220)	72.1
		Not at all (N=85)	27.9
2	Form/types of participation (multiple responses possible)	Yes	%
	Participating in planting trees or vegetation	212	96.4
	Participating in cleaning and waste management	171	77.7
	Participating in attending community meetings about NbS	108	49.1
	Participating in planning and designing NbS	33	15
	Participating in the maintenance of NbS	123	55.9
	Participating in fundraising or donations for NbS	125	11.4
	Others	2	0.9
3	Motivation for Participation (multiple responses possible)	Yes	%
	Environmental concern	207	94.1
	Community spirit	97	44.1
	Personal health and well-being	101	45.9
	Social interaction	138	62.7
	Incentives or rewards	108	49.1
	Others (government mobilization, landslide protection, and owning land)	5	2.3

Source: Survey Output (2025)

Participation Levels in NbS-related Activities

The low mean score of 1.00 indicates that very few community members are involved in the planning and design of NbS, as shown in Table 3. The significant SD of 1.059 implies a wide range of experiences, with many participants indicating no involvement at all. This lack of engagement aligns with findings from Barton *et al.* (2016), who emphasize the importance of community participation in the successful implementation of NbS (Barton *et al.*, 2016). Holt *et al.* (2018) highlight that active involvement fosters a sense of ownership and can improve the effectiveness of these solutions (Holt *et al.*, 2018). However, Kumar and Sunder (2020) caution that without proper mechanisms for community engagement, planning efforts may not accurately reflect the needs and preferences of local populations (Kumar and Sunder, 2020). These insights underscore

the necessity of enhancing community involvement in the planning and design processes to ensure that NbS are effective and widely accepted. Better engagement of the community was observed in maintenance of NbS ($M=1.35$) and in tree planting activities ($M=1.29$). A study by Cilliers *et al.* (2016) revealed that perceived barriers, such as a lack of time and awareness, significantly hinder community involvement in these activities. To overcome such problems, Fischer *et al.* (2019) suggested the need for designing effective communication and incentive strategies that would help to enhance their engagement and to promote a sense of responsibility towards urban green spaces. The SD of 1.135 for tree planting indicates variability in responses, suggesting differing levels of participation and awareness among community members. This aligns with findings from González *et al.* (2017), who note that a lack of resources and understanding of opportunities often limits community involvement in such activities. Furthermore, Boulton *et al.* (2018) emphasize that fostering a culture of participation can significantly enhance community engagement in green initiatives. These insights underline the need for strategies to boost community engagement in activities related to NbS.

On the other hand, the participation of respondents in awareness campaigns, meetings, or public forums related to NbS yielded a mean score of 1.11, with a standard deviation (SD) of 1.041 (Table 3). This metric indicates a low level of engagement among participants in these activities. This score is significantly below the midpoint of the scale (which ranges from 0 to 3), indicating that most respondents either do not participate at all or have very limited engagement in such initiatives. Cohen *et al.* (2016) emphasize the importance of public engagement in raising awareness about NbS, noting that effective communication strategies can enhance community participation. Additionally, Bennett *et al.* (2020) highlights that public forums can serve as critical platforms for sharing information and fostering dialogue among community members. These insights underline the need for improved outreach efforts to bolster community involvement in awareness campaigns. Similarly, the very low mean score of 0.82 highlights an even more pronounced lack of financial support from community members for NbS initiatives. Financial contributions are critical for the sustainability of NbS (Lehmann *et al.*, 2020). Besides, community members may be more willing to contribute if they understand the tangible benefits of these initiatives. As a result, enhancing awareness and addressing perceived barriers could encourage greater financial support for NbS.

Table 3: Participation Levels of the Community

Participation Levels	N	Mean	SD
I actively participate in the planning and design of nature-based solutions in my community.	305	1.00	1.059

I actively participate in activities related to the maintenance or management of UGS	303	1.35	1.157
I regularly engage in activities like tree planting, landscaping, or maintenance of green spaces	304	1.29	1.161
I participate in awareness campaigns, meetings, or public forums related to nature-based solutions	304	1.11	1.041
I contribute financially or materially to the development and upkeep of nature-based solutions	304	.82	.998

Source: Survey Output (2025)

4.3 Perception of Participants on the Perceived Benefits of NbS

Typologies of NbS

Different forms of NbS are identified in the Dessie City administration. The major one is the forest resource in and around the city (mainly in the surrounding *Tossa* mountain range, which was reforested in the previous regime during 1974-1991). Besides, both biological and physical forms of NbS have been introduced over the last ten years. The dominant tree types include the eucalyptus tree (planted by the government, Religious institutions, and local social associations as well as at the individual level), which has multi-purpose (provides conservation role, source of fuel wood, construction materials, among others). *Juniperus procera* forest ranks second in terms of geographical coverage. Most of the mountain range and church compounds are covered with this type of tree. Some indigenous trees are also found in scattered places. Grass families are also found in some localities (Figure 8). According to the FGD we conducted with experts of urban agriculture and natural resource management, the most challenging environmental hazards in Dessie city are flooding and landslides. These hazards have been causing severe disasters in the town. In response, government-sponsored NbS development in the city began in 2010; since then, numerous NbS sites have been established. The most notable sites include Sire Minch and Segno Gebeya. Later, NGOs and the World Bank also joined in supporting NbS development through various intervention projects. One of such projects is the Climate Change Adaptation (CCA) project at Sire Minch in Hotie sub-city, which introduced different biological and physical conservation measures. According to these respondents, the biological conservation interventions helped to increase rainwater infiltration, which significantly reduced the frequency and magnitude

of flooding. In contrast, the table terraces and gabions reduced the impact of landslides and associated hazards like rock falls and talus flow.



Figure 8: Major topologies of NbS interventions (partial): reforestation, terracing, hillside plantation, riverside conservation, slide stabilization, natural regeneration

(Photo Credit: The Research Team, 2025)

Perceived Benefits of NbS in Dessie City Administration

The study's findings offer valuable insights into the perceptions of residents in Dessie City regarding the benefits of NbS (Table 4 and Figure 9 for detailed perceived economic, health, ecological, social, and environmental benefits of NbS). The results show significant differences between the four main benefit categories: financial, health, social, and environmental/ecological. We used a neutral test value of 3 to conduct a one-sample t-test.

Perceived Economic Benefits of NbS

The economic benefits of NbS in Dessie are a topic of debate. Although respondents strongly agreed that investments in NbS can result in more job opportunities ($M = 3.71$, $p < 0.001$) and attract new businesses to the area ($M = 3.68$, $p < 0.001$), many disagreed or were unsure about other economic consequences. The study did not anticipate that NbS would significantly increase property values ($M = 2.76$, $p < 0.01$), attract tourists, and boost the local economy ($M = 2.66$, $p < 0.001$). Although stakeholders recognize NbS as a key employer and business driver, its impact on tourism, value growth, and leisure-based revenue in Dessie remains unclear. The results can reflect the city's poor leisure culture and inadequate tourism infrastructure. Community voices support this: one young respondent said, "Many young people in our area get temporary jobs when there are tree planting or watershed projects." Even temporary employment enables them to support their families. "I don't think tourists will come here just because of the green area," remarked an older local. But perhaps tourists would appreciate our green areas if there were adequate amenities. The Climate Resilient Green Economy (CRGE) strategy in Ethiopia places a strong emphasis on eco-enterprises and the creation of green jobs as a means of achieving sustainable urban growth (FDRE, 2011). The expected economic gains, however, might not materialize in mid-sized cities like Dessie, where the real estate and tourism industries are less developed (Amhara National Regional State, 2019). According to research conducted in other African cities, the economic potential of NbS is underestimated frequently due to the lack of ecotourism infrastructure and underdeveloped real estate markets (Kabisch *et al.*, 2016).

Health Benefits

Most inhabitants agreed that there are several ways in which NbS enhance health and wellbeing. The respondents reported significant improvements in noise pollution ($M = 4.13$, $p < 0.001$), prevention of heat-related illnesses ($M = 4.07$, $p < 0.001$), air quality ($M = 4.13$, $p < 0.001$), promotion of healthier lifestyles ($M = 4.02$, $p < 0.001$), and encouragement of exercise and outdoor activities ($M = 4.06$, $p < 0.001$). These findings demonstrate widespread consensus regarding the positive impacts of NbS on public health, which is essential in Dessie, where urbanization and climate change exacerbate environmental health hazards. Green spaces and tree-planting initiatives, for example, can lower air pollution and urban heat while encouraging outdoor recreation for families and children. The opinions of the community support this: "We feel healthier when we walk in shaded areas," a female respondent stated. "The shade of trees is a blessing during the hot season," said a senior participant. These findings align with global studies that demonstrate urban green spaces enhance respiratory health, reduce heat stress, and encourage active lifestyles (WHO, 2016; Jennings & Bamkole, 2019). They also encourage outdoor exercise, which leads to healthier lifestyles (Twohig-Bennett & Jones,

2018). The WHO (2020) states that urban greening is an affordable public health initiative.

Perceived Social Benefits of NbS

Respondents agreed that NbS has social value because it helps people connect ($M = 3.92$, $p < 0.001$) and provides places for people to gather and engage in activities together ($M = 3.72$, $p < 0.001$). However, NbS had a neutral and statistically insignificant impact on encouraging community involvement and volunteering ($M = 3.02$, $p = 0.814$). This suggests that people typically view NbS as public spaces that unite communities, but it remains unclear how effectively they might encourage community involvement. The community's opinions show this. One older person said, "Green spaces are where we relax and talk to our neighbors." Women stressed the importance of family time: "We mothers use this time to talk to other families while our kids play in green spaces." This outcome aligns with international studies, which indicate that while green spaces foster social cohesion, their capacity to stimulate active civic participation requires deliberate planning and programming (Pauleit *et al.*, 2017). The absence of volunteer engagement in NbS programs may be attributed to the prevalence of social gatherings in numerous African cities, which often occur within cultural or religious contexts rather than in public parks. Similar outcomes have been observed in Sub-Saharan Africa, where NbS are underutilized as platforms for civic engagement yet valued as communal spaces (Cohen-Shacham *et al.*, 2019).

Perceived Environmental Benefits of NbS

NbS provide significant ecological and environmental benefits, supported by robust data. NbS reduces air pollution ($M = 4.35$, $p < 0.001$), enhances biodiversity and wildlife habitats ($M = 4.40$, $p < 0.001$), mitigates the urban heat island effect ($M = 4.08$, $p < 0.001$), improves water quality ($M = 4.47$, $p < 0.001$), aids in carbon sequestration ($M = 4.15$, $p < 0.001$), prevents soil erosion ($M = 4.60$, $p < 0.001$), and enhances storm water management while lowering flooding risk ($M = 4.53$, $p < 0.001$). The high mean scores indicate widespread recognition of NbS's value for ecological and climate resilience, particularly in Dessie City, which faces frequent flooding, land degradation, and soil erosion in its peri-urban areas. Residents view NbS as a vital solution to these environmental challenges. As a reflection of local challenges with land and water management, the benefits identified with the highest ratings were flood control and prevention of soil erosion. The community supports this, with one senior respondent stating, 'The soil does not wash away easily when the hills are covered with trees.' This keeps our farmland safe. "We see that places with more vegetation are less affected by flooding," a young respondent continued. Trees are better at retaining water. Dessie's

local reality of frequent flooding, soil erosion, and land degradation is reflected in these perceptions. Similarly, a 58-year resident shared his observation on the role of NbS as: *“...the green spaces have proven effective in managing storm water runoff, reducing the risk of landslides and flooding mainly in the vulnerable areas. Their natural design helps absorb excess rainwater, mitigating potential damage during heavy rainfall events.”* These findings align with Ethiopia's National Adaptation Plan and CRGE strategy, which emphasize the importance of green infrastructure, soil conservation, and watershed restoration in enhancing climate resilience (FDRE, 2011; FDRE, 2019). Globally, NbS have proven highly effective in increasing urban resilience to flooding and mitigating heat island effects (Raymond et al., 2017). Research strongly supports these conclusions. Wetlands, green roofs, and tree cover are NbS that reduce flood risks and improve water quality (Nesshöver et al., 2017). They also capture carbon (Strohbach and Haase, 2012), enhance urban biodiversity (Haase et al., 2014), and prevent soil erosion while stabilizing riverbanks (Cohen-Shacham et al., 2019). In addition to community perspectives, discussions with municipal officials, head of urban productive safety net program, and natural resource management top officials revealed that local authorities acknowledge the strategic importance of NbS in mitigating flooding, stabilizing slopes, and landslide risks, besides their role in improving the city's livability. However, they emphasized that the absence of clear institutional frameworks and sustainable financing mechanisms remains a barrier to effective scaling-up. City officials expressed the need for better policy alignment and interdepartmental coordination to mainstream NbS into urban planning and budgeting processes. An official from the natural resource management department strongly blamed the lack of coordination as far as NbS is concerned, stating that areas rehabilitated are used for housing construction by the municipality. Head of urban productive safety net program also shared the concerns raised by head of Dessie city natural resource management that unless a coordinated action is not taken, areas which are susceptible for flooding and landslide are at risk of encroachment and expansion of settlement.

Table 4: The perceived benefits of NbS in Dessie city Administration

Category of Benefits	Perceived Benefits (Alternatives)	N	Mean	SD	One-sample t-test (t-value=3)					
					t	df	Sig. (2-tailed)	Mean Difference	95% CI of the d/ce	
									Lower	Upper
Economic	NbS increases property values in my community	304	2.76	1.395	-3.002	303	.003	-.240	-.40	-.08
	NbS attract tourists and visitors, benefiting and boosting the local economy	303	2.66	1.585	-3.770	302	.000	-.343	-.52	-.16
	Investing in NbS creates more job opportunities	303	3.71	1.248	9.896	302	.000	.710	.57	.85
	NbS encourages new businesses to open in the area	303	3.68	1.291	9.209	302	.000	.683	.54	.83
	NbS increases revenue from recreational activities	301	2.76	1.575	-2.598	300	.010	-.236	-.41	-.06
Health	NbS improves my physical health and promotes healthier lifestyles for children and families	304	4.02	.904	19.657	303	.000	1.020	.92	1.12

	Access to NbS encourages outdoor physical activity and exercise	305	4.06	.843	21.871	304	.000	1.056	.96	1.15
	NbS improves air quality, benefiting my respiratory health	304	4.13	.803	24.636	303	.000	1.135	1.04	1.23
	The presence of NbS in the city prevents heat-related illnesses	303	4.07	.813	22.899	302	.000	1.069	.98	1.16
	NbS helps reduce noise pollution	301	4.13	.925	21.249	300	.000	1.133	1.03	1.24
Social	NbS brings people together and strengthens community bonds and interactions	305	3.92	1.117	14.457	304	.000	.925	.80	1.05
	NbS provides a space for social events and gatherings	303	3.72	1.191	10.559	302	.000	.723	.59	.86
	NbS provides opportunities for volunteering and community engagement	305	3.02	1.462	.235	304	.814	.020	-.15	.18
Environmental/ecological	NbS helps reduce air pollution	305	4.35	.746	31.549	304	.000	1.348	1.26	1.43
	NbS provide habitats for wildlife and promote biodiversity	303	4.40	.682	35.631	302	.000	1.396	1.32	1.47
	NbS reduces the urban heat island effect	304	4.08	.786	23.857	303	.000	1.076	.99	1.16
	NbS improves water quality by filtering runoff	303	4.47	.684	37.279	302	.000	1.465	1.39	1.54

	NbS contributes to carbon sequestration and reduces greenhouse gas emissions	305	4.15	.753	26.616	304	.000	1.148	1.06	1.23
	NbS helps prevent soil erosion	303	4.60	.600	46.308	302	.000	1.597	1.53	1.67
	NbS contributes to better stormwater management and reduces flooding	303	4.53	.624	42.743	302	.000	1.531	1.46	1.60

The Responses were rated as: (1=strongly disagree, 2=Disagree, 3=Neutral, 4=Agree, 5=Strongly Agree)

Source: Survey Output (2025)

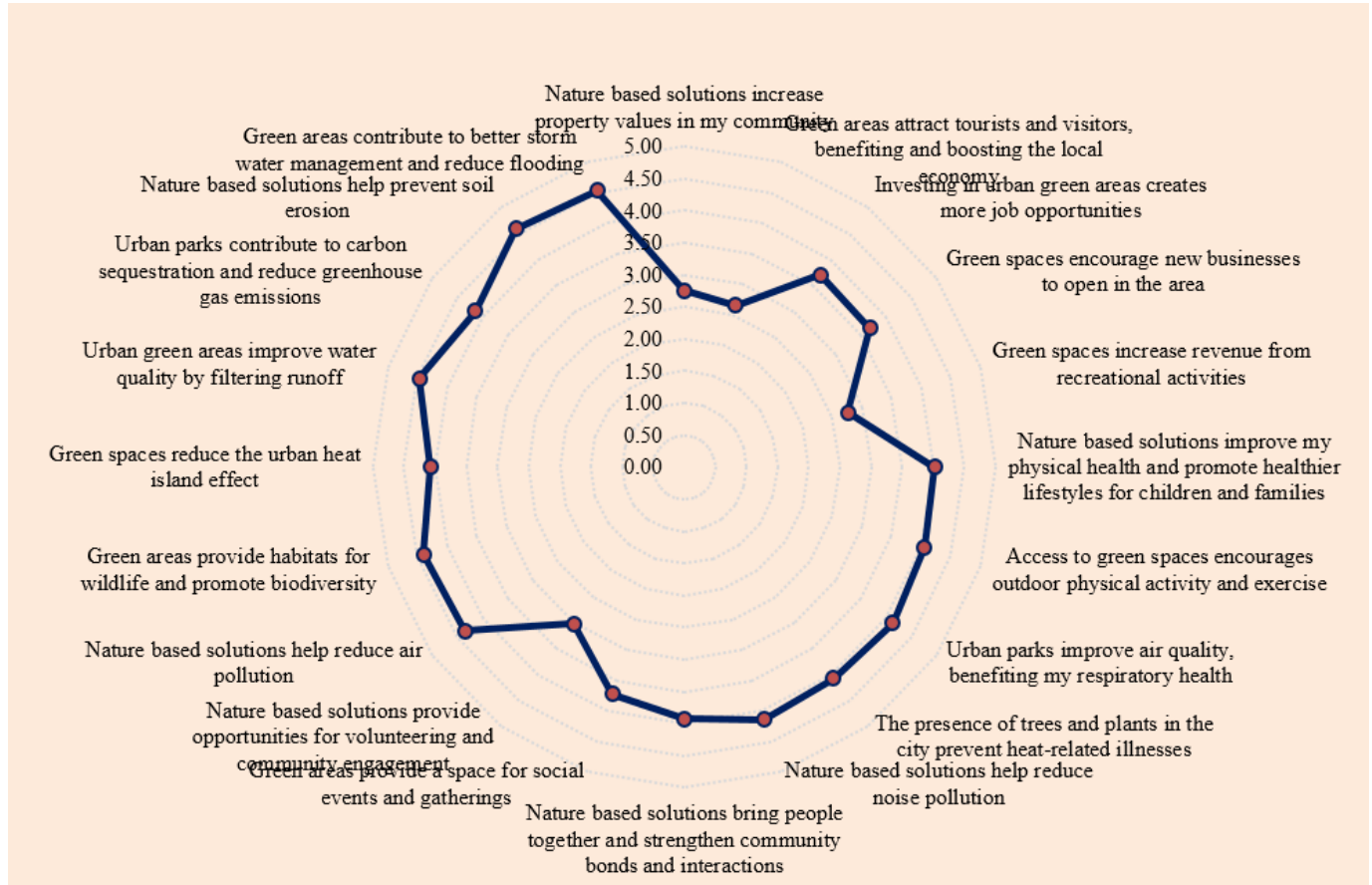


Figure 9: Spider diagram that shows the perceived benefits of NbS

Source: (Survey, 2025)

4.4 Perception of Respondents on the Actual Benefits of NbS

The analysis of residents' perceptions of NbS in Dessie City Administration, based on the weighted mean value and a one-sample t-test, provides valuable insights into how local communities evaluate the actual benefits of these interventions. As indicated below, the findings revealed distinct patterns across four major categories of benefits: economic, health, social, and environmental/ecological (Table 5). The integration of case study analysis from Sire Minch, Segno Gebeya, Mitiro, and Arera sites provided qualitative depth to the quantitative survey findings. These case studies illustrated how varying environmental conditions, governance structures, and community engagement levels influenced the performance and sustainability of NbS interventions. The triangulation of case study evidence with survey data strengthened the reliability of the results and clarified the contextual factors driving success or failure across different urban settings.

Actual Economic Benefits of NbS

Perceptions of residents on the economic benefits of NbS were mixed. Respondents largely disagreed that NbS increased their property values ($M = 2.41$, $SD = 1.267$) or attracted tourists that generated direct household income ($M = 2.08$, $SD = 1.293$). These findings suggest that NbS are not yet perceived as yielding tangible economic benefits at the individual or household level (Figures 10 and 11). A similar study conducted using meta-analysis indicated that the economic benefits of NbS are sensitive to various contexts. For instance, large, well-managed, and high-amenity green spaces sometimes correlate with higher property values. In contrast, many smaller or less accessible green interventions show little or no effect on property prices or direct household income unless accompanied by broader planning, accessibility, and market factors (Bockarjova et al., 2020). By contrast, there was moderate agreement that NbS contributed to local employment and business opportunities. The statement “Investing in NbS created more job opportunities” received a slightly positive rating ($M=3.24$, $SD =1.395$), while “NbS encouraged new businesses to open in the area” was also rated favorably ($M =3.23$, $SD =1.423$). The one sample t-test result revealed that the results are statistically and significantly different from neutral at 5% significance level. This suggests that, although the broader economic impacts of NbS may not yet be widely felt, residents recognize their potential role in stimulating employment and business development. Similarly, an assessment by the International Labor Organization indicated that NbS can create local employment opportunities. However, the quantity and quality of jobs depend on how NbS projects are financed, governed, and integrated into local livelihood strategies (ILO/IUCN/UNEP, 2022).

A key informant participant from the natural resource management department (Dessie city agricultural office) shared her experience regarding the ecological and economic benefits of NbS as: NbS has benefited the local community and the city in different ways. Their role in mitigating flooding during the rainy season by reducing water inflow and landslide hazards is appreciable. However, incidents still prevail in areas where such infrastructures are weak. Consistent with the broader body of literature, the study confirmed that while communities recognize the multiple benefits of NbS, their utilization is constrained by structural and economic barriers. Limited institutional capacity, fragmented governance, and a lack of financial incentives hinder the ability to scale up NbS practices. These constraints align with findings from other Sub-Saharan African cities, where the success of NbS largely depends on integrating them into local policy frameworks, securing sustainable financing, and mobilizing partnerships between the private sector and communities. Expanding NbS mainly in the upstream regions will enable us to reduce such climate change hazards substantially. Regarding their economic contribution, much work remains to be done to convert these resources into a source of

income for the residents. Besides serving as forage for their animals and a source of fuel wood and construction materials, the NbS currently provides little economic benefits. Unless NbS developments bring economic returns, their sustainability might be questionable. To do so, there is a need to expand auxiliary infrastructure, mainly road access and lighting.

According to the FDG participants, tree planting along the riverbanks and on slopes has enabled a reduction in soil erosion and landslides, along with regulating runoff. Besides their ecological benefits, NbS provides sociocultural importance where such spaces serve as gathering points for the community. Though it is not as expected, NbS also plays a role in being a source of livelihood, mainly for peri-urban residents. The attempt to make rehabilitated areas a source of livelihood for unemployed youths has failed due to misunderstandings and a lack of commitment from the beneficiaries' side. According to FGD participants, although training and awareness creation activities focused on animal fattening and fruit production in the rehabilitated areas, youths struggled to succeed due to their ambition to reap benefits quickly.



Figure 10: Ecosystem services of NbS (partial):

Stabilizing susceptible lands, protecting the soil from erosion, providing fuel and construction material, and providing drinking water (Photo Credit: WU Research Team, 2025)



Figure 11: NbS as a source of forage and grazing land for livestock, and a source of livelihood (fruit and vegetable cultivation, beekeeping)

(Photo Credit: WU Research Team, 2025)

Actual Health Benefits of NbS

The strongest positive perceptions were recorded under health-related benefits. Respondents overwhelmingly agreed that NbS reduced stress and anxiety ($M = 4.23$, $SD = 0.672$), improved respiratory health through enhanced air quality ($M = 4.20$, $SD = 0.676$), and helped reduce noise pollution ($M = 4.19$, $SD = 0.819$). Access to NbS was also strongly associated with encouraging outdoor activities and exercise ($M = 4.00$, $SD = 0.844$) and promoting healthier lifestyles for children and families ($M = 3.90$, $SD = 0.873$). In addition, respondents acknowledged that NbS fostered social connections ($M = 3.92$, $SD = 1.101$). The one-sample t-test result revealed that the results are statistically and significantly different from neutral at 5% alpha level. These results demonstrate that the community places a high value on the mental, physical, and social health benefits of NbS, underscoring their significance beyond purely ecological functions. The positive perceptions of the community on the actual health benefits of NbS are strongly supported by a recent study, which indicated that being near nature (green and blue spaces) leads to less stress, more exercise, and benefits from cleaner air and less noise (Jimenez et al., 2021). This is also true in Ethiopia, where a study in Addis Ababa found that young adults living in greener areas had fewer emotional and behavioral problems, proving that access to nature is essential for mental health in Ethiopian cities as well (Zewdie et al., 2022).

Actual Social Benefits of NbS

Residents' perceptions of the social benefits of NbS were moderately positive but less consistent. Residents agreed that NbS improved social cohesion and cooperation ($M = 3.74$, $SD = 1.147$), created spaces for social gatherings ($M = 3.61$, $SD = 1.167$), and provided opportunities for cultural and recreational activities ($M = 3.64$, $SD = 1.178$). However, inclusivity was a concern because the perception of NbS's role in promoting cultural and recreational activities for all age groups was rated below the average value ($M = 2.56$, $SD = 1.470$), suggesting that not all segments of society feel equally represented in NbS benefits. Similarly, NbS were not perceived as strong drivers of volunteering and community engagement ($M = 2.85$, $SD = 1.429$). The one-sample t-test result revealed that the results are statistically and significantly different from neutral at 5% alpha level. This highlights a significant gap in NbS's potential for inclusivity and participatory engagement. These mixed social perceptions mirror broader literature indicating that while NbS can foster place-making, social interaction, and community resilience, outcomes for inclusion, equity, and participation depend heavily on participatory design, governance structures, and proactive measures to ensure equitable access (Pinto *et al.*, 2023). In an interview, 48-year-old residents strongly agreed that easily accessible NbS resources are becoming conducive areas for social gathering. Different community discussions are being held in such places, which strengthen the sense of belonging among the residents. Utilizing these opportunities for awareness campaigns about the multifaceted benefits of NbS resources is necessary.

Actual Environmental and Ecological Benefits of NbS

The residents of Dessie City highly value the environmental and ecological benefits of NbS. Respondents strongly agreed that NbS reduced air pollution ($M = 4.41$, $SD = 0.697$) and enhanced biodiversity by providing habitats for wildlife ($M = 4.46$, $SD = 0.584$). Perceptions were powerful regarding the role of NbS in mitigating natural hazards. Residents recognized the contribution of NbS in preventing soil erosion ($M = 4.68$, $SD = 0.557$), in reducing landslide and flooding risks ($M = 4.69$, $SD = 0.548$), and in improving water storage capacity ($M = 4.42$, $SD = 0.609$, $t = 40.610$, $p < 0.001$). Moreover, improving water quality ($M = 4.60$, $SD = 0.554$) and reducing the urban heat island effect ($M = 4.16$, $SD = 0.70$) were additional actual benefits of NbS, which received a positive perception from residents, where all results were statistically different from neutral at a 5% significance level. These observations align with reviews that indicated that NbS can reduce runoff and flood risk, retain sediment and stabilize slopes, improve infiltration and water quality, support urban biodiversity, and provide measurable local cooling effects.

However, their effectiveness depends on the appropriateness of NbS design, climate, morphology, intervention scale, and maintenance (Li et al., 2024). In the Ethiopian context, field studies confirm significant climate-mitigation and biodiversity contributions of urban green spaces; for example, detailed work in Dessie documented substantial carbon storage and woody species richness (being refugee camps for indigenous species), underlining that local green spaces can deliver essential ecological services when conserved and managed (Muluneh and Worku, 2022).

FGD and KII participants unequivocally affirmed that NbS has changed the microclimate of the surrounding area in regulating the temperature, reducing dust pollution, becoming a refuge for wild animals, making the scenery attractive, regulating the run-off, stabilizing the land slide, among others and according to the FGD conducted with few residents at a small village around *Sire Minch* confirmed that formerly the area was highly prone to flooding and landslides. However, it was after the introduction of government-owned NbS that they could deter landslide and flooding impacts. Moreover, they asserted that nowadays they are fetching high-quality, pure drinking water from their nearby spring water, which emerged and developed after the introduction of the NbS that enhanced percolation of rainwater upstream of the spring site.

As a concluding remark, the findings of this study reveal a clear hierarchy in the perception of residents on the actual benefits of NbS. Ecological and health benefits of NbS are found to be most strongly recognized, which reflects widespread awareness of the community on the role of NbS in safeguarding the environment and improving quality of life (see Figure 12 and Case Study 1-4). Social benefits were acknowledged, but their impact was limited by concerns over inclusivity and the remaining lack of participatory opportunities. Economic benefits of NbS were viewed as relatively weak, with most residents not perceiving direct household-level gains except for modest opportunities in employment and small business development. These findings underscore the need for a more integrated approach to implementation of NBS. For local authorities and stakeholders in Dessie City, future efforts should build upon the strong ecological and health dimensions while addressing the weaker economic and social aspects. Enhancing inclusivity, strengthening community engagement, and creating livelihood-oriented opportunities can help ensure that NbS interventions are not only environmentally sustainable but also socially equitable and economically visible. Such an approach would maximize community acceptance and ensure the long-term sustainability of NbS as a core strategy for building urban climate resilience.



Figure 12: Environmental and Ecological benefits of NbS (partial): Land stabilizing structure, river side protection, and Stone Bund terracing

(Photo credit: WU Research Team, 2025)

Table 5: Perception of residents on the actual Benefits of the NbS in Dessie City Administration.

Category of Benefits	Actual benefits alternatives						N	Mean	SD	One-Sample Test (t-value=3)					
		SDA	DA	N	A	SA				Calculated t-value	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the d/ce	
		1	2	3	4	5								Lower	Upper
Economic	NbS increased my property values	101	68	62	58	16	305	2.41	1.267	-8.137	304	.000	-.590	-.73	-.45
	NbS attracted tourists, and that benefited me economically	145	70	24	49	16	304	2.08	1.293	-12.371	303	.000	-.918	-1.06	-.77
	Investing in NbS created more job opportunities	58	42	22	131	50	303	3.24	1.395	3.007	302	.003	.241	.08	.40
	NbS encouraged new businesses	61	43	19	127	54	304	3.23	1.423	2.821	303	.005	.230	.07	.39
Health	NbS improved my physical health and promoted healthier lifestyles for children and families	5	14	61	152	73	305	3.90	.873	17.965	304	.000	.898	.80	1.00
	Spending time in NbS reduced stress and anxiety	1	2	29	164	106	302	4.23	.672	31.872	301	.000	1.232	1.16	1.31
	Access to NbS encouraged my outdoor physical activity and exercise	2	15	50	149	87	303	4.00	.844	20.699	302	.000	1.003	.91	1.10

	NbS improved air quality, benefiting my respiratory health	1	2	32	165	100	300	4.20	.676	30.836	299	.000	1.203	1.13	1.28
	NBS helps me reduce noise pollution	1	5	56	111	127	300	4.19	.819	25.223	299	.000	1.193	1.10	1.29
Social	NBS helped to enhance my social connections	14	22	44	114	105	299	3.92	1.101	14.399	298	.000	.916	.79	1.04
	NbS brought people better social cohesion and cooperation	17	31	54	114	88	304	3.74	1.147	11.253	303	.000	.740	.61	.87
	NbS provided me with a space for social events and gatherings	21	32	68	108	75	304	3.61	1.167	9.043	303	.000	.605	.47	.74
	NbS provided us with opportunities for cultural and recreational activities	22	32	57	116	77	304	3.64	1.178	9.448	303	.000	.638	.51	.77
	NbS promoted cultural and recreational activities for all age groups	111	52	34	69	36	302	2.56	1.470	-5.206	301	.000	-.440	-.61	-.27
	NbS provided opportunities for volunteering and community engagement	82	51	33	99	35	300	2.85	1.429	-1.858	299	.064	-.153	-.32	.01
Environmental or Ecological	NbS reduced air pollution	1	4	19	126	155	305	4.41	.697	35.315	304	.000	1.410	1.33	1.49
	NbS provides habitats for wildlife and promotes biodiversity	1		8	144	152	305	4.46	.584	43.701	304	.000	1.462	1.40	1.53

NbS reduced the urban heat island effect	1	2	43	159	99	304	4.16	.706	28.670	303	.000	1.161	1.08	1.24
NbS improved water quality by filtering runoff	1		4	109	190	304	4.60	.554	50.460	303	.000	1.602	1.54	1.66
NbS prevented soil erosion	1		8	77	218	304	4.68	.557	52.605	303	.000	1.681	1.62	1.74
NbS prevented landslides and flooding	1		7	76	219	303	4.69	.548	53.631	302	.000	1.690	1.63	1.75
NbS increased water storage capacity and availability	1		13	144	144	302	4.42	.609	40.610	301	.000	1.424	1.35	1.49

Note: respondents rated alternative as [1=strongly disagree (SDA), 2=Disagree (DA), 3=Neutral (N), 4=Agree (A), 5=Strongly Agree (SA)]

Source: Survey Output (2025)

Case study 1: Amanueal Rehabilitated Forest Site

The Amanueal rehabilitated area is located in Arera Kebele of Hotie Sub-City, within the Dessie City Administration. Covering more than 30 hectares of protected forest land, the site is owned and managed by the Amanueal Orthodox Christian Church. According to the coordinator of the Church's forest development program, the restoration of this area is the outcome of more than two decades of dedicated effort and consistent investment by the Church and its partners. Formerly, the area was highly degraded. It was characterized by severe land degradation, frequent landslides, and deep dissected gorges, which made the site vulnerable to further ecological deterioration. Considering the urgency of the problem, the Church initiated, with the generous support of different actors, both physical and biological land conservation measures to reverse the damage. The project primarily focused on planting indigenous tree species and promoting natural regeneration, which allowed the ecosystem to recover gradually. In response to increasing demand for timber and income generation, exotic tree species such as eucalyptus are also introduced for their commercial value.



Note: Area under protection ^{A and B}, and well-protected area ^{C and D} (Photo credit: WU Research Team, 2025)

Now, almost the entire degraded landscape has been rehabilitated, and the scenery has undergone drastic changes. It is now covered with a rich variety of trees, shrubs, and grasses, with only a few small patches remaining unprotected. The site has become a diverse ecological sanctuary, hosting a wide range of indigenous plants, shrubs, and grasses. Beyond its vegetation cover, the rehabilitated forest has also become a home for different species of wild animals and birds, thereby contributing to local biodiversity conservation. The forest also provides essential ecosystem goods, including forage resources (mainly elephant grass) that support animal fattening, as well as a diversity of flowering shrubs and trees that sustain apiculture activities. Additionally, the holy water inside the forest area holds profound spiritual and cultural implications within the community. It is revered as a sacred source of healing and a traditional therapeutic resource, drawing people from distant localities who come in search of both spiritual

renewal and physical relief. The area, often surrounded by a dense and calm vegetated forest, also functions as a space of religious devotion and learning. Within this serene environment, religious students gather to rehearse their teachings, grounding their studies in an atmosphere imbued with blessedness and peacefulness. Although these opportunities have not yet been fully utilized, they demonstrate the forest's potential to support livelihood diversification and eco-friendly income generation for the local community.

Case study 2: Sire-Minch Rehabilitated Forest Site

The *Simre Minch* area of Menafesh Sub-City has long been considered one of the most fragile landscapes and highly susceptible to landslides in the city, which threatens the residents. Recognizing the urgent need to address these challenges, Amhara National Regional State, in close partnership with the Dessie Agricultural Office's Natural Resource Department and Dessie city urban safety net office, launched a biophysical land conservation initiative aimed at safeguarding the area while simultaneously strengthening community resilience. The project achieved the restoration and conservation of more than 12 hectares of degraded land using a variety of carefully planned and executed biophysical measures with the consent and participation of local communities, including the development of hillside terraces and check dams to stabilize slopes and control runoff, the construction of soil bunds to reduce erosion, and tree planting to restore ecological balance. There was remarkable engagement of the local community, where more than 212 individuals actively participated. The project created temporary job opportunities, allowing them both to earn much-needed income and to take part in the protection of their own environment. By stabilizing soils, reducing runoff, and restoring vegetation, the project has lessened the frequency and severity of flooding and landslides in the Simre Minch area. The project demonstrated how environmental protection and socio-economic development can be pursued hand-in-hand, the effectiveness of NGO-government collaboration, setting an example of how shared resources, expertise, and responsibilities can be harnessed to achieve long-term community and environmental resilience. This initiative serves as an inspiring model for other flood- and landslide-prone areas, showing that when communities, civil society, and government work together, the results are both impactful and enduring. But due to encroachment and expansion of illegal settlements, coupled with weak surveillance, most of the biophysical schemes are damaged, which urges immediate responses.



Project signage and biophysical soil and water conservation work of the project

Case Study 3: Salaysh Model Conservation Site

Being surrounded by steep slopes has been among the problems of Dessie city, which has exposed the city to frequent flooding and landslides. Local communities living near the mountain ranges have faced the consequences of this damage. To overcome such challenges, the Dessie City Safety Net Programme launched a water and soil conservation campaign in different parts of the susceptible areas that not only restored the land but also created vital opportunities for the people who needed them most. One such exemplary watershed initiative is *Salaysh* model conservation site in the *Segno-Gebaya* sub-city, implemented during 2024/2025, that achieved in rehabilitating 1.5 hectares of highly degraded and steep-slope land through different conservation activities like digging trenches, installing small check dams, building soil and stone bunds, and planting trees and grasses to stabilize the soil, reduce landslides and run-off, and enhance water infiltration. What made this project especially meaningful was the way it connected environmental protection with the livelihoods of local people. More than 116 household heads, primarily women and people from vulnerable households, were engaged as part of the safety net program to carry out the conservation work. By restoring steep slopes, the risk of flooding and landslides was reduced, making nearby communities safer. The new vegetation cover also improved soil health and opened up possibilities for more sustainable land use in the future. There is a plan to integrate the rehabilitated areas with the livelihoods of the nearby residents by planting edible and marketable fruits, which would have a win-win benefit in improving the income sources and fostering sustainable and healthy ecosystems. The project demonstrated that, with the right approach, a program designed to help the most vulnerable can achieve far more than short-term relief-it can restore landscapes, create opportunities, and strengthen the bonds between people and their environment.



Biophysical soil and water conservation schemes

Case Study 4: Abuye Site (Integrating Watershed Management with Livelihood)

The Abuye micro watershed, located in Segno-Gebaya sub-city, represents an exemplary NbS site that effectively harmonizes conservation of natural resources with community livelihood enhancement. Established in 2018 and managed by the Dessie Urban Productive Safety Net Program, the site has demonstrated the practical integration of environmental stewardship and socioeconomic development. Currently, the site encompasses 3.54 hectares of land and serves a total of 68 household head beneficiaries, including households and their respective family members. The site, though small in size, stands out as a model site for potential scaling-up of NbS initiatives, illustrating the feasibility of simultaneously promoting ecological sustainability and improving local livelihoods. The site integrates a diverse range of NbS innovations, mainly soil and water conservation schemes, fruit and vegetable cultivation, beekeeping, and animal fattening, collectively contributing to both community well-being and environmental resilience.



Well-maintained terracing in the Abuye micro watershed with grass for animal fattening, beekeeping, and fruit cultivation (apple)

4.5 Challenge in the Development of NbS

4.5.1. Perceptions on the Challenges Related to Nature-Based Solutions

Participants strongly perceived that NbS require high maintenance and resources, as indicated by the high mean score of 3.95 in (Figure 13). This suggests that most respondents are aware of the ongoing effort required to uphold these solutions, with a relatively low standard deviation (SD of 0.957) indicating agreement among participants on this observation. Participants were cognizant of the issues represented by the relative mean scores of 3.64 and 3.66 for wildlife and safety concerns, respectively. The SD values, albeit somewhat high, do suggest some variation, particularly for safety, where the higher SD of 1.179 indicates diverse perceptions of safety at night, which may in turn discourage them from the full use of green spaces. Goddard *et al.* (2013) point out that urban green spaces can be ecological sinks for various species of wildlife, which raises problems of pests and safety, and hence proper management is necessary. McCunn and Baird (2019) discuss the issue of urban wildlife in the context of its interrelations with human populations, noting that green spaces, despite enhancing urban biodiversity, may increase the risk of danger if unmanaged or unsupervised. This bears out the participants' sentiments regarding the potential wildlife and safety issues posed by green spaces and exposes the need to adopt a more integrated management framework.

Regarding human-wildlife conflict, respondents reported that:

Predatory wild animals-particularly hyenas, monkeys, and apes-pose a threat to both agricultural and livestock production. These animals frequently attack domesticated animals and cause damage to crops, fruits, and vegetables, especially in peri-urban areas, where the expansion of human settlements has increased the overlap between wildlife habitats and community livelihoods. This situation highlights the growing tension between conservation and subsistence needs, reflecting broader challenges of coexistence at the urban-rural interface.

The low mean score of 2.45 indicates that participants had mixed responses towards the statement that the development of green spaces results in less land being available for housing or business activities. The higher SD of 1.378 suggests that a good number of the respondents had green space concerns, perhaps. Thompson *et al.* (2012) argue that property value increases along with green spaces' potential, and land use conflict is a weak argument in the case of development, meaning land use conflict is secondary to

the value of green space. Communities would be directly involved in land use planning, and planners would be more likely to consider their input (Jim and Chen, 2006). These conflicts suggest that some participants were able to bridge green land use concerns with social value and land use conflict.

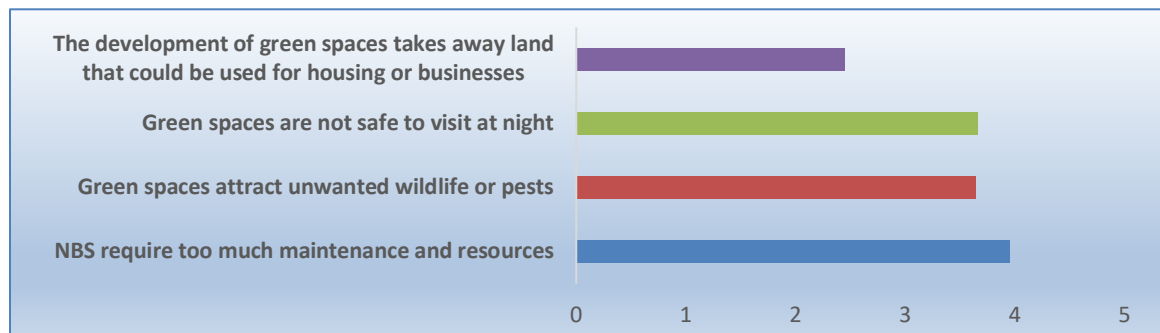


Figure 13: Attitude towards the Constraints of NbS

Source: (Survey, 2025)

Note: Respondents rated as [1=strongly disagree (SDA), 2=Disagree (DA), 3=Neutral (N), 4=Agree (A), 5=Strongly Agree (SA)]

4.5.2 Constraints Confronted To Implement NbS

Economic-related Constraints

Participants highlighted financial barriers as a significant obstacle to engaging in NbS. The findings show a moderate recognition of the need for financial incentives ($M = 2.66$), with most respondents agreeing that the absence of such support discourages participation. During the interview, it was confirmed that most of the Safety Net beneficiaries participate in the development and maintenance of NbS with minimal monthly payment. According to these respondents, they participated with such minimal remuneration due to a lack of other alternatives. The result coincides with previous studies (Bennett *et al.*, 2019) that stress the role of sufficient incentives in enhancing community involvement. Respondents also perceived the maintenance of NbS as potentially too costly ($M = 2.53$), particularly for lower-income groups, reflecting concerns that financial burdens could deter engagement. The key informant participant also confirmed that maintaining damaged NbS costs the city administration a lot. As revealed in Cilliers & Timmermans (2020), high maintenance costs in most cases limit the participation of residents unless proper cost management and funding strategies are in place. At the same time, participants expressed greater willingness to engage if financial benefits or compensation were available ($M = 2.73$), showing strong consensus on the value of incentives in boosting participation. Interview participants boldly requested an

optimal monthly payment, which encourages them to engage in the development, conservation, and maintenance of NbS. Officials from the Dessie administration also affirmed that the payment is very low, which discourages residents from engaging in NbS activities with courage. This is consistent with literature highlighting the motivating role of financial rewards (Miller et al., 2017; Harrison & Ritchie, 2019). However, when it came to direct financial contributions, willingness was low ($M = 2.26$), with wide variation in opinions. Many respondents were reluctant to contribute, likely due to the perceived high costs of NbS. Scholars note that without incentives or a sense of ownership, communities are unlikely to offer financial support (Bennett et al., 2020).

Attitudinal Constraints

Survey results showed that a remarkable number of respondents viewed the management of NbS as the responsibility of the government ($M = 1.53$). While this belief reflects limited community ownership, responses varied ($SD = 1.703$), which shows differences among respondents, with some recognizing the importance of shared responsibility. Scholars warn that, since collective involvement is vital for sustainable NbS outcomes, such perceptions can discourage participation (Cilliers et al., 2016; Roe et al., 2013; Fischer et al., 2019). As indicated in Table 6, a significant proportion of respondents lack interest in participating in NbS, primarily due to the low payment modality and incentives ($M = 2.280$). Respondents also reported low personal motivation to engage, with many not seeing direct benefits from NbS activities ($M = 1.67$). This lack of perceived value may reduce participation, underscoring the need to raise awareness about the social, health, and personal gains of involvement (Cilliers et al., 2016; Fischer et al., 2020). According to an FGD participant from the safety net office, most residents participate in such activities mainly for the monthly payment given, and volunteerism is very weak, which demands awareness creation campaigns. Similarly, a very low score ($M = 1.11$) on their belief in the contribution of community participation suggests that most participants doubt their individual contributions can influence NbS outcomes. This uncertainty on their role weakens motivation, highlighting the need for further communication and awareness creation strategies, mainly focusing on demonstrating the impact of personal and collective actions.

On a more positive note, respondents moderately agreed that NbS enhances community quality of life ($M = 2.33$). Hence, strengthening communication around NbS benefits could increase the support and engagement of residents in NbS-related activities (Roe et al., 2013). Finally, participants acknowledged that other community issues often take priority over NbS ($M = 2.38$). While this suggests competition with pressing concerns, it also highlights the importance of integrating NbS into broader community agendas to enhance relevance and participation.

Regarding the cleanliness and maintenance of NbS, different views were expressed.

In some localities, they are kept clean and attractive. However, in most cases, they are used as dumping grounds for waste, and some are not maintained for a long time. Illegal activities, including dumping garbage at night, breaking small fences, cutting down premature trees, uprooting tree seedlings, and other similar malpractices, are practiced. These make the places less attractive and discourage people from using them. The problem is more serious in government-owned resources, while those owned by local institutions (such as idir) and religious institutions are better maintained. Regular maintenance and surveillance are essential, along with awareness-raising programs to foster a sense of ownership of these resources.

Table 6: Challenges/Constraints faced while engaging in NbS in Dessie city administration

Category	Possible challenge or constraint	N	Mean	SD
Economic Constraint	There is a lack of financial incentives for community members to engage in NbS management.	304	2.66	.674
	The cost of maintaining NbS is too high for community members to contribute effectively	305	2.53	.702
	I would participate more if there were financial benefits or compensation for my involvement	305	2.73	.580
	I am willing to contribute financially to NBS management if affordable options are available	304	2.26	.942
Attitude Constraint	Many people believe NbS management is the sole responsibility of the government	305	1.53	1.073
	There is a lack of interest in participating in NbS management	304	2.28	.808
	I do not see any personal benefit from engaging in nature-based solutions activities	305	1.67	1.064
	I believe that my participation in NbS management would not make a significant difference	304	1.11	.966
	I believe that NbS significantly enhances the quality of life in our community	304	2.33	.866

	People in my community prioritize other issues over NbS maintenance	303	2.38	.898
Social constraints	Local institutions do not prioritize the sustainability of NbS	304	2.48	.779
	Vandalism and security concerns discourage community participation in NbS management	303	2.03	.993
	Cultural beliefs and traditions influence the way people perceive and use NbS	304	1.16	1.055
Accessibility constraints	Urbanization and land use changes limit the availability of space for NbS	302	2.49	.822
	There is limited accessibility to green spaces due to poor infrastructure and location	304	2.79	.602
Institutional constraints	There is a lack of collaboration between local authorities and community members	305	2.34	.878
	There are sufficient training opportunities to acquire skills related to NbS management	305	1.90	.860
	There are no clear policies encouraging community involvement in NbS management	304	1.66	1.102
	The local government provides adequate support for community involvement	305	2.03	.906
	Information about NbS initiatives is easily accessible to all community members	304	1.93	.820
	Local organizations or groups involved in NbS management are accessible and inclusive	304	1.87	.808
	Safety concerns (e.g., crime, poor lighting) prevent me from participating in NbS activities	301	1.37	1.143

Note: Respondents rated the constraints as: (0-not at all, 1-low problem, 2-medium problem, and 3-High problem)

Source: Survey Output (2025)

Social and Accessibility Constraints:

The survey results disclosed different social and institutional barriers that hinder community engagement in NbS. Concerns about vandalism and security emerged as moderately restrictive (mean = 2.03), with responses showing variability: while some participants felt secure, many saw vandalism as a significant obstacle. Interviewed participants confirmed that most of the NbS, mainly forest areas, are found outside the control of the security bodies and are becoming hiding spaces for illegal activities—the absence of infrastructure and lighting facilities exposed visitors to different forms of harm. NbS nearby settlement areas are used as open space toilets mainly due to inadequate sanitary facilities. This underscores the importance of safety and effective community management strategies to build public confidence (Bennett *et al.*, 2020; Cilliers *et al.*, 2016). Limited accessibility to green spaces was another key issue, receiving a relatively high mean score (2.79). Most NbS, as confirmed during field observation, are found in the fringes of the city where accessibility is a significant challenge. Respondents widely agreed that poor infrastructure and inconvenient locations restrict opportunities for community interaction with NbS. As a result, improving accessibility is essential for increasing participation as well as visiting such areas, introducing new businesses, and ensuring equitable engagement (Bennett *et al.*, 2019; Cilliers *et al.*, 2016). Moreover, participants expressed dissatisfaction with the role of local government, reflected in a very low mean score (1.03). Many felt that authorities provide insufficient support for community involvement, which weakens motivation and trust. This aligns with findings that adequate government backing, including resources, facilitation, and active engagement, is vital for successful NbS management (Bennett *et al.*, 2019; Cilliers *et al.*, 2016). Regarding the accessibility and safety of NbS, a 28-year-old youth shared his experience as follows:

Access to younger residents like me is not a problem, and we can easily climb and utilize them. However, the walkways are rough, with some being very steep and unpaved. However, since the paths are not level and have no handrails for support, and are risky in some places, they are not accessible to older people and those with disabilities. Hence, in my observation, though the NbS are technically open to everyone in principle, they are not equally accessible in practice to all segments of the residents. Unless such problems are adequately addressed, the most vulnerable groups of our community might not benefit equally from such resources. Due to insufficient lighting, the places are not safe, particularly at night. Some people are frustrated to cross such places alone, even during the daytime, because of the fear of theft or harassment.

Concerning the significant challenges faced while implementing and managing NbS, conflict of interest, mainly relating to land allocation, is one major problem, as confirmed during FGD and KII. Some residents prioritize the land for use in construction or commercial purposes (Figures 14 and 15). Farmers in the urban periphery also worried when their open grazing lands were converted into green spaces. Such a conflict of interest needs continuous negotiation and awareness creation campaigns regarding the long-term benefits of NbS. Another problem faced was a lack of sufficient funds, which hinders the expansion of NbS and regular maintenance. Bureaucracy is another challenge, as procurement, land allocation disputes, and slow decision-making processes hinder the project's proper implementation. As far as coordination among different stakeholders is concerned, most participants agreed that it was weak. Most NGOs gave priority to rural areas rather than urban ones. The regional disaster preparedness office, for example, lacks an intervention plan in place for disasters that occur in urban areas.



Figure 14: Settlement in the buffer zone (Highly susceptible to landslides and flooding)

(Photo Credit: WU Research Team, 2025)

During the FGD, participants from the Dessie City Natural Resource Conservation Office highlighted weak institutional coordination among different offices, even at the City Administration level. They admitted that rehabilitated buffer zones, where biological and physical conservation activities have been established, are reallocated for settlement programs by the municipalities. This results in the destruction of these structures, illegal extraction of construction materials like stone, cutting down plants for fuel wood and construction purposes, theft of barbed wires, among other issues. Some rehabilitated yet

sensitive areas are allocated to investors by the municipalities without consultation with the relevant offices. As underscored by the experts, such malpractices not only undermine the effectiveness of NbS but also erode public trust and discourage further community participation in conservation initiatives.



Figure 15: Expansion of informal settlements into designated buffer zones and the use of NbS zones as unmanaged waste disposal areas

(Photo Credit: WU Research Team, 2025)



Figure 16: Encroachment of NbS sites through reallocation of investment land for poultry farming and housing construction

(Photo Credit: WU Research Team, 2025)

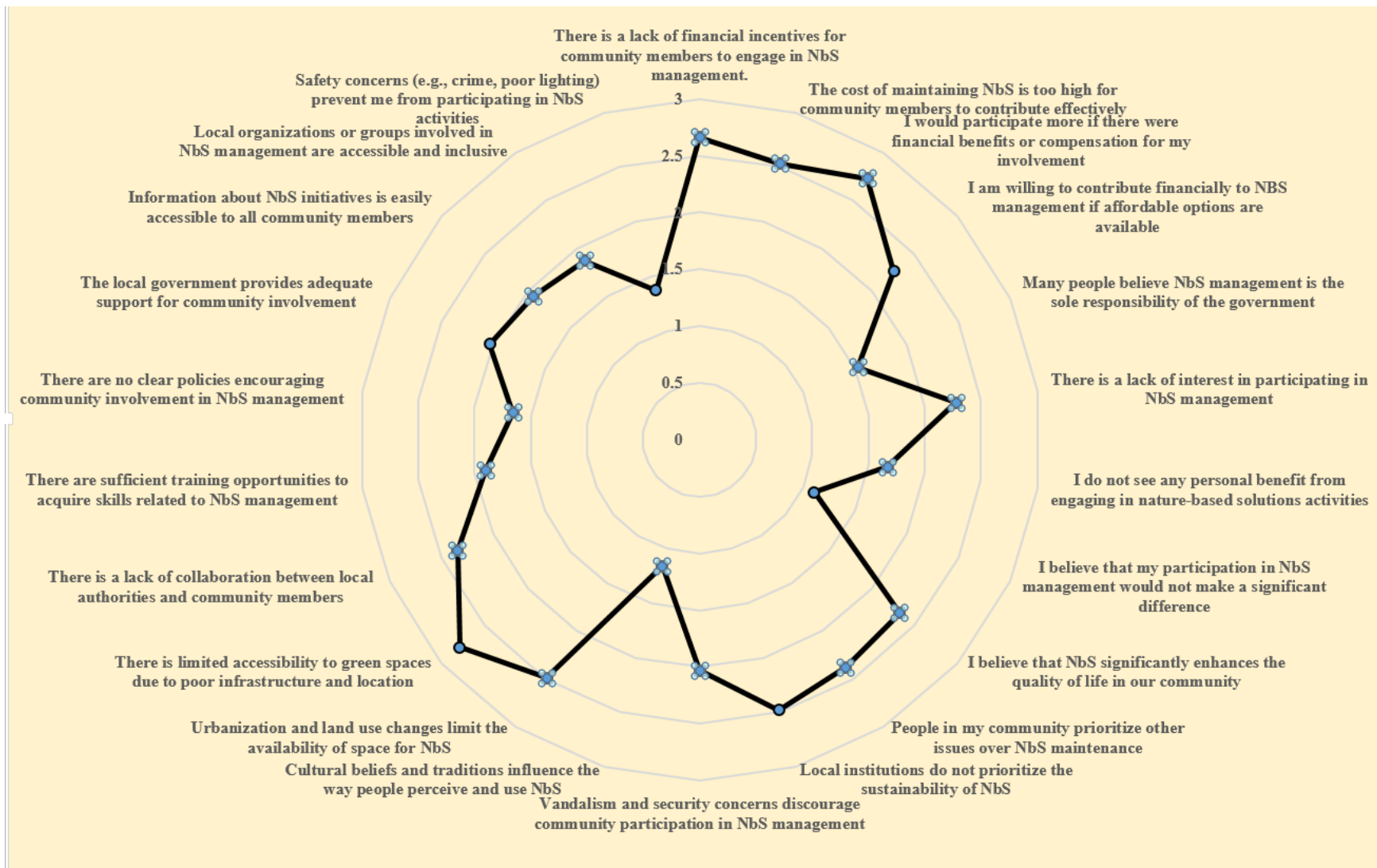


Figure 17: Key challenges and constraints encountered in the implementation of NbS

(Source: Survey, 2025)

Accessibility of Information and Institutional Constraints

According to the survey results, inclusivity, communication, and safety were essential obstacles to community participation in NbS-related activities. Respondents confirmed that information on NbS initiatives is not easily accessible (mean = 1.93), evidenced by poor communication and limited awareness. Transparent and inclusive information channels are essential for enabling effective community engagement (Fischer *et al.*, 2020; Roe *et al.*, 2013). Similarly, participants felt that local organizations involved in NbS are not sufficiently accessible or inclusive (mean = 1.87) and that there is limited government support (mean = 2.03). This suggests challenges in stakeholder engagement and representation, which can hinder long-term success. Ensuring shared responsibilities, equitable participation, and power balance is key to sustainable NbS outcomes. During KII and FGD, it was confirmed that the communication channel among different stakeholders and actors, as well as the support given at various levels, is weak as long as the NbS intervention is concerned. Poor communication and coordination hinder the overall success of the activities. Besides, safety concerns such as crime and poor lighting were noted as moderate deterrents (mean = 1.37), though opinions varied widely. Some respondents considered safety a significant barrier, while others did not. Thus, a conducive and welcoming environment is vital for encouraging broader participation of different actors in NbS initiatives. Survey findings revealed several institutional and capacity-related barriers to community engagement in NbS, including limited training opportunities for building the skills needed to manage NbS (mean = 1.90). This lack of capacity is seen as a significant obstacle, consistent with studies noting that skill gaps undermine effective participation in environmental initiatives (Fletcher and Potts, 2007). Besides, weak collaboration between local authorities and communities (mean = 2.34). While some acknowledged existing cooperation, many felt it was inadequate to support meaningful involvement. Strong partnerships are critical for the success of NbS, as emphasized in the literature (Daw *et al.*, 2011). Finally, respondents expressed uncertainty about policies guiding community participation in NbS (mean = 1.66). The variability in responses suggests uneven awareness and understanding of existing frameworks, which can discourage engagement. Scholars argue that clear, accessible, and well-communicated policies are vital for building trust, confidence, and participation in NbS initiatives (Fischer *et al.*, 2020).

Concerning informal groups or committees that oversee the management of NbS in their locality, both interviewed and FGD participants affirmed that, except for community-based organisations (such as Iddir) and religious institutions, which sometimes organize tree-planting and cleaning campaigns, there are no strong such arrangements in their locality. School-based environmental clubs rarely participated in awareness creation campaigns, mainly during annual ecological days. Most of the NbS-related activities are

primarily organized once a year by government mobilization. Different actions for the betterment of NbS were suggested. The first step is to create awareness campaigns highlighting the multiple benefits of NbS. Besides, using community-based organizations (like Iddir, religious institutions, and associations) could be a good entry point for mobilizing the community. Such intervention could enhance their participation and foster a sense of ownership. Due to their inaccessibility, the potential of existing NbS for revenue generation is not yet fully exploited. As a result, much work remains to be done to utilize such resources as a source of livelihood and income for society. Thus, constructing proper walkways and installing adequate lighting is needed. Another action to implement is addressing inclusivity. All segments of the community should have their engagement starting from the inception, which enhances their participation.

4.6 Vulnerability and Suitability Analysis

Flood Vulnerability Mapping

The map in Figure 18 illustrates the flood vulnerability of Dessie City, Ethiopia, categorized into four classes: low, moderate, high, and very high, which were derived using a Multi-Criteria Evaluation (MCE) approach, integrating various factors that contribute to flood vulnerability. Moderate vulnerability constitutes 102.15 km² (57.64%) of the 177.23 km² study area, followed by low vulnerability (40.08 km² or 22.61%). Areas with extreme vulnerability were 10.67 km² or 6.02% of the total area. That means, the majority of Dessie City falls into the moderate vulnerability category, comprising approximately 57.6% of the total area. This suggests that while many areas are at risk, they are not at the highest levels of vulnerability, indicating potential for mitigation and management strategies. The high (24.33 km²) and very high (10.67 km²) vulnerability classes collectively cover a significant portion of the city (around 19.74% of the total area). These areas require urgent attention for flood risk management, as they are likely to experience severe impacts during flood events. The low vulnerability areas, accounting for about 22.6% of the total area, are crucial for urban planning and disaster preparedness. These regions can serve as potential safe zones or relocation areas during flood events. The findings underscore the need for targeted flood management strategies, particularly in high and very high vulnerability zones. Urban planners and policymakers should prioritize these areas for infrastructure improvements, effective drainage systems, and community awareness programs. The use of Multi-Criteria Evaluation (see Annex I and II) in deriving the vulnerability index highlights its effectiveness in integrating various factors influencing flood risk. Generally, the GIS-based flood vulnerability index provides valuable insights into the spatial distribution of flood risk for focused interventions in high-risk areas.

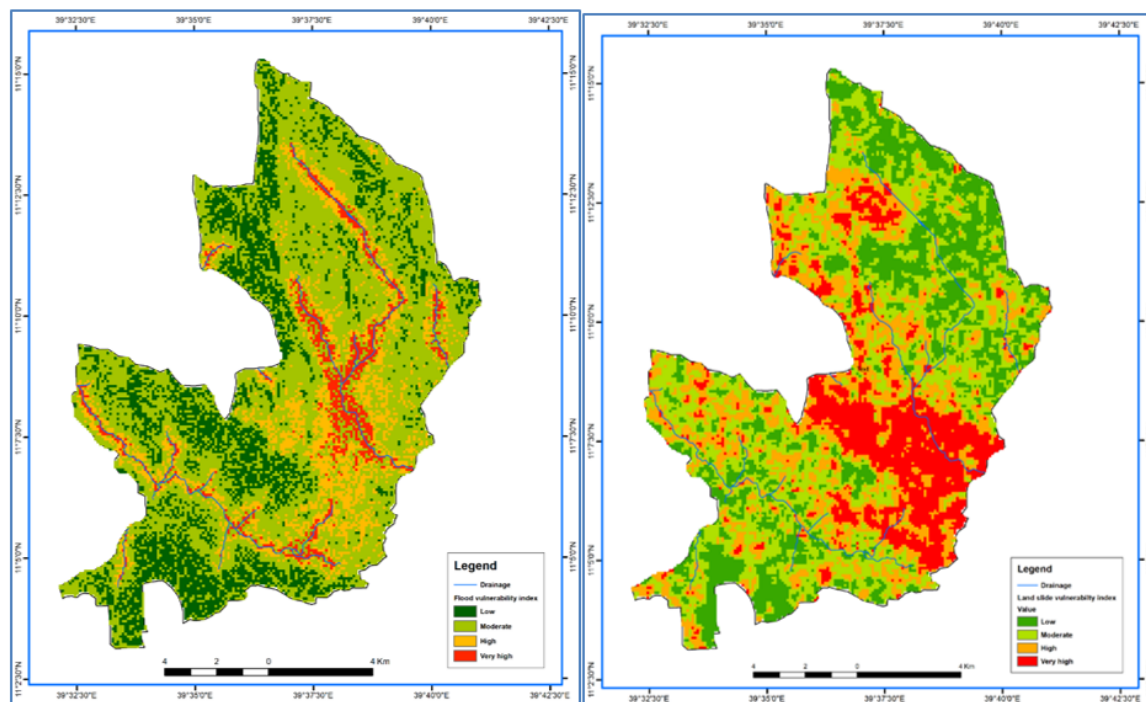


Figure 18: GIS-based flood vulnerability Map of Dessie City

Figure 19: GIS-based landslide susceptibility Index map of Dessie

GIS-Based Landslide Susceptibility Mapping

Using the MCE approach, the landslide susceptibility of Dessie City, Ethiopia, was categorized into four classes: low, moderate, high, and very high. The MCE incorporated various factors contributing to landslide risk. Figure 2 presents the area coverage of each susceptibility class in square kilometers, and Figure 19 displays the spatial distribution of the landslide susceptibility across the study area. The majority of Dessie City is categorized as moderate susceptibility, comprising approximately 34.4% of the total area (60.94 km²). This indicates a significant portion of the city is at risk of landslides, highlighting the need for preventive measures. The high (44.37 km²) and very high (30.32 km²) susceptibility classes cover a considerable area (around 42.1% of the total area). These zones are critical for intervention, as they are more likely to experience landslide events. The low susceptibility areas, constituting about 23.4% of the total area (41.60 km²), can be considered safer zones. These areas may serve as potential locations for infrastructure development or community relocation in the event of landslides.

The findings stress the importance of implementing targeted landslide risk management strategies, especially in high and very high susceptibility zones. Urban planners should focus on enhancing drainage systems, stabilizing slopes, and educating communities about landslide risks. Utilizing Multi-Criteria Evaluation to derive the landslide susceptibility

index demonstrates a comprehensive approach to integrating various risk factors. This methodology could be applicable in similar contexts facing landslide hazards. Overall, the GIS-based landslide susceptibility index for Dessie City provides essential insights into the spatial distribution of landslide risk. It emphasizes the need for focused risk mitigation strategies in vulnerable areas while recognizing the potential of low susceptibility zones for safe development and urban planning.

Urban Heat Intensity Mapping

Figure 20 illustrates the urban heat intensity across Dessie City, Ethiopia, categorized into four classes: low, moderate, high, and very high, which was derived from satellite thermal data combined with environmental factors, providing a comprehensive view of urban heat distribution. The very high vulnerability category represents the largest share of the total area (33.75%), indicating significant portions of Dessie City are subject to extreme urban heat. This finding suggests a considerable risk to public health, particularly during heat waves. Areas classified as high vulnerability cover approximately 24.65% of the city (43.68 km²). This indicates that nearly one-quarter of the urban landscape is at risk, necessitating targeted interventions to mitigate heat exposure. Moderate vulnerability areas account for 18.35% (32.53 km²), while low vulnerability areas comprise 23.24% (41.19 km²) of the city. While these areas are less at risk, they still require monitoring and potential adaptive measures to prevent future increases in heat intensity. The findings underscore the need for urban planning strategies that address heat vulnerability. This includes implementing green spaces, enhancing building materials to improve thermal insulation, and developing cooling centers to protect vulnerable populations during extreme heat events. The urban heat intensity map and corresponding vulnerability index for Dessie City reveal critical insights into the spatial distribution of heat risks. The high prevalence of very high and high vulnerability areas necessitates immediate action to mitigate the impacts of urban heat, emphasizing the importance of strategic urban planning and community resilience initiatives.

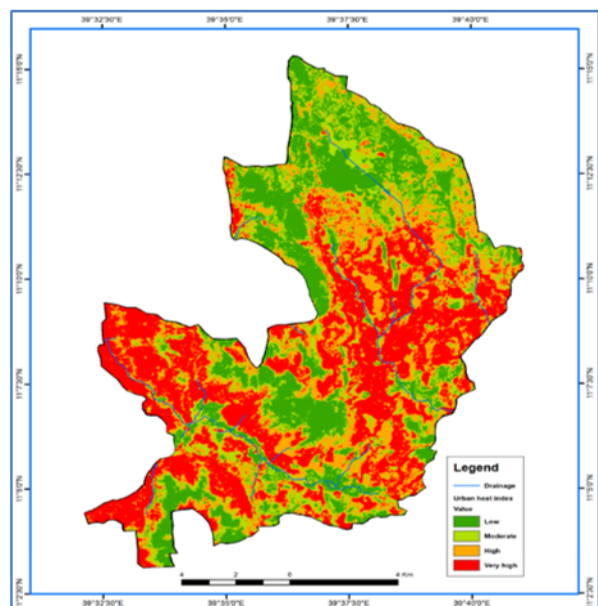


Figure 19: Urban Heat intensity map of Dessie City

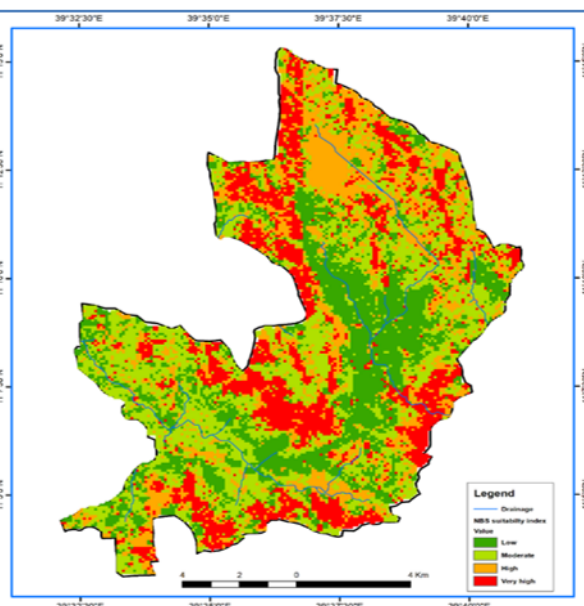


Figure 20: Nature-Based Solution suitability map of Dessie City

Nature-Based Solution Suitability Mapping

By considering various environmental and spatial factors, the suitability for implementing NbS across Dessie City, Ethiopia, was categorized into four classes: low, moderate, high, and very high (see Figure 21). The moderate suitability category encompasses the largest area (58.40 km²), indicating that substantial portions of Dessie City are suitable for NbS but may require enhancements to maximize their effectiveness. This suggests potential for improvement and adaptation in urban planning. The low suitability areas account for 42.80 km² (approximately 24.2% of the total area), indicating significant regions where NbS may not be effective. This necessitates careful consideration of alternative strategies or supplementary measures for these locations. The high (38.49 km²) and very high (37.54 km²) suitability classes together cover about 42.4% of the area. These zones are critical for implementing NbS, providing opportunities to enhance urban resilience through green infrastructure. The observation that areas near rivers are only moderately suitable raises questions about the criteria used for the evaluation. Factors such as flood risk, land use, and ecological conditions may have influenced this classification, warranting a review for more effective planning. We found an intense match between the GIS-based analysis and the participatory mapping results, particularly in relation to the suitability of NbS and landslide vulnerability. This consistency highlights the reliability and complementarity of integrating scientific modelling with local knowledge systems for spatial vulnerability

assessments. However, the degree of agreement was relatively moderate in the case of flood vulnerability, suggesting potential discrepancies either in community perceptions, data resolution, or the spatial dynamics of flooding events. The findings emphasize the importance of integrating NbS into urban planning, particularly in areas identified as high and very high suitability, including restoring green spaces, creating urban forests, and incorporating water management solutions to enhance urban resilience. The inclusion of GIS-based vulnerability and suitability mapping represents a pioneering application of GIS-based multi-criteria evaluation for urban resilience planning in Dessie City and provides a novel contribution to local NbS planning. This analytical approach offers city planners a scientific basis to prioritize interventions in high-risk zones and integrate NbS within land-use plans.

5. Summary, Conclusion, and Policy Recommendations

5.1 Summary of Findings

Dessie City's unique topography, rapid urbanization, and fragile infrastructure make it one of the most vulnerable Ethiopian cities to floods and landslides. These hazards are worsened by unregulated waste disposal and informal settlements expanding into buffer zones. In this context, NbS, such as forest rehabilitation, urban greening, tree planting, and watershed management, offer cost-effective, socially inclusive, and environmentally sustainable strategies to reduce the risks. The study chose to explore the potential of NbS for improving urban resilience in a changing climate using a mixed research approach. This investigation combined empirical data collection and geospatial analysis to assess the current status of NbS, their perceived benefits, existing challenges, and options for scaling them up. Surveys were conducted with 305 residents across four sub-cities, while qualitative data were gathered through focus group discussions, key informant interviews, and direct field observations. Data analysis involved descriptive statistics (percentage, mean, weighted mean, and one-sample t-test). Geospatial technologies, including Digital Elevation Models and Sentinel-2 imagery, were used to develop vulnerability and suitability maps.

The findings revealed four significant insights. First, community participation in NbS was moderate but uneven. While many residents engaged in tree planting, waste management, and maintenance activities, fewer participated in planning, financial contributions, or long-term stewardship. Motivations for participation were primarily environmental concern, social interaction, and, to some extent, incentives. Second, community perceptions of NbS benefits were overwhelmingly positive in terms of ecological and health outcomes.

Residents recognized NbS as effective in reducing soil erosion, regulating floods, enhancing biodiversity, improving water and air quality, and reducing the urban heat island effect. Health-related benefits, including reduced noise, prevention of heat-related illnesses, and improved opportunities for exercise and recreation, were also widely acknowledged. Social benefits were identified mainly in terms of providing communal spaces for interaction, though the role of NbS in promoting civic engagement and volunteering was perceived as limited. Economic benefits were less pronounced, with respondents noting temporary job creation and local business opportunities but expressing doubt about property value increases or tourism potential. Third, the study identified significant barriers to effective NbS implementation. These include inadequate financial support, weak institutional coordination, limited community knowledge, lack of incorporation into formal urban plans, and encroachment of informal settlements into NbS-designated zones. Such constraints impair sustainability and limit scalability. Fourth, geospatial research found that approximately one-quarter of Dessie City is particularly vulnerable to climatic hazards, especially flooding and landslides, with a concentration of informal housing in these zones. At the same time, 42.4% of the city was mapped as highly suited for NbS expansion, underlining prospects for deliberate interventions in places that could deliver maximum ecological and social benefits. The integration of case study analysis from Sire Minch, Segno Gebeya, Mitiro, and Arera sites provided qualitative depth to the quantitative survey findings. These case studies illustrated how varying environmental conditions, governance structures, and community engagement levels influenced the performance and sustainability of NbS interventions. The triangulation of case study evidence with survey data strengthened the reliability of the results and clarified the contextual factors driving success or failure across different urban settings.

5.2 Conclusion

The study concludes that NbS are vital tools in addressing the complex climate risks facing Dessie City. They provide co-benefits that extend beyond environmental restoration to include public health, social cohesion, and livelihood opportunities. However, their current potential remains constrained by institutional, financial, and social challenges. One of the central findings is the pivotal role of community engagement. Where communities are actively involved in the implementation and stewardship of NbS, projects tend to be more sustainable and impactful. Conversely, limited participation in planning and weak ownership structures reduce the long-term viability of interventions. This emphasizes the need for participatory governance models that place local actors at the heart of NbS initiatives. Another critical conclusion is the necessity of embedding NbS within urban planning and policy frameworks. Addressing coordination gaps through institutional reform, legal enforcement, and participatory governance is vital for enhancing the

resilience and long-term sustainability of NbS in urban areas. The insights from case studies conducted in Sire Minch, Segno Gebeya, Mitiro, and Arera have substantiated the study's broader conclusions. Each site demonstrated unique approaches to implementing NbS under varying socio-environmental contexts, providing practical evidence on how community participation, institutional collaboration, and ecological design determine project success.

While community action is essential, it cannot replace institutional leadership, coordination, and clear policies. Incorporating NbS into the municipal development plan will allow for systematic scaling, resource mobilization, and effective hazard reduction. Additionally, research shows that NbS are highly context dependent. Their success relies not only on ecological factors but also on socio-economic realities such as poverty, informal housing, and cultural practices. Therefore, solutions must be tailored to local needs and supported by enabling measures like livelihood support, awareness campaigns, and infrastructure development. This study shows that NbS are a crucial pathway for creating climate-resilient, inclusive, and sustainable urban systems in Dessie City. Their practical implementation requires combining ecological restoration with social empowerment and institutional innovation. With coherent policies, sufficient funding, and genuine community participation, NbS can help transform Dessie into a model of climate resilience for other rapidly growing cities in Ethiopia and beyond. The study enhances understanding of how cities in the Global South can adopt NbS as strategies for climate resilience. It emphasizes that while global frameworks, such as the Sustainable Development Goals and Ethiopia's Climate Resilient Green Economy (CRGE) Strategy, offer necessary guidance, local evidence is essential for designing practical, inclusive, and sustainable solutions. The insights generated from this study extend beyond Dessie City. The evidence base generated by this study, particularly the documented economic, social, and environmental benefits of NbS, can serve as a persuasive model for other Ethiopian and regional cities seeking to integrate NbS into their urban resilience strategies. By demonstrating how NbS yield ecological, social, and economic co-benefits, the study offers a transferable framework for other rapidly urbanizing Ethiopian and regional cities seeking to integrate NbS into local climate adaptation and urban planning strategies.

5.3 Policy Recommendations

Based on the findings and conclusions, the following policy recommendations are proposed:

Institutional and Governance Measures: this includes the integration of NbS into municipal planning frameworks as part of the urban development strategies, zoning regulations, and climate adaptation policies; enhancing institutional coordination that consists of the establishment of a dedicated NbS taskforce that brings together municipal

authorities, environmental agencies, NGOs, and community-based organizations to harmonize efforts and avoid duplication; and strengthening regulatory enforcement to implement and enforce land use regulations that prevent encroachment into buffer zones and environmentally sensitive areas.

Raising awareness and building environmental literacy on the multifunctional benefits of NbS is essential. It is recommended that the City Administration and local partners launch targeted awareness campaigns, school-based environmental education programs, and community dialogues that communicate how NbS contribute to health, economic, and resilience outcomes. Such initiatives can enhance community ownership and stimulate behavioral change toward sustainable NbS management.

Community Participation and Capacity Building: which encompasses promoting participatory planning where residents are actively engaged in the design, prioritization, and monitoring of NbS projects to foster ownership and ensure interventions are context-sensitive; implement community outreach campaigns, as part of educational and awareness programs, highlighting the benefits of NbS for health, resilience, and livelihoods; and building the local skills by offer training programs in tree management, watershed conservation, and urban gardening to strengthen community capacity in managing NbS.

Financial and Economic Incentives: this can be attained by creating livelihood linkages (align NbS projects with income-generating opportunities, such as eco-enterprises, urban agriculture, or community-based tourism); providing financial incentives through the establishment of subsidies, grants, or microfinance schemes to encourage household and community investment in NbS; and by mobilizing external funding to leverage partnerships with international donors, climate funds, and private sector actors to expand NbS financing.

Spatial Planning and Hazard Mitigation: through prioritizing high-risk zones, mainly direct NbS interventions to areas most vulnerable to flooding, landslides, and heat stress, as identified by the vulnerability maps; by developing green corridors (establish interconnected green spaces across sub-cities to improve biodiversity, regulate temperature, and provide recreational opportunities); and modernizing the A waste management system that incorporates waste recycling and management systems into NbS sites to address pollution challenges.

Establish a multi-stakeholder coordination platform: there is a need to have such a platform at the city administration level that brings all relevant stakeholders working on NbS, and the platform should have a clear legal mandate to harmonize policies, align land-use planning with conservation goals, and resolve institutional conflicts. This approach

ensures that NbS interventions are not undermined by institutional fragmentation and conflicting land-use priorities, while fostering shared accountability among all stakeholders. Besides, the platform can facilitate a joint monitoring and enforcement mechanism for periodic inspections and participatory community-based oversight systems, to deter encroachment and unsanctioned exploitation of rehabilitated areas.

Promotion of Domestic Tourism through Nature-Based Solutions (NbS): NbS can be strategically developed as key destinations for the growth of domestic tourism. Such initiatives could offer a range of socio-economic and environmental benefits, including employment opportunities in guiding, hospitality, and related services, thereby supporting community livelihoods. Additionally, developing tourism infrastructure—such as roads, visitor centers, and eco-lodges—can improve accessibility and regional development overall. Furthermore, generating income and involving residents in managing and promoting NbS sites can foster a sense of ownership and stewardship, which is essential for the long-term sustainability of these ecosystems.

Improve Accessibility and Safety: Invest in infrastructure improvements such as walkways, lighting, and signage to ensure safe, equitable access for all, including vulnerable groups.

Research and Knowledge Sharing: this might include monitor and evaluate NbS outcomes: (establish long-term monitoring frameworks to assess ecological, social, and economic impacts of NbS interventions); encourage replication and scaling (document and disseminate best practices from Dessie to other Ethiopian cities facing similar challenges); and by promote multi-disciplinary research (strengthening collaborations between universities, municipalities, and civil society to generate context-specific evidence on NbS effectiveness).

Law enforcement: vigorous law enforcement is essential to prevent illegal activities occurring within established NbS sites and to regulate encroachments and unauthorized settlements in the buffer zones

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Annex 1: Pairwise comparison for climate flood hazard, land slide, and urban heat vulnerability index

Flood vulnerability pair wise confusion matrix										
	Dd	Rf	Pw	LULC	SI	TWI	Pd	So	As	Cu
Dd	1	2	3	4	5	6	7	8	9	9
Rf	0.5	1	2	3	4	5	6	7	8	8
Pw	0.33	0.5	1	2	3	4	5	6	7	7
LULC	0.25	0.33	0.5	1	2	3	4	5	6	6
SI	0.2	0.2	0.33	0.5	1	2	3	4	5	5
TWI	0.16	0.2	0.25	0.33	0.5	1	2	3	4	4
Pd	0.14	0.16	0.2	0.25	0.33	0.5	1	2	3	3
So	0.12	0.14	0.16	0.2	0.25	0.33	0.5	1	2	2
As	0.11	0.13	0.14	0.17	0.2	0.25	0.33	0.5	1	1
Cu	0.11	0.13	0.14	0.17	0.2	0.25	0.33	0.5	1	1
Employ eigen vector method to drive the parameter weight from the matrix of pairwise comparison for flood vulnerability index.										
Parameters	v wgt	Nwgt	%	Consistency Check: $\lambda_{\max} = 10.1284$ Consistency Index (CI)= 0.0143 CR = 0.0124 < 0.1 $\Rightarrow$ Acceptable						
Dd	3.0809	0.2433	24.33							
Rf	2.494	0.197	19.70							
Pw	1.9206	0.1517	15.17							
LULC	1.5116	0.1193	11.93							
SI	1.1791	0.093	9.30							
TWI	0.952	0.0751	7.51							
Pd	0.7937	0.0626	6.26							
So	0.6047	0.0477	4.77							
As	0.4573	0.0361	3.61							
Cu	0.4573	0.0361	3.61							
Total	12.4512	1	100.00%							
Land slide vulnerability pair wise confusion matrix										
	SPI	TWI	SI	So	Pd	LULC	Rf	Ge		

SPI	1	2	3	4	5	6	7	8
TWI	0.5	1	2	3	4	5	6	7
SI	0.33	0.5	1	2	3	4	5	6
So	0.25	0.33	0.5	1	2	3	4	5
Pd	0.2	0.25	0.33	0.5	1	2	3	4
LULC	0.17	0.2	0.25	0.33	0.5	1	2	3
Rf	0.14	0.17	0.2	0.25	0.33	0.5	1	2
Ge	0.12	0.14	0.17	0.2	0.25	0.33	0.5	1

Employ Eigen vector method to drive the parameter weight from the matrix of pairwise comparison for land slide vulnerability index.

Parameters	V wgt.	Nwgt	%	Consistency Check: $\lambda_{max} = 8.275$ $CI = 0.0393$ $CR = 0.0279 < 0.1 \Rightarrow \text{Acceptable}$
SPI	3.7644	0.3282	32.82	
TWI	2.6618	0.2321	23.21	
Slope	1.817	0.1584	15.84	
Soil	1.2213	0.1065	10.65	
Pop. Density	0.8167	0.0712	7.12	
LULC	0.5503	0.048	4.8	
Rainfall	0.3752	0.0327	3.27	
Geology	0.264	0.023	2.3	
Total	11.4707	1	100.00	

Extreme heat event vulnerability pair wise confusion matrix

	LST	NDVI	LULC
LST	1	2	3
NDVI	0.5	1	2
LULC	0.33	0.5	1

Employ eigen vector method to drive the parameter weight from the matrix of pairwise comparison for Extreme heat event vulnerability index.

Parameters	V gwt	Nwgt	%	$\lambda_{max} = 3.005$ $CI = 0.0025$ $CR = 0.0043 < 0.1 \Rightarrow \text{Perfectly consistent.}$
LST	1.8171	0.539	53.9	
NDVI	1	0.297	29.7	
LULC	0.546	0.164	16.4	

Total	3.3631	1	100.00									
NBS suitability pair wise confusion matrix												
	LULC	SPI	SI	Rf	LST	So	NDVI	Dd	Pw	TWI	As	Cu
LULC	1	2	3	4	5	6	7	7	8	8	9	9
SPI	0.5	1	2	3	4	5	6	6	7	7	8	8
SI	0.333	0.5	1	2	3	4	5	5	6	6	7	7
Rf	0.25	0.333	0.5	1	2	3	4	4	5	5	6	6
LST	0.2	0.25	0.333	0.5	1	2	3	3	4	4	5	5
So	0.167	0.2	0.25	0.333	0.5	1	2	2	3	3	4	4
NDVI	0.143	0.167	0.2	0.25	0.333	0.5	1	1	2	2	3	3
Dd	0.143	0.167	0.2	0.25	0.333	0.5	1	1	2	2	3	3
Pw	0.125	0.143	0.167	0.2	0.25	0.333	0.5	0.5	1	2	2	3
TWI	0.125	0.143	0.167	0.2	0.25	0.333	0.5	0.5	0.5	1	2	2
As	0.111	0.125	0.143	0.167	0.2	0.25	0.333	0.333	0.5	0.5	1	2
Cu	0.111	0.125	0.143	0.167	0.2	0.25	0.333	0.333	0.333	0.5	0.5	1

Employ eigen vector method to drive the parameter weight from the matrix of pairwise comparison for NBS suitability index

Parameters	v wgt	Nwgt	%	$\lambda_{max} = 12.60$ $CI = 0.0545$ $CR = 0.0368 < 0.1 \Rightarrow$ consistent, and reliable the computed weights can be confidently used in NBS suitability modeling.
LULC	4.8811	0.2639	26.39%	
SPI	3.7088	0.2005	20.05%	
SI	2.7366	0.1480	14.80%	
Rf	1.9786	0.1070	10.70%	
LST	1.4066	0.0761	7.61%	
So	0.9815	0.0531	5.31%	
NDVI	0.6624	0.0358	3.58%	
Dd	0.6624	0.0358	3.58%	

Pw	0.4798	0.0259	2.59%	
TWI	0.4133	0.0223	2.23%	
As	0.3140	0.0170	1.70%	
Cu	0.2704	0.0146	1.46%	
Total	18.4955	1	100.00	

Note: v wgt: eigen vector weight, Nwgt: normalized weight, Dd: Drainage density; Rf: Rain falls; Pw: Proximity to water body; LULC: Land Use Land Cover; Sl: Slope; TWI: Topographic Witness Index; Pd: Population density; So: Soil; As: Aspect; Cu: Curvature; Ge: Geology; NDVI: Normalized Different Vegetation, Index; LST: Land Surface temperature.

Annex 2: Climate Vulnerability Index

Indicators		Original class range	Reclassification/Score	Weighted value original weight (Wi)	Calculate the Climate Vulnerability Index
1.Flood hazard climate vulnerability index $CVI=\sum(W_i \times X'_i)$ $CVI = \sum (W_i \times X'_i)$	Curvature	-13.754 to -1.203	4	0.0361	Weighted sum spatial analysis is used to obtain the final CVI using Arc GIS pro.
		-1.203 to -0.096	3		
		-0.096 to 1.134	2		
		1.134 to 17.623	1		
	Aspect	1 to 89.557	4	0.0361	
		89.557 to 175.869	3		
		157.869 to 262.181	2		
		262.181 to 359.813	1		
	Soil type	Rock surface	1	0.0477	
		Lithosols	2		
		Regosols	3		
		Cambisols	4		
		Verisols	5		
	Population density	1072.770	1	0.0626	
		1072.770-1147.366	2		
		1147.366-2378.192	3		
		2378.192-6630.137	4		
		6630.137-10583.700	5		
	Topographic witness index	-0.79 to 2.395	1	0.0751	
		2.395 to 4.718	2		
		4.718 to 8.103	3		
		8.103 to 16.133	4		
	Slope	0-8.865	4	0.093	
		8.65-18.805	3		
		18.805-30.088	2		
		30.088-68.505	1		
	Land Use Land Cover	Water body	1	0.1193	
		Vegetation	2		
Wet/grazing land		3			
Farm land		4			
Bare land		5			
Urban development		6			
Proximity to water body	0- 50 meters	4	0.1517		
	50-100 meters	3			
	100-200 meters	2			
	200-500 meters	1			

	Rain falls	927.782-996.545mm	1	0.197	
		996.545-1061.011 mm	2		
		1061.011-1125.477 mm	3		
		1125.477-1201.762 mm	4		
	Drainage density	0-0.365 km ²	1	0.2433	
		0.0365-1.055 km ²	2		
		1.055-1.835 km ²	3		
		1.835-3.320 km ²	4		
2.Landslide susceptibility	Population density	1072.770	1	0.0712	
		1072.770-1147.366	2		
		1147.366-2378.192	3		
		2378.192-6630.137	4		
		6630.137-10583.700	5		
	Land use	Water body	1	0.048	
		Vegetation	2		
		Wet/grazing land	3		
		Farm land	4		
		Bare land	5		
		Urban development	6		
	Geology	Dessie basalt Formation	1	0.023	
		Dessie basalt Formation	1		
		Ashangi Formation	2		
		Alluvial soil	3		
	Soil type	Rocksurface	1	0.1065	
		Lithosols	2		
		Cambisols	3		
		Regosols	4		
		Verisols	5		
	Slope	0-8.865	1	0.1584	
		8.65-18.805	2		
		18.805-30.088	3		
		30.088-68.505	4		
	Rain falls	927.782-996.545mm	1	0.0327	
		996.545-1061.011 mm	2		
		1061.011-1125.477 mm	3		
		1125.477-1201.762 mm	4		
	SPI	0-60080.810	1	0.3282	

		60080.810-307079.697	2		
		307079.697-787226.179	3		
		787226.179-1702289.625	4		
	TWI	-0.79 to 2.395	1	0.232	
		2.395 to 4.718	2		
		4.718 to 8.103	3		
		8.103 to 16.133	4		
3.Extreme heat events	Urban heat (LST)	21.693-30.689	1	53.9	
		30.689-35.085	2		
		35.085-39.073	3		
		39.073-47.763	4		
	NDVI	-0.052-0.154	4	29.7	
		0.154-0.228	3		
		0.228-0.313	2		
		0.313-0.553	1		
	LULC	Water body	1	16.4	
		Vegetation	2		
		Wet/grazing land	3		
		Farm land	4		
		Bare land	5		
		Urban development	6		
4.Suitability index (NBS)	Land Use Land Cover	Water body	1	0.2639	
		Vegetation	2		
		Wet/grazing land	3		
		Farm land	4		
		Bare land	5		
		Urban development	6		
	SPI	0-60080.810	1	0.2005	
		60080.810-307079.697	2		
		307079.697-787226.179	3		
		787226.179-1702289.625	4		
	Slope	0-8.865	1	0.1480	
		8.65-18.805	2		
		18.805-30.088	3		
		30.088-68.505	4		
	Rain falls	927.782-996.545mm	1	0.1070	
		996.545-1061.011 mm	2		

		1061.011-1125.477 mm	3		
		1125.477-1201.762 mm	4		
	LST	21.693-30.689	1	0.0761	
		30.689-35.085	2		
		35.085-39.073	3		
		39.073-47.763	4		
	Soil type	Rocksurface	1	0.0531	
		Lithosols	2		
		Cambisols	3		
		Regosols	4		
		Verisols	5		
	NDVI	-0.052-0.154	1	0.0358	
		0.154-0.228	2		
		0.228-0.313	3		
		0.313-0.553	4		
	Drainage density	0-0.365 km ²	4	0.0358	
		0.0365-1.055 km ²	3		
		1.055-1.835 km ²	2		
		1.835-3.320 km ²	1		
	Proximity to water body	0- 50 meters	1	0.0259	
		50-100 meters	2		
		100-200 meters	3		
		200-500 meters	4		
	TWI	-0.79 to 2.395	1	0.0223	
		2.395 to 4.718	2		
		4.718 to 8.103	3		
		8.103 to 16.133	4		
		1 to 89.557	4		
	Aspect	89.557 to 175.869	4	0.0170	
		157.869to 262.181	3		
		262.181to 359.813	2		
		-13.754 to -1.203	1		
	Curvature	-1.203 to -0.096	4	0.0146	
		-0.096 to 1.134	3		
		1.134 to 17.623	2		
		1 to 89.557	1		

Annex 3: Survey Questionnaire Items

Instructions: The following survey questionnaire has been designed to evaluate the effectiveness, community perceptions, and challenges associated with the implementation of Nature-based solutions (NbS) within the Dessie City Administration, Ethiopia. Your participation and response is crucial for the successful scaling-up of these initiatives, and you are earnestly encouraged to provide honest and accurate responses based on your experience and knowledge. The findings of this study will be presented in aggregate form, ensuring that individual identities remain confidential. Participation in this survey is entirely voluntary, and you have the right to withdraw at any stage without any consequences.

Consent to Participate: Do you voluntarily agree to participate in this interview?
(For the data enumerator: If the respondent agrees, proceed with the interview;
otherwise, terminate the interview)

Date enumerator's Name: _____ Signature: _____
Date: _____ Time begins: _____ Time Ended: _____

Section I: Demographic and General Information

Address

Sub-City: _____

Keble: _____

Specific Location (Village): _____

Age of the respondent in years: _____

Sex of the respondent: 1. Male 2. Female

Marital status of the respondent: 1. Single 2. Married 3. Divorced 4. Widowed 5. Separated

Educational level of the respondents: 1; no formal education 2. Informal education 3. Have formal education

4.1 If formal education; the maximum grade level completed in years: _____

5. What is your principal occupation?

1. Student

2. Employed (public/private sector)

3. Self-employed (business person)

4. Unemployed

5. Urban agriculture

6. Retired

7. Other (specify) _____

6. Monthly estimated income in Ethiopian Birr: _____

7. How long have you lived in this area?

1. Less than 1 year

2. 1–5 years

3. 6–10 years

4. More than 10 years

8. Do you have your own house? 1. Yes 2. No

9. How often do you visit NbS in your area? 1. Daily 2. Weekly 3. Monthly 4. Rarely 5. Never

10. Have you ever participated in activities related to the maintenance or management of UGS? 1. Yes 2. No

10.1 If yes, what type of activities have you participated in? (Select all that apply)

Planting trees or vegetation

Cleaning and waste management
 Attending community meetings about NBS
 Planning and designing NBS
 Maintenance of NBS
 Fundraising or donation for NBS
 Advocacy or awareness campaigns
 Other (specify)_____

11. What motivates you to participate in NBS activities? (Select all that apply)

Environmental concern
 Community spirit
 Personal health and well-being
 Social interaction
 Incentives or rewards
 Other (specify)_____

Section II: Survey Questionnaire Items: Attitude and Perception of Local Community on the perceived benefits of NBS

Instruction: Hereunder are possible benefits of NbS. Based on your experience and perception rate each item (1-strongly disagree, 2-disagree, 3-neutral, 4-agree, and 5-strongly agree)

NOTE: Nature-based solution in this study includes: agroforestry, NbS (green corridor and parks), reafforestation/afforestation, tree-planting, and similar activities/practices

Category	Items	1	2	3	4	5
Economic Benefits	NbS increase property values in my community					
	Green areas attract tourists and visitors, benefiting and boosting the local economy					
	Investing in urban green areas creates more job opportunities					
	Green spaces encourage new businesses to open in the area					
	Green spaces increase revenue from recreational activities					
Health Benefits	NbS improve my physical health and promote healthier lifestyles for children and families					
	Spending time in green areas reduces stress and anxiety; and improves mental well-being					
	Access to green spaces encourages outdoor physical activity and exercise					
	Urban parks improve air quality, benefiting my respiratory health					
	The presence of trees and plants in the city prevent heat-related illnesses					
	NbS help reduce noise pollution					

Social Benefits	NbS bring people together and strengthen community bonds and interactions					
	Green areas provide a space for social events and gatherings					
	NbS provide opportunities for volunteering and community engagement					
Environmental and Ecological Benefits	NbS help reduce air pollution					
	Green areas provide habitats for wildlife and promote biodiversity					
	Green spaces reduce the urban heat island effect					
	Urban green areas improve water quality by filtering runoff					
	Urban parks contribute to carbon sequestration and reduce greenhouse gas emissions					
	NbS help prevent soil erosion					
	Green areas contribute to better storm water management and reduce flooding					
Accessibility and Equity	NbS are easily accessible to all members of the community					
	Green spaces are distributed equally across different neighborhoods					
	The design of NbS meets the needs of diverse groups (e.g., children, elderly, disabled)					
	NbS are well-maintained and clean					
	There are enough green spaces in my area to meet the community's needs					
Perceived Challenges or Concerns	NbS require too much maintenance and resources					
	Green spaces attract unwanted wildlife or pests					
	Green spaces are not safe to visit at night					
	The development of green spaces takes away land that could be used for housing or businesses					

Section III: Participation of Local Community in the Designing and Management of NbS; and problems/barriers or challenges faced

Direction: The following items are intended to evaluate the participation of the local community in the development of NbS, as well as any potential challenges affecting their involvement. Please rate each item based on your personal experience regarding both your level of participation and the severity of each issue, using the following scale:[3-High, 2-Medium, 1-Low, 0-Not at all]

Section 1: Level of Participation

No	Description on Level of Participation	3	2	1	0
P1	I actively participate in the planning and design of NbS in my community.				
P2	I actively participate in activities related to the maintenance or management of UGS				
P3	I regularly engage in activities like tree planting, landscaping, or maintenance of green spaces				

P4	I participate in awareness campaigns, meetings, or public forums related to NbS				
P5	I contribute financially or materially to the development and upkeep of NbS				

Section 2: Constraints/Problems faced (in participation and management)

[3-High, 2-Medium, 1-Low, 0-Not at all]

Category	Description on Level of Participation	3	2	1	0
Economic Constraints	There is a lack of financial incentives for community members to engage in green space management				
	The cost of maintaining NbS is too high for community members to contribute effectively				
	I would participate more if there were financial benefits or compensation for my involvement				
	I am willing to contribute financially to NbS management if affordable options are available				
Attitudinal Constraints	Many people in my community believe NbS management is the sole responsibility of the government				
	There is lack of interest in participating in NbS management				
	I do not see any personal benefit from engaging in NbS activities				
	I believe that my participation in NbS management would not make a significant difference				
	I believe that NbS significantly enhance the quality of life in our community				
	People in my community prioritize other issues over NbS				
Skill and Knowledge Constraints	There are sufficient training opportunities related to NbS management				
	There is a lack of collaboration between local authorities and community members in NbS initiatives				
	There are no clear policies encouraging community involvement in NbS management				
	Local institutions do not prioritize the sustainability of NbS				
Social and Cultural Factors	Vandalism and security concerns discourage community participation in NbS management				
	Cultural beliefs and traditions influence the way people perceive and use NbS				
Accessibility	Urbanization and land use changes limit the availability of space for NbS				
	There is limited accessibility to green spaces due to poor infrastructure and location				
Institutional Constraints	The local government provides adequate support for community involvement in NbS management				
	Information about NbS initiatives is easily accessible to all community members				
	Local organizations involved in NBS management are accessible and inclusive				
	Safety concerns (e.g., crime, poor lighting) prevent me from participating in NbS activities				

Section IV: Survey Questionnaire Items: Responses of Local Community on the Effectiveness of existing NBS

Instruction: hereunder are possible benefits of NbS. Based on your experience and perception, rate each item (1-strongly disagree, 2-disagree, 3-neutral, 4-agree, and 5-strongly agree)

Category	NO	Items	1	2	3	4	5
Economic Benefits	EE1	NbS increased my property values					
	EE2	NbS attracted tourists and that benefited me economically					
	EE3	Investing in urban green areas created more job opportunities					
	EE4	NbS encouraged new businesses to open in the area					
Health Benefits	HE1	NbS improved my physical health and promoted healthier lifestyles for children and families					
	HE2	Spending time in green areas reduced stress and anxiety					
	HE3	Access to green spaces encouraged my outdoor physical activity and exercise					
	HE4	NbS improved air quality, benefiting my respiratory health					
	HE5	NBS help me reduced noise pollution					
	HE6	NBS helped to enhance my social connections					
Social Benefits	SE1	NbS brought people better social cohesion and cooperation					
	SE2	NbS provided me a space for social events and gatherings					
	SE3	NbS provided us with opportunities for cultural and recreational activities					
	SE4	NbS promoted cultural and recreational activities for all age groups					
	SE5	NbS provided opportunities for volunteering and community engagement					
Environmental and Ecological Benefits	EEE1	NbS reduced air pollution					
	EEE2	NbS provided habitats for wildlife and promote biodiversity					
	EEE3	NbS reduced the urban heat island effect					
	EEE4	NbS improved water quality by filtering runoff					
	EEE5	NbS prevented soil erosion					
	EEE6	NbS prevented land slide and flooding.					
	EEE7	NbS increased water storage capacity and availability.					

Annex 4: Interview and FGD items

Section I: Interview Items for elders, community leaders, Religious leaders, and youth and women representatives

A. Effectiveness of NbS

Are the NbS easily accessible to all residents, including children, older people, and people with disabilities?

Have you noticed any improvements in air quality, temperature regulation, or biodiversity since the establishment of these NbS?

Do the green spaces effectively manage stormwater runoff, reduce land slippage, or reduce flooding in the area?

How well are the green spaces maintained (e.g., cleanliness, infrastructure, vegetation)?

Are there any issues with vandalism, littering, or misuse of the spaces?

B. Community Perception and Participation

Are there any concerns or negative perceptions about the green spaces (e.g., safety, noise, maintenance)?

Are there programs or campaigns to raise awareness in the community about the benefits of green spaces?

Do community members feel a sense of ownership or responsibility toward the green spaces?

Are there any formal or informal groups or committees that oversee the management of the NBS?

C. Major Problems Faced in Implementation

Did the project face conflicts of interest or disagreements from any stakeholders or community groups?

Were there sufficient funds, materials, and labor to implement the green spaces?

Were there any bureaucratic or regulatory hurdles in implementing the green spaces?

Is there adequate coordination between local authorities, NGOs, and the community in managing the green spaces?

D. Suggestions for Improvement

What additional features or amenities would you like to see in the green spaces (e.g., playgrounds, walking paths, seating areas)?

What suggestions do you have to improve community participation in NbS management?

What role do you think the local government should play in NbS management?

How can NbS be made more inclusive and accessible to all members of the community?

Section II: FGD for key government Officials, local Administrators, and Local NGOs

Are the green spaces easily accessible to all residents, including children, older people, and people with disabilities?

What are the contributions of NbS in your locality?

How do the local communities perceive NbS?

What are the significant challenges faced in NbS development and management? (site selection, conflicts, fund, coordination, material and labor inputs, etc.)

What additional features or amenities would you like to see in the green spaces (e.g., playgrounds, walking paths, seating areas)?

What can be done to increase community participation in the planning and management of green spaces?

What role should local governments or NGOs play in supporting NBS development and management?

Are there any funding or policy changes that could improve the implementation and sustainability of green spaces?

What suggestions do you have to improve community participation in NbS management?

How can NbS be made more inclusive and accessible to all members of the community?