Transforming Ethiopian Botanical Gardens into Socio-Ecological Systems for Sustainable Land Use and Climate Resilience

Getahun Hassen[1], Haile Ketema [2],Getahun Haile[2],Mitiku Muanenda[3]*
[1]Dilla University, Dept. of Geography and Environmental Studies, Ethiopia
[2]Dilla University, Dept. of Natural Resource Management, Ethiopia
[3]Dilla University, Dept. of Horticulture, Ethiopia
Corresponding author email: getahunhassen5@gmail.com

Abstract
Botanical gardens have advanced from simple plant collections into dynamic socio-ecological hubs for biodiversity conservation, environmental education and cultural heritage preservation. In biodiversity-rich yet economically developing countries such as Ethiopia, ongoing land system pressures pose significant challenges. These pressures including deforestation, urban expansion, and climate variability threaten both ecosystem integrity and human well-being. Addressing these challenges is crucial for sustainable development and environmental conservation. This study evaluates three Ethiopian botanical gardens (Gullele, Shashemene, and Dilla University) across several dimensions: governance, research, infrastructure, health, education and cultural integration. Utilizing mixed methods, including 300 stakeholder surveys and 15 in-depth interviews, the results highlight governance and infrastructure as key drivers of institutional performance. Institutional fragmentation and uneven resource distribution constrain broader impact. Embedding botanical gardens within coordinated national strategies aligned with Ethiopia's Climate-Resilient Green Economy plan presents promising pathways for sustaining planetary health amid ongoing land system transitions.

Introduction
Land system changes including the conversion of natural landscapes, land degradation, and urbanization are primary drivers of global biodiversity loss, ecosystem disruption and declines in human well-being (Foley et al., 2005). Addressing these complex challenges requires innovative socio-ecological approaches that integrate biodiversity conservation with sustainable development objectives. Botanical gardens represent such hybrid institutions combining plant conservation, environmental education and community engagement to enhance socio-environmental resilience (Chen & Sun, 2018; Mounce et al., 2017).

Ethiopia, which harbors over 6,000 vascular plant species with approximately 20% endemism (Asefa et al., 2020), faces intense pressures from deforestation, agricultural expansion, and climate variability. Within this context, botanical gardens play a critical role in supporting Ethiopia's Climate-Resilient Green Economy (CRGE) strategy by conserving endemic species such as *Ensete ventricosum*, integrating Indigenous knowledge systems, and promoting sustainable land management practices (Fashing et al., 2022; Yaynemsa, 2023). However, challenges including institutional fragmentation, funding limitations and insufficient community involvement continue to constrain their overall effectiveness (Godefroid et al.,

2011; Rakow & Lee, 2011). This study systematically evaluates three prominent Ethiopian botanical gardens to clarify their operational effectiveness, identify key drivers of performance, and examine systemic barriers that limit their contributions to sustainable land use and planetary health.

Materials and Methods

Study Sites

Three botanical gardens were purposively selected to represent diverse institutional models and socio-ecological contexts (Table 1).

Table 1: Characteristics of studied Ethiopian botanical gardens

Botanical Garden	Location	Year Established	Area (ha)	Governing Institution	Primary Objectives
Gullele BG (GUBG)	**Addis Ababa**	**2009**	**705 ha**	**Addis Ababa City Admin. & Addis Ababa University**	**Ex-situ conservation, research, education, recreation**
Shashemene BG (SHBG)	Oromia Region	2005	17 ha	Ethiopian Biodiversity Institute (EBI)	In-situ & ex-situ conservation, ethnobotanical research
Dilla University BG (DUBEG)	SNNP Region	2017	137 ha	Dilla University	Conservation of endemic species (e.g., Enset, coffee), ecotourism, research

Source: Survey document analysis

Data Collection

Data collected from May to December 2024 included:

- Structured surveys with 300 stakeholders rating governance, research, education, infrastructure, health and cultural integration on a 5-point Likert scale.
- Fifteen (15) semi-structured interviews with garden directors, officials, and community elders.
- Secondary document review of policy and institutional records.

Data Analysis

- Quantitative data were analyzed using descriptive statistics, ANOVA, Chi-square and logistic regression to identify predictors of high performance (composite score ≥3.8).
- Qualitative data were thematically coded and integrated to enrich interpretation

Results

Institutional Performance

Composite scores showed notable differences (Figure 1). GUBG leads overall (4.08/5) with high governance (4.4), infrastructure (4.1), and education (4.5). DUBEG excels in research (4.0) but lower in infrastructure (3.2) and health (2.5). SHBG excels culturally (4.7) but scores lower infrastructure (2.9) and health (2.6).

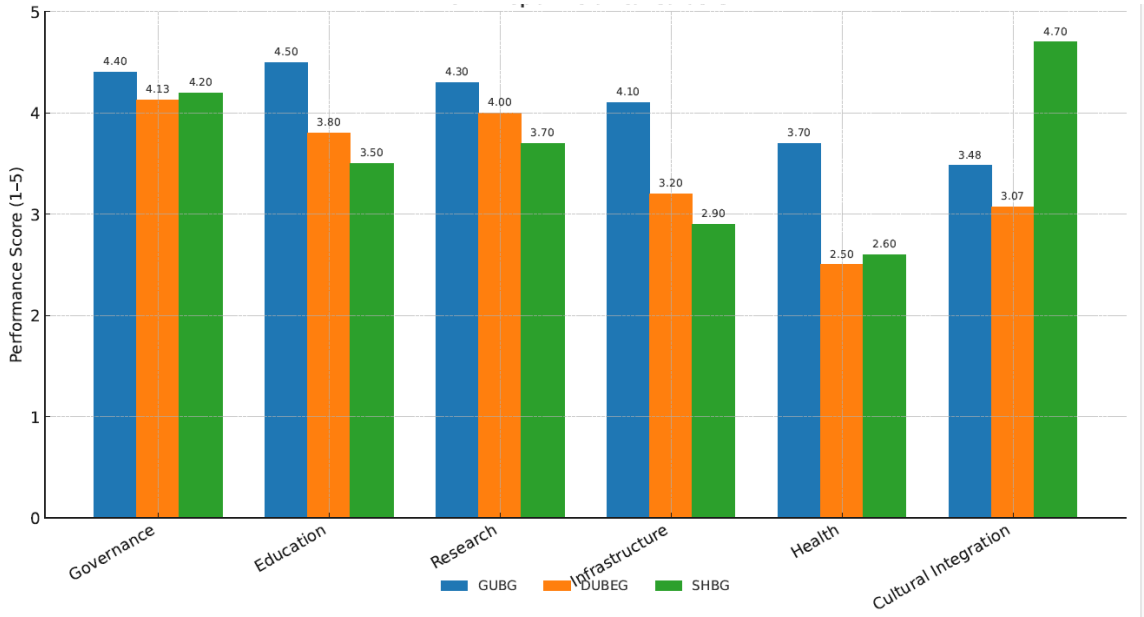

Figure 1: Composite performance scores across key domains for Ethiopian botanical gardens
Source: Survey data analysis

Performance Predictors

Logistic regression (Table 2) confirms infrastructure ($\beta = 1.2$, $p < 0.05$) and governance ($\beta = 0.9$, $p < 0.1$) as significant institutional performance predictors

Table 2: Logistic regression of performance predictors.

Domain	Beta (β)	Significance (p)
Infrastructure	1.2	<0.05 *
Governance	0.9	<0.10 †
Research	0.3	>0.10
Education	0.2	>0.10

Significant (), Marginally significant ()*

Source: Survey data analysis

Institutional Challenges

Fragmented governance among universities, municipalities and national agencies weakens strategic coherence and funding stability. GUBG's dual institutional support enhances operational maturity; DUBEG and SHBG are limited by overlapping mandates and constrained finances.

Discussion

Ethiopian botanical gardens serve as multifunctional socio-ecological hubs, crucial for biodiversity conservation and sustainable land management amid dynamic land system changes. Gullele Botanical Garden (GUBG) excels in urban education and robust infrastructure, Dilla University Botanical Garden (DUBEG) prioritizes endemic species research, and Shashemene Botanical Garden (SHBG) safeguards cultural heritage. Together, their

complementary roles create a strategic foundation for ecological resilience and community engagement

Governance and infrastructure are critical to effectiveness, underscoring the need for participatory, unified governance and sustainable financing (Rakow & Lee, 2011; Richardson et al., 2016). Enhanced Indigenous knowledge integration and greater community participation further empower resilience and climate adaptation, aligning with Ethiopia's CRGE and global SDGs (11, 13, 15).

Conclusion and Recommendations

- Ethiopian botanical gardens demonstrate promising yet uneven potential to mitigate land system threats and promote planetary health.

Recommended actions include:

- Establishing a unified national governance framework to clearly define mandates and coordinate stakeholders.
- Securing sustainable and diversified financing through public-private partnerships and payments for ecosystem services.
- Systematically integrating Indigenous knowledge into garden programming.
- Expanding participatory co-management and community engagement.
- Making targeted infrastructure investments to support their multifunctional roles.

These measures will optimize BGs as strategic green infrastructures supporting biodiversity, climate resilience, cultural heritage and well-being.

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