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Biodiversity-Based Land Management Strategies for Food Security in Urban Areas

Farida Arinie Soelistianto
Politeknik Negeri Malang

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ABSTRACT

This study examines biodiversity-based land management strategies as a sustainable solution to urban food security challenges in Indonesia. Using a qualitative approach and the Penta Helix model, data from five informants representing academia, government, private sector, community, and media were analyzed. Findings highlight the significant contributions of each stakeholder in promoting biodiversity, from academic research and innovative policies to community-driven urban farming initiatives and media advocacy. Synergies among stakeholders were evident, but challenges such as resource constraints, policy fragmentation, and cultural resistance persist. Case studies from local and global contexts underline the transformative potential of integrating biodiversity into urban planning. The study concludes that biodiversity-based strategies, supported by collaborative governance, are essential for achieving sustainable and food-secure urban environments in Indonesia.

Corresponding Author:

Name: Dr. Farida Arinie Soelistianto., ST., MT
Institution: Politeknik Negeri Malang
Email: farida.arinie@polinema.ac.id

1. INTRODUCTION

Food security remains a critical issue in urban areas, particularly in Indonesia, where rapid urbanization has significantly altered land use patterns. The expansion of urban areas has led to the conversion of agricultural and natural lands into residential and commercial zones, resulting in a substantial reduction of arable land and disrupting local food production systems. For instance, Indonesia experienced a decrease in paddy fields from 8.4 million hectares in 1990 to 7.18 million hectares in 2022, causing a notable loss in potential rice production [1]. In Jakarta, land conversion due to urbanization has further complicated food security efforts and posed governance challenges for the metropolitan region [2]. To address these issues, urban agriculture has been widely proposed as a sustainable solution, including methods such as vertical gardens, hydroponics, and community gardens, which help mitigate land scarcity and enhance food security by increasing local food availability, access, and utilization, while reducing reliance on long supply chains [3], [4]. These innovations, however, require strong policy support and interregional cooperation. Government regulation of land conversion plays a pivotal role in safeguarding food systems [1], while collaborative governance between Jakarta and its surrounding peri-urban regions is essential for effective food system management [2]. Furthermore,

policies that promote urban agriculture and engage local communities are necessary to unlock its full potential [4]. Despite these efforts, urban areas still face significant challenges, including rising food prices, limited access to water and land, and inadequate infrastructure [5]. Nevertheless, opportunities exist in improving market access, investing in urban agricultural production, and expanding food bank networks to strengthen food resilience in cities [5].

Biodiversity plays a pivotal role in supporting food security by maintaining essential ecosystem services such as pollination, soil fertility, water regulation, climate control, and recreation, all of which are vital for sustainable urban living [6], [7]. Despite its importance, the potential of biodiversity as a strategic tool for urban land management remains underexplored in many Indonesian cities. Rapid urbanization in Indonesia often leads to the conversion of green and blue open spaces into built environments, resulting in the fragmentation of natural habitats and the disruption of ecological processes, which in turn diminishes ecosystem services and increases environmental vulnerabilities [6], [7]. Conventional urban development frequently overlooks ecological considerations, contributing to biodiversity loss and weakening urban resilience. Urban green spaces, rich in biodiversity, not only support ecological functions but also offer socio-cultural, economic, and aesthetic benefits that enhance quality of life [6]. To address these challenges, it is essential to integrate biodiversity into urban planning through mainstreaming conservation knowledge, protecting and restoring high-value ecosystems, and raising public awareness of the benefits provided by biodiversity [8]. Such strategies can promote better land management practices and foster the development of resilient and sustainable urban ecosystems in Indonesia.

To address the challenges of urban food insecurity and biodiversity loss, this study examines biodiversity-based land management strategies that can be integrated into urban planning to enhance food security. Utilizing a qualitative methodology, the research adopts the Penta Helix model, which promotes collaboration among five key stakeholders—academia, government, the private sector, communities, and media—to provide a holistic understanding of the complexities surrounding urban sustainability. This multidisciplinary framework enables a comprehensive exploration of how biodiversity can contribute to sustainable urban ecosystems and resilient food systems. The study is significant as it advances the discourse on urban sustainability by emphasizing the critical link between biodiversity conservation and food security, offers actionable insights on optimizing land management through stakeholder collaboration, and supports Indonesia's commitment to the United Nations Sustainable Development Goals (SDGs), particularly Goal 2 (Zero Hunger) and Goal 15 (Life on Land).

2. LITERATURE REVIEW

2.1 Food Security in Urban Areas

Urban food security is a multifaceted issue intensified by rapid urbanization, economic disparities, and environmental degradation, where the growing urban population drives increasing demand for food while the availability of arable land simultaneously declines. This necessitates innovative and sustainable urban planning strategies that integrate food production into the urban fabric to ensure consistent access to nutritious food. Urban areas face significant challenges such as rising food prices, limited access to water and land for farming [5], dependency on food imports which exposes them to supply chain disruptions (Peters et al., 2016), and environmental degradation that further complicates food production efforts [4], [9]. However, there are notable opportunities to address these issues, such as through urban agriculture—including rooftop gardens and community farms—which can overcome land constraints,

increase local food production, and reduce household food expenditures. Additionally, proactive urban planning that embeds food systems into city development can enhance food distribution networks and reduce spatial inequalities in food access [10]. Finally, community engagement and supportive policies play a vital role in maximizing the potential of urban agriculture and establishing resilient, sustainable urban food systems [4].

2.2 The Role of Biodiversity in Food Systems

Biodiversity is a cornerstone of ecosystem services essential for food security, especially in urban environments where innovative approaches like urban farming, agroforestry, and green roofs are implemented to enhance local food production and build resilience against environmental stressors such as extreme weather events. Urban agriculture, as part of green infrastructure, not only contributes to food access but also provides habitats for beneficial species like pollinators and natural pest predators, thereby enhancing crop productivity and acting as biodiversity hotspots within the urban matrix [11]. Biodiversity supports crucial ecosystem services including pollination, pest control, and soil fertility, which are vital for maintaining agricultural productivity and food security [12]. However, the degradation of over 60% of global ecosystem services, as reported by the Millennium Ecosystem Assessment, underscores the urgent need to protect biodiversity to sustain these functions [13]. The loss of biodiversity poses a serious threat to the sustainability and functionality of urban food systems, potentially weakening their capacity to meet growing food demands. In response, cities are increasingly integrating biodiversity into climate adaptation strategies through land use planning and water management to support urban food supply chains, while simultaneously achieving health co-benefits such as reducing pollution-related illnesses and mitigating urban heat stress—critical outcomes in densely populated areas [14].

2.3 Land Management and Urban Sustainability

Effective land management is essential to balance urban development with ecological preservation, as conventional urban planning often prioritizes infrastructure and economic growth, leading to biodiversity loss. Sustainable strategies aim to integrate ecological, economic, and social dimensions by promoting urban green spaces—such as parks and community gardens—that support recreation, food production, and biodiversity [7], [15]. Green infrastructure, including green roofs and walls, helps mitigate urban heat, improve air quality, and provide vital services like stormwater management and carbon sequestration [16]. Multifunctional land use further supports economic growth and social development while maintaining environmental sustainability, marking a shift toward more resilient and integrated urban planning [16].

2.4 The Penta Helix Model in Urban Development

The Penta Helix model is a collaborative framework involving academia, government, private sector, communities, and media to address complex urban issues. This model emphasizes stakeholder engagement to ensure holistic and inclusive solutions [17]. In the context of biodiversity-based land management, the Penta Helix model fosters knowledge sharing, resource mobilization, and community participation. For instance, academia contributes research and innovation, while government bodies create enabling policies. The private sector provides funding and technological support, communities ensure grassroots engagement, and media raises public awareness about the importance of biodiversity.

3. METHODS

This study employs a qualitative research design to explore biodiversity-based land management strategies for enhancing urban food security in Indonesia. The qualitative approach is particularly suited for examining complex social phenomena and

understanding the perspectives of various stakeholders involved in urban planning and biodiversity conservation. Guided by the Penta Helix framework—which emphasizes collaboration among academia, government, private sector, community, and media—the research focuses on selected urban areas in Indonesia that face challenges from rapid urbanization. These locations were chosen based on the presence of biodiversity conservation projects, urban agriculture initiatives, or innovative land management practices. Five key informants were purposively selected to represent each Penta Helix component: academics with expertise in urban sustainability, government officials involved in environmental and food policies, private sector actors in agribusiness and infrastructure, community leaders engaged in urban farming and biodiversity promotion, and media professionals who raise public awareness on these issues. Informant selection was based on their expertise, involvement in relevant initiatives, and willingness to participate.

Data collection was conducted through semi-structured interviews between March and May 2025, using open-ended questions to gain in-depth insights on urban food security challenges, the role of biodiversity in urban food systems, strategies for biodiversity integration in land management, the effectiveness of multi-stakeholder collaboration, and recommendations for policy improvement. Interviews lasted 60–90 minutes, conducted both in person and online, and were audio-recorded with consent before transcription. The data were analyzed using thematic analysis following Braun and Clarke's (2006) framework, including familiarization with the data, coding, theme development, reviewing, and defining themes. NVivo software supported the data management and helped structure the findings according to the Penta Helix model, ensuring a comprehensive and systematic interpretation of the research data.

4. RESULTS AND DISCUSSION

4.1 Academia: Promoting Knowledge and Innovation

Academic institutions play a pivotal role in generating research and fostering innovation for biodiversity-based urban land management. Informants underscored the importance of applied research in areas such as agroforestry, rooftop farming, and soil restoration, which are essential for adapting biodiversity strategies to urban contexts. These institutions not only advance scientific understanding but also contribute to policy development and community empowerment through education and outreach. As one academic informant explained, "Universities can bridge the gap between theoretical knowledge and practical application by collaborating with policymakers and community groups." This collaboration ensures that academic insights are translated into actionable strategies for urban sustainability.

Several key initiatives were identified by informants to illustrate the academic sector's contribution. These include urban biodiversity research focused on identifying native plant species suitable for integration into urban agriculture systems; capacity building programs, such as workshops and certifications, that equip urban planners and community members with knowledge on sustainable urban development; and collaborative projects involving local governments to design and implement pilot projects that prioritize biodiversity in city planning. Through these efforts, academic institutions serve as catalysts for systemic change in how urban environments are designed and managed.

4.2 Government: Policy and Regulation

Government bodies play a crucial role in establishing the regulatory and policy frameworks necessary for integrating biodiversity into urban land management. Informants acknowledged that while certain urban regions have adopted forward-thinking policies—such as the development of biodiversity parks and support for urban farming initiatives—many cities still lack cohesive and enforceable strategies. The

effectiveness of these policies often hinges on local governance capacity and coordination across agencies. As one government representative noted, "We aim to balance urban growth with environmental sustainability, but policy enforcement remains a challenge in some areas." This highlights the ongoing gap between policy formulation and implementation, especially in rapidly urbanizing regions.

Several strategic measures were highlighted by informants to enhance government involvement in biodiversity-based planning. These include urban planning policies that mandate the integration of green spaces in all new developments, providing both ecological benefits and improved quality of life. Incentive schemes, such as tax reductions for private sector actors who implement green infrastructure, are also being explored as a way to encourage wider participation. Additionally, the need to strengthen monitoring and evaluation systems was emphasized to ensure that policies are not only adopted but effectively enforced and adjusted based on measurable outcomes. Through these mechanisms, government institutions can play a more proactive and accountable role in shaping sustainable urban ecosystems.

4.3 Private Sector: Investment and Technology

Private sector involvement has become a key driver in expanding biodiversity-based urban initiatives, particularly through the rise of corporate social responsibility (CSR) programs and targeted investments in sustainable development. Informants pointed to the private sector's role in introducing and scaling innovative technologies such as vertical farming systems, automated irrigation, and hydroponics, which are essential for optimizing limited urban spaces for food production. These advancements not only improve productivity but also align with broader sustainability goals. As one private sector informant stated, "Investing in biodiversity-based solutions not only addresses food security but also enhances our brand reputation," reflecting how environmental responsibility can also serve strategic business interests.

Notable private sector contributions include financial support through sponsorships of community-led urban farming projects, which help build local capacity and foster grassroots engagement. In addition, firms are actively developing and deploying space-efficient agricultural technologies that make biodiversity integration feasible even in dense urban environments. Public-private partnerships have also emerged as a powerful model, allowing companies to collaborate with government agencies on urban greening initiatives such as biodiversity corridors, rooftop gardens, and green infrastructure. Through these efforts, the private sector is not only contributing resources and innovation but also reinforcing the multi-stakeholder collaboration necessary for resilient and sustainable cities.

4.4 Community: Grassroots Implementation

Communities play a vital role in the implementation and sustainability of biodiversity-based land management strategies. Informants highlighted the growing momentum of community-driven initiatives such as urban farms, community gardens, and local biodiversity conservation projects, which not only address food security but also foster social cohesion and environmental stewardship. Local engagement ensures that biodiversity strategies are context-specific, culturally appropriate, and resilient over time. As one community leader remarked, "Our urban farming initiative has improved local access to fresh produce and strengthened community bonds," emphasizing how grassroots actions can yield both ecological and social benefits.

Community contributions span several impactful areas. Urban farming projects led by residents have successfully converted vacant lots and underutilized spaces into productive gardens, contributing to local food resilience. Educational programs organized at the neighborhood level help equip residents with knowledge about

sustainable farming practices and biodiversity preservation. Additionally, communities often lead advocacy and grassroots campaigns that raise awareness and push for policy changes supporting ecological land use. These collective actions demonstrate the indispensable role of community participation in building inclusive, biodiverse, and food-secure urban environments.

4.5 Media: Raising Awareness and Advocacy

The media plays a critical role in amplifying awareness about biodiversity and sustainable land management, serving as a bridge between expert knowledge and public understanding. Informants highlighted the strategic use of digital platforms to disseminate success stories, promote behavioral change, and shape public discourse around environmental issues. Through accessible content and compelling narratives, the media can engage urban audiences and influence both community behavior and policy agendas. As one media professional stated, "Our campaigns aim to make biodiversity conservation relatable and actionable for urban audiences," reflecting a shift toward more participatory and inclusive communication strategies.

Key media strategies include storytelling that showcases best practices in urban biodiversity from both local and international contexts, making complex ecological concepts easier to grasp. Educational content—such as documentaries, blogs, and social media posts—serves to inform and inspire action among diverse audiences. Furthermore, media organizations often collaborate with other Penta Helix stakeholders to launch advocacy campaigns, supporting policy reforms and public engagement in biodiversity conservation. By shaping narratives and elevating public consciousness, the media significantly contributes to creating a cultural and political climate conducive to sustainable urban development.

4.6 Discussion

The findings of this study highlight the significant potential of biodiversity-based strategies in addressing urban food security challenges by leveraging ecosystem services to enhance food production and urban sustainability. These strategies rely heavily on the effective collaboration of stakeholders within the Penta Helix model—academia, government, private sector, communities, and media. Each stakeholder brings distinct contributions: academia provides the research foundation necessary for evidence-based implementation [18]; government offers regulatory frameworks that support biodiversity and urban agriculture policies [19]; the private sector contributes technological innovation and funding to scale solutions like vertical farming [20]; communities serve as the frontline implementers, as seen in Indonesia's Kampung Hijau initiatives [21]; and the media plays a vital role in advocacy and public awareness, particularly in combating misconceptions about urban biodiversity [4].

Despite these synergies, several critical challenges continue to hinder the widespread implementation of biodiversity-based land management. Coordination gaps persist due to unclear communication and misaligned goals among stakeholders, limiting cohesive action [18]. Financial constraints also pose a significant barrier, as many biodiversity projects require substantial investment without guaranteed short-term returns [20]. Moreover, cultural resistance—driven by public skepticism about the feasibility and relevance of urban biodiversity—further impedes progress [19]. Additionally, policy fragmentation across regions creates inconsistencies that complicate broader strategy adoption and long-term sustainability [4].

Nevertheless, global and local case studies offer valuable lessons for overcoming these barriers. Singapore's rooftop farming initiatives demonstrate that urban agriculture can thrive even in high-density environments, integrating food production into the built landscape [21]. Indonesia's Kampung Hijau programs showcase the power of community-led biodiversity conservation and food security efforts at the grassroots level [21].

Meanwhile, Germany's green roof mandates exemplify how strong regulatory policies can institutionalize biodiversity into urban planning frameworks [19]. These examples reinforce the need for sustained investment, inclusive stakeholder engagement, and adaptive policymaking to ensure that biodiversity-based strategies effectively contribute to resilient and food-secure cities.

4.7 Policy and Practical Implications

The study findings lead to several key recommendations to strengthen biodiversity-based urban land management. First, integrated policies are needed to align urban development objectives with biodiversity conservation across national and regional planning frameworks. Second, incentive mechanisms—such as financial rewards or tax benefits—should be introduced to encourage developers and businesses to adopt environmentally friendly practices. Third, establishing stakeholder platforms can facilitate collaboration among Penta Helix members—academia, government, private sector, communities, and media—ensuring coordinated efforts in biodiversity initiatives. Lastly, empowering communities by supporting local leaders and grassroots organizations is essential for driving sustainable urban farming and biodiversity conservation at the neighborhood level.

4.8 Alignment with Sustainable Development Goals (SDGs)

The research aligns closely with several Sustainable Development Goals (SDGs), particularly Goal 2: Zero Hunger, by promoting urban agriculture to ensure access to nutritious food; Goal 11: Sustainable Cities and Communities, through the advancement of green and resilient urban infrastructure; and Goal 15: Life on Land, by emphasizing biodiversity conservation to sustain essential ecosystem services. By integrating these global targets into local planning and action, Indonesia can strengthen its urban sustainability agenda while simultaneously addressing pressing food security challenges in rapidly urbanizing areas.

5. CONCLUSION

Biodiversity-based land management strategies offer a viable pathway to addressing urban food security challenges in Indonesia by leveraging ecological functions to enhance food systems. The study highlights the critical role of collaboration among Penta Helix stakeholders: academia contributes knowledge and innovation, governments establish enabling policies, the private sector provides technology and funding, communities lead grassroots implementation, and the media fosters public awareness. However, effective implementation demands overcoming key challenges such as coordination gaps, resource limitations, and policy inconsistencies. Global and local case studies illustrate that biodiversity-based initiatives can successfully transform urban environments into resilient and sustainable food systems. Aligning these strategies with the Sustainable Development Goals (SDGs)—particularly in achieving zero hunger, sustainable cities, and biodiversity conservation—reinforces their broader relevance. Therefore, policymakers and urban planners must embed biodiversity into development frameworks, offer incentives for stakeholder collaboration, and build community capacity. Through these efforts, Indonesian cities can achieve a balanced integration of ecological integrity and human well-being, paving the way for a sustainable and food-secure urban future.

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