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Urban agriculture in a changing world: a thematic review of global trends, innovations, governance, and pathways to sustainability

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Urban agriculture (UA) has emerged as a key strategy to address food insecurity, climate change, and urban sustainability. This review synthesizes global evidence on the historical evolution, regional variations, and multifunctional roles of UA. It examines technological innovations, governance frameworks, and socio-economic impacts, with attention to the Global South and India. By integrating case studies and policy models, the review highlights how UA contributes to Sustainable Development Goals (SDGs) while recognizing its limitations in producing staples and animal protein at scale. A conceptual framework distinguishes formal vs. informal and low-tech vs. high-tech UA, underscoring diverse pathways of practice. The review concludes by identifying unresolved debates and proposing future research priorities, including longitudinal studies on climate resilience and cost–benefit analyses of smart farming in low-income contexts. UA is best understood as a complement to rural agriculture, offering both ecological services and social resilience within rapidly urbanizing landscapes.

KEYWORDS

urban agriculture, global south, technological innovations, socio-economic impacts, sustainable development goals (SDGs), climate resilience, policy and governance

1 Introduction

Urban agriculture (UA) has gained increasing attention as a multifaceted solution to the intertwined challenges of urban food insecurity, climate vulnerability, and unsustainable city planning. As more than half of the global population now resides in urban areas and this figure is projected to rise to 68% by 2050 the pressure on urban food systems and infrastructure continues to intensify (United Nations, 2019). Urban agriculture, encompassing the production, processing, and distribution of food in and around cities, has evolved from a subsistence or emergency practice into a strategic component of sustainable urban development (de Zeeuw and Drechsel, 2015; Orsini et al., 2013).

Historically, UA has served critical roles during times of crisis, such as wartime and economic recessions, but its modern resurgence is linked to broader goals of environmental sustainability, social equity, and food system resilience (Mok et al., 2014; Opitz et al., 2016). In the Global South, UA contributes significantly to household nutrition, income generation, and community cohesion in the face of rapid urbanization and informal settlement growth (Cohen and Garrett, 2010; Frayne et al., 2014). In contrast, urban farming in developed nations is increasingly associated with technological innovation, civic engagement, and ecological design ranging from rooftop gardens and vertical farms to sensor-based and AI-driven production systems (Despommier, 2010; Goldstein et al., 2016).

UA has thus been described in diverse ways, spanning survival strategies in informal settlements to high-tech vertical farming in advanced economies. To clarify these multiple manifestations, this review introduces a conceptual typology (Figure 1) that positions UA along two key dimensions: (i) production system (soil-based vs. soilless) and (ii) institutional formality (informal vs. formal). Crossing these dimensions yields four broad categories: informal soil-based, formal soil-based, informal soilless, and formal soilless.

Given the growing academic and policy interest in UA, there is a need for a structured synthesis that goes beyond case-based or geographically limited reviews. This review aims to fill that gap by offering a comprehensive, thematically organized analysis of urban agriculture across multiple dimensions historical development, global and regional trends, technological advances, policy and governance frameworks, social and economic impacts, ecosystem services, and alignment with the Sustainable Development Goals (SDGs). By mapping these themes, the review provides a global perspective on how urban agriculture contributes to more equitable, resilient, and sustainable urban food systems.

2 Review methodology

A systematic screening process was followed to identify relevant literature on urban agriculture (UA). Searches were conducted across major academic databases, including Scopus, Web of Science, ScienceDirect, and Google Scholar, using Boolean combinations of keywords such as "urban agriculture" OR "urban farming" AND "policy" OR "sustainability." The initial search yielded 1,263 records. After removing duplicates, 1,050 records remained for further screening.

Titles and abstracts were then screened for relevance, leaving 857 records. Of these, 212 articles were assessed in full text against predefined inclusion and exclusion criteria. Studies were included if they addressed UA in an urban or peri-urban context, were peer-reviewed or from credible institutional sources, and focused on themes related to history, policy, governance, sustainability, or socio-economic impacts.

Exclusion criteria ruled out unverified grey literature (except for policy documents from recognized international organizations such as FAO and UN-Habitat), publications lacking a direct focus on urban agricultural systems, opinion pieces without empirical basis, and non-English language publications. All selected literature was further screened for thematic and methodological relevance before being critically analyzed and synthesized.

Case studies (e.g., Cuba, Singapore, India, Belo Horizonte) were chosen for representativeness, geographical balance, policy relevance, and data availability. These case studies span various regions and provide a comprehensive view of the diverse UA practices and their outcomes in different socio-political and economic contexts. They offer valuable insights into how urban agriculture is practiced across developed and developing nations and its varying impacts based on geographic, political, and socio-economic factors.

In total, 136 studies met the eligibility criteria and were included in the qualitative synthesis. However, to avoid redundancy and overlapping findings, 76 representative references are cited in this review. The additional studies contributed to the thematic synthesis but were not cited individually, as they helped shape the analysis without offering novel, independently-cited insights.

The synthesis was organized under nine thematic sections, derived from recurring concepts across the literature and aligned with contemporary global discourses on food systems transformation, climate resilience, and urban sustainability. The thematic categories include: (1) Historical Development of Urban Agriculture; (2) Global Urban Agriculture Trends and Divergences; (3) Urban Agriculture in the Global South; (4) Urban Agriculture in India; (5) Technological Innovations in Urban Agriculture; (6) Policy and Governance Framework; (7) Social and Economic Impacts; (8) Ecosystem Services and Sustainability; (9) Urban Agriculture and the Sustainable Development Goals (SDGs). This thematic structure provides a comprehensive and policy-relevant framework for understanding the multi-functionality and evolving role of urban agriculture in addressing contemporary food system challenges.

	Soil based Systems	Soilless Systems
Formal	Community Allotments Peri-urban Cooperatives	Corporate Vertical Farms Municipal Hydroponics
Informal	Slum Gardening Roadside Cultivation	Household Hydroponics DIY Balcony System

FIGURE 1
Typology of urban agriculture. Classification of urban agriculture by production system (soil-based vs. soilless) and governance (formal vs. informal), highlighting examples from community allotments and peri-urban cooperatives to vertical farms and household hydroponics. Source: Compiled by author.

2.1 Limitations

Restricting the review to English-language publications may introduce selection bias by excluding valuable local or regional sources, especially from Latin America, Africa, and Asia. Informal practices in the Global South are under-documented, which could bias the sample toward more formalized projects. Moreover, the reliance on case studies limits generalizability, as many of these are descriptive rather than longitudinal. Future reviews would benefit from incorporating multilingual databases and grey literature to capture a broader range of perspectives and experiences (Page et al., 2021) (see Figures 2, 3).

3 Thematic review sections

3.1 Historical development of urban agriculture

Urban agriculture has evolved significantly over time, transitioning from a fundamental survival strategy to a critical

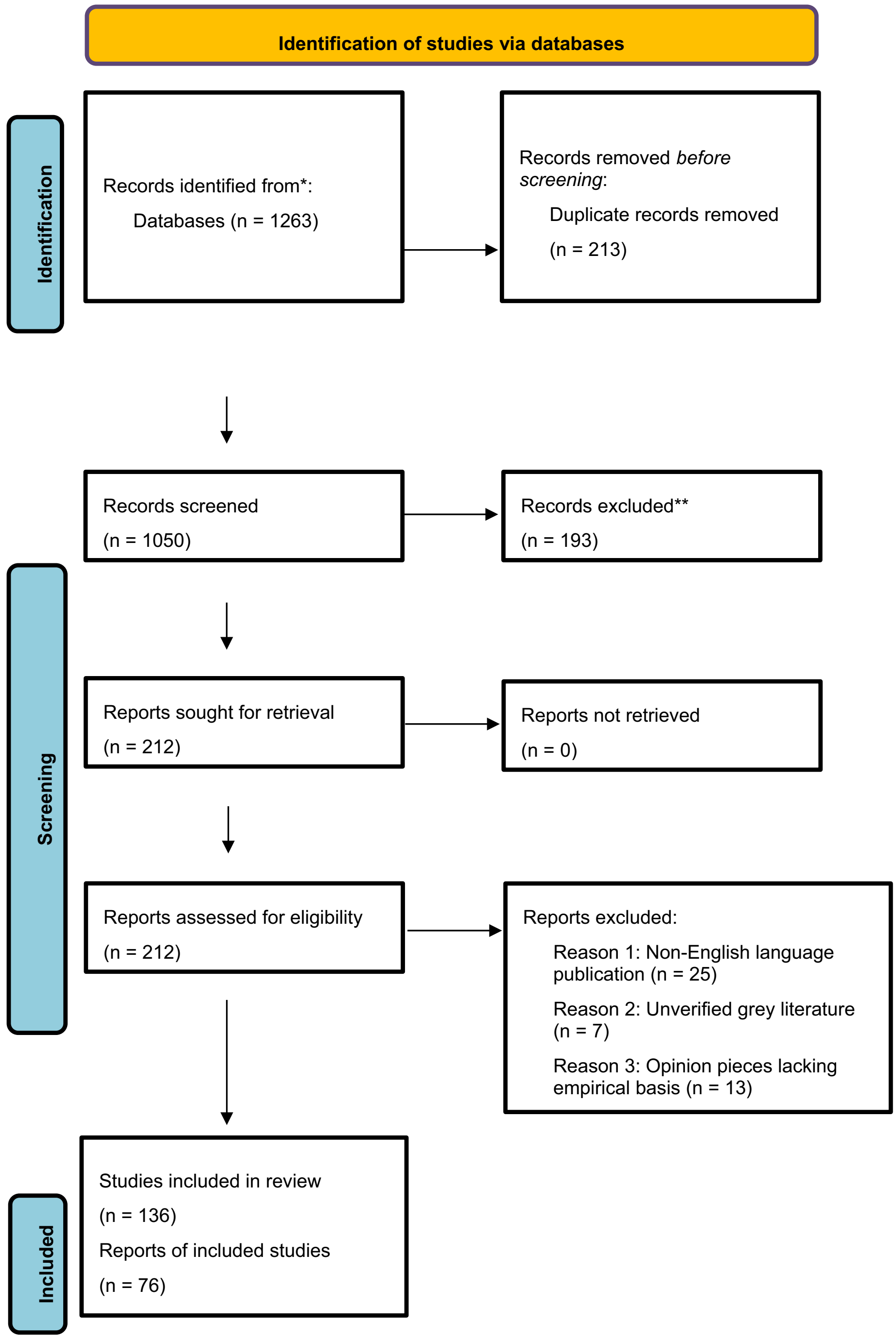

FIGURE 2
PRISMA flowchart of literature screening. Flowchart illustrating the systematic literature search, screening, and selection process, including numbers of records identified, screened, included, and excluded, with reasons for exclusion. *Consider, if feasible to do so, reporting the number of records identified from each database searched (rather than the total number across all databases). **If automation tools were used, indicate how many records were excluded by a human and how many were excluded by automation tools. Source: Page et al. (2021).

component of sustainable urban development. Historically, urban farming emerged as a means to secure food supplies, particularly during times of crisis. However, in contemporary society, it has expanded to address climate change adaptation, urban resilience, community well-being, and economic empowerment. The historical development and evolving multifunctionality of urban agriculture are summarized in Table 1.

3.1.1 Ancient origins and early urban agriculture

The practice of cultivating food within or near urban areas is as old as civilization itself. Ancient societies recognized the importance of locally grown food and incorporated agricultural practices into their city landscapes. The Mesopotamian civilization (circa 3,000 BCE) is one of the earliest examples where urban agriculture was practiced extensively (Crawford, 2020). Cities such as Babylon utilized advanced

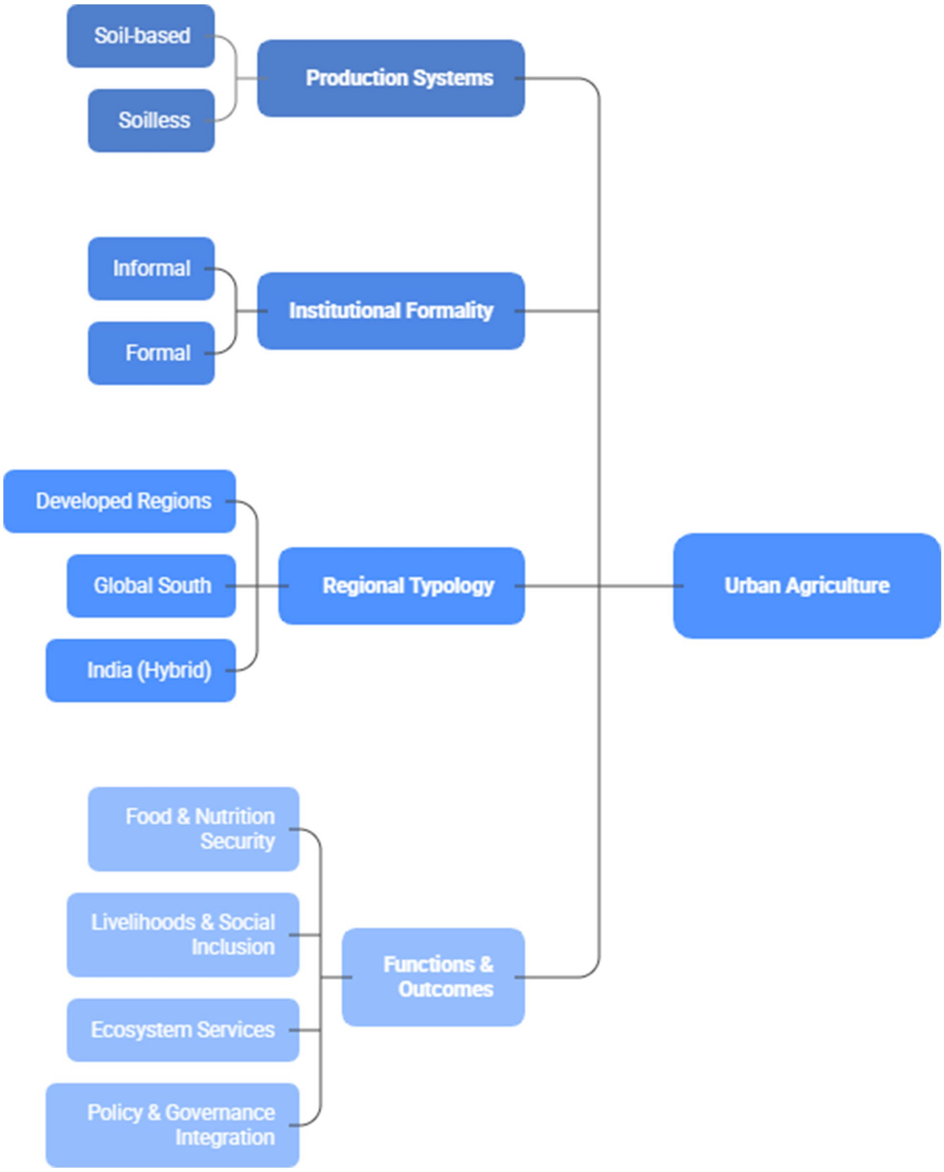

FIGURE 3
Conceptual framework for literature analysis on urban agriculture (UA). Schematic framework depicting the relationships between UA types, socio-economic impacts, technological innovations, policy frameworks, and contributions to Sustainable Development Goals (SDGs). Source: Compiled by author.

irrigation systems to support agriculture along the banks of the Tigris and Euphrates rivers. The legendary Hanging Gardens of Babylon are believed to be an early example of vertical farming, where terraced gardens allowed for efficient food cultivation in an urban setting. In Mesoamerica, the Aztecs developed chinampas, or floating gardens, in the 1400s CE. These were artificial islands built on lakes to maximize land use efficiency for growing crops, a concept that finds echoes in modern hydroponic and rooftop farming systems (González Jácome, 2004). In medieval Europe (5th–15th century CE), monastic communities maintained self-sufficient agricultural gardens within their walls, serving not only as a food source but also for medicinal and spiritual purposes (Dalziel, 2018). These medieval gardens highlighted the multifunctionality of farming, a feature that remains relevant in contemporary urban agriculture.

3.1.2 Industrialization and urbanization: the decline and revival of urban agriculture

With the rise of industrialization in the 18th and 19th centuries, urban agriculture experienced a decline as cities expanded and rural agriculture became the dominant food source. Industrial growth led to increased migration to cities, reducing available land for urban farming (Bassett, 1981). However, during periods of war, economic crises, and food shortages, urban farming regained importance as a resilience strategy. During World War I and World War II, urban agriculture became a crucial component of national food security efforts. The Victory Garden Movement encouraged urban residents in the United States, Canada, and Britain to grow their own food to reduce pressure on national food supply chains (Lawson, 2005). At its peak, the United States had over 20 million

TABLE 1 Historical milestones in urban agriculture, summarizing key periods, functions, and geographic focus areas.

Period/milestone	Key characteristics/ functions	Geographic focus	Multifunctional aspects	References
Ancient Civilizations (circa 3,000 BCE onwards)	Integration of food production into urban settings; irrigation and terraced farming (e.g., Hanging Gardens)	Mesopotamia, Babylon	Food security, early urban greening	Crawford (2020)
Mesoamerican Chinampas (1400s CE)	Floating gardens for efficient land use	Aztec Empire (Mexico)	Land use optimization, ecological farming	González Jácome (2004)
Medieval Monastic Gardens (5th–15th Century CE)	Self-sufficient gardens for food, medicine, and spirituality	Europe	Multifunctionality: food, medicine, spiritual use	Dalziel (2018)
Industrialization Era (18th–19th Century)	Decline of urban farming due to industrial expansion	Europe, North America	Reduced food production role	Bassett (1981)
Wartime Victory Gardens (World Wars I & II)	Emergency food production during crises	United States, Britain, Canada	Community resilience, food security	Lawson (2005)
Post-War Urbanization & Green Revolution (1950s–1970s)	Shift to industrial agriculture and rural production	Global	Urban agriculture marginalization	Pingali (2012)
Late 20th Century Resurgence (1990s)	Urban agriculture for sustainability and food self-sufficiency (e.g., Cuba)	Cuba, United States, Europe	Sustainability, poverty alleviation, food security	Altieri and Funes-Monzote (2012); Lawson (2005)
21st Century Urban Agriculture	Multifunctional role: food security, climate adaptation, economic empowerment	Global	Urban resilience, environmental benefits, social inclusion	Mok et al. (2014); Poulsen et al. (2015); McClintock (2010)

Source: Compiled by author.

Victory Gardens, contributing nearly 40% of the nation's vegetable supply.

Ebenezer Howard's Garden City movement in the late 19th century played a critical role in the modern conceptualization of urban agriculture. Howard's vision emphasized the integration of green spaces, agriculture, and urban planning to create self-sustaining communities (Howard, 1898). His ideas about Garden Cities, where cities and nature coexist harmoniously, laid the foundation for future urban agriculture models that sought to combine housing, industry, and agriculture in a way that promoted both urban development and sustainability.

3.1.3 The post-war period and the green revolution

The post-war period witnessed rapid urbanization and the emergence of the Green Revolution in the 1960s and 1970s, which significantly increased food production in rural areas through mechanization, high-yield crop varieties, and chemical fertilizers (Pingali, 2012). While this revolution improved global food security, it also led to the centralization of food production in rural regions, marginalizing the presence of farming within urban landscapes.

3.1.4 Urban agriculture in the late 20th century: a shift toward sustainability

3.1.4.1 Re-emergence of UA

By the late 20th century, urban agriculture re-emerged as a response to food insecurity, urban poverty, and environmental concerns. A defining example of this resurgence was Cuba's urban agriculture model in the 1990s, following the collapse of the Soviet Union, which caused a severe food crisis due to agricultural imports.

3.1.4.2 Cuba's response

In response, the Cuban government promoted organic urban farming, converting vacant lots, rooftops, and unused land into productive urban farms (Altieri and Funes-Monzote, 2012).

3.1.4.3 Global context

At the same time, community gardening movements gained traction in the United States and Europe. Initiatives such as allotment gardens, urban farms, and school gardens were established to improve food security while providing social, economic, and environmental benefits (Lawson, 2005).

3.1.5 Contemporary urban agriculture: a cross-cutting approach

3.1.5.1 Modern role and contributions

In the 21st century, urban agriculture is increasingly recognized not only as a food security strategy but also as a tool for sustainable urban development. Its applications span food security, climate change mitigation, economic development, and social empowerment (Mok et al., 2014).

3.1.5.2 Access to food in urban areas

Urban agriculture enhances nutrition by improving access to fresh, locally grown produce, particularly in low-income urban neighborhoods and food deserts (Poulsen et al., 2015). Cities such as

Detroit (USA) and Nairobi (Kenya) have implemented urban farming programs to combat hunger and malnutrition.

3.1.5.3 Environmental and policy integration

In developing countries, urban farming has played a significant role in women's empowerment, providing economic independence and improving household food security. As urban agriculture evolves, it is increasingly integrated into urban planning and policy frameworks, with municipalities introducing zoning laws, financial incentives, and public-private partnerships to support its expansion (McClintock, 2010).

3.2 Global urban agriculture trends and divergences

Urban agriculture (UA) has emerged as a critical response to the intersecting challenges of rapid urbanization, climate change, food insecurity, and socio-economic inequalities. Over the past two decades, there has been a marked shift in how cities across the globe conceptualize and implement UA initiatives. This transformation reflects the growing recognition of UA not merely as a subsistence strategy but as a multifaceted approach contributing to urban sustainability, resilience, and inclusive development (Specht et al., 2014; Siegner et al., 2018).

3.2.1 Evolving models in developed nations

In high-income countries, UA has evolved from grassroots gardening movements into highly systematized, technologically advanced, and policy-integrated forms of food production. Cities in North America, Europe, and East Asia have increasingly adopted vertical farming, hydroponics, aquaponics, and controlled environment agriculture (Benke and Tomkins, 2017). These innovations are not only space-efficient but also resource-conserving, offering urban solutions to food production that align with broader goals of circular economy and carbon neutrality. Municipal governments play a pivotal role in mainstreaming UA through supportive policies, zoning regulations, and financial incentives. For instance, the Milan Urban Food Policy Pact exemplifies a holistic governance framework that integrates UA into food waste management, redistribution, and urban resilience planning (Siegner et al., 2018). Moreover, cities like Berlin and Tokyo have embedded UA into their climate adaptation and biodiversity strategies by promoting green roofs, community-supported agriculture (CSA), and agroecological networks (Specht et al., 2014).

3.2.2 Community-driven practices in developing nations

In contrast, UA in developing countries is often driven by necessity and community engagement rather than technological innovation or formal policy support. In African, Latin American, and South Asian urban contexts, urban farming functions as a critical livelihood strategy, particularly among low-income households. Over 60% of urban dwellers in Sub-Saharan Africa are engaged in some form of UA, often cultivating on vacant public lands, riverbanks, or rooftops to meet their food and income needs (Zezza and Tasciotti, 2010). These models are typically low-input, relying on organic composting, intercropping, and recycled wastewater for irrigation. Despite limited institutional support, these systems contribute significantly to local food availability, dietary diversity, and economic resilience. Furthermore, UA in developing nations serves as a frontline response to climate-related shocks, as seen in cities like Dhaka and Lima, where rooftop farming and drought-resistant crops are promoted to counter environmental vulnerabilities (Galli et al., 2019).

3.2.3 Converging trends across global contexts

Despite differing socio-economic contexts, there are converging global trends in urban agriculture. Firstly, cities across both hemispheres are increasingly recognizing UA's potential in climate change adaptation and mitigation. UA contributes to reducing urban heat island effects, enhancing stormwater management, and lowering greenhouse gas emissions through localized food production (Specht et al., 2014). Secondly, urban agriculture is progressively being institutionalized within city planning, with a growing number of governments adopting regulatory frameworks that incentivize land access, offer tax benefits, and integrate UA into public health and nutrition agendas (Rocha and Lessa, 2009). Lastly, UA is gaining traction as a mechanism for social inclusion and empowerment. Projects targeting women, youth, and marginalized populations are demonstrating the potential of urban farming to support food sovereignty, community cohesion, and employment generation. These initiatives often blend traditional knowledge systems with innovative practices, fostering a hybrid model of UA that is both culturally embedded and future-ready.

3.2.4 Technological advancements and innovation in urban agriculture

Urban agriculture in the 21st century is increasingly shaped by technological advancements aimed at optimizing space, water, and nutrient use. Hydroponics, aeroponics, and aquaponics have gained significant traction, especially in cities with limited arable land. These soilless systems enable high-density farming in small spaces such as rooftops, abandoned buildings, and vacant lots. The rise of vertical farming is another key innovation, with entire buildings or skyscrapers dedicated to producing food for local consumption. These technologies not only increase urban food production but also contribute to the Sustainable Development Goals (SDGs) by promoting sustainable cities and communities (SDG 11) and responsible consumption and production (SDG 12) (Despommier, 2010).

In cities like New York, London, and Tokyo, these technological innovations are being integrated into urban regeneration projects. For example, in Singapore, the government's push for high-tech vertical farming and hydroponics has positioned the country as a global leader in urban agriculture innovation (Goldstein et al., 2016). These technologies address the growing demand for local food in densely populated areas, contributing to climate adaptation and urban sustainability (see Table 2).

3.3 Urban agriculture in the global south

3.3.1 Urbanization, food security, and the emergence of urban agriculture

Urbanization across the Global South has introduced a complex nexus of challenges involving food insecurity, economic volatility, and

TABLE 2 Regional UA typology: comparative socio-economic impacts across different regions, highlighting dominant forms of urban agriculture, socio-economic drivers, benefits, and challenges.

Region	Dominant forms of UA	Socio-economic drivers	Benefits	Challenges
Developed Regions (e.g., Europe, North America, East Asia)	• Community allotments • Rooftop gardens • Vertical farms (corporate/ municipal)	• Sustainability and climate goals • Lifestyle and wellness • Niche food markets	• Strengthens social cohesion • Provides ecosystem services (cooling, biodiversity) • Access to local/organic food	• High capital and energy costs (vertical farms) • Risk of gentrification • Limited contribution to staple crops
Global South (e.g., Sub-Saharan Africa, Latin America, South Asia)	• Informal settlement gardening • Peri-urban farming • Roadside/vacant lot cultivation	• Food security necessity • Poverty alleviation • Women's and household survival strategies	• Improves household food supply and nutrition • Provides employment and income • Enhances resilience during crises	• Insecure land tenure • Limited policy recognition • Environmental/health risks (wastewater irrigation, pollution)
India (Hybrid Case)	• Rooftop and hydroponic farming (middle-class, commercial) • Slum and roadside gardening (low-income groups) • Peri-urban vegetable farming (market supply)	• Food security (low-income) • Market expansion (peri-urban) • Health/lifestyle (affluent)	• Supplies significant share of leafy vegetables to cities (e.g., Delhi, Bengaluru) • Provides income diversification for peri-urban farmers • Growing urban consumer demand for hydroponics	• Urban sprawl threatens peri-urban land • Weak formal recognition of informal UA • Class divide between elite hydroponics and grassroots farming

Source: Compiled by author.

environmental stress. Rapid population growth in cities has placed substantial pressure on conventional food supply chains, often leading to increased food prices, dependency on imports, and heightened vulnerability to market and climatic disruptions. These pressures disproportionately affect low-income communities, where access to affordable, nutritious food remains severely constrained. Urban agriculture has become a pragmatic, often necessity-driven strategy in these settings, emerging from the grassroots rather than through top-down planning (Beach, 2013). In cities such as Nairobi, Accra, Dar es Salaam, and Lagos, urban dwellers cultivate food in backyards, vacant plots, and community-managed spaces. While such practices are often informal and unregulated, they provide essential benefits enhancing food availability, generating livelihoods, and fostering ecological resilience (Beach, 2013). However, critical constraints such as insecure land tenure, limited policy recognition, and exposure to climate-related risks persist (Zezza and Tasciotti, 2010).

3.3.2 Urban agriculture as a response to food insecurity

3.3.2.1 Localized responses to urban food insecurity

Sub-Saharan Africa experiences one of the highest levels of urban food insecurity globally, with a significant proportion of urban residents facing difficulty in accessing sufficient food (Battersby and Watson, 2018). Market-based food systems, often susceptible to price volatility and global shocks, dominate food access in urban areas. This reliance leaves marginalized populations particularly exposed, exacerbating malnutrition and food poverty. Urban agriculture has provided a localized solution to these challenges. In Nairobi, Kenya, compost derived from household waste is used to improve soil fertility, thereby lowering input costs and enhancing food production at the household level (Prain and Lee-Smith, 2010). Peri-urban agriculture in Kampala, Uganda, is estimated to supply a substantial share of the city's vegetables, while in Accra, Ghana, the use of treated wastewater for irrigation ensures year-round cultivation (FAO, 2010). Climate-resilient urban agriculture initiatives such as drought-tolerant crop varieties, rooftop gardens, and hydroponic systems have also been introduced through collaborations between NGOs, research institutions, and local authorities to ensure productivity amid climatic and spatial constraints (Redwood, 2009).

3.3.2.2 Reducing dependency on food imports

Urban agriculture contributes to food sovereignty by reducing reliance on imported food, which is especially critical during periods of economic instability or international trade disruptions. During Zimbabwe's economic collapse in the early 2000s, urban agriculture provided a vital buffer against food scarcity, with families cultivating maize and vegetables for subsistence (Matamanda et al., 2022). Similarly, in Venezuela, state-supported urban farming initiatives emerged during times of food shortages, empowering communities to grow food on rooftops, balconies, and idle land (Herrera-Cuenca et al., 2021).

3.3.3 Economic contributions of urban agriculture

Urban agriculture is not merely a subsistence activity it is also a contributor to household incomes, employment, and informal economies. Women and marginalized populations are particularly active in this sector, often leveraging small-scale agriculture to generate income and improve household welfare. In Accra, urban farming is predominantly undertaken by women, who form a significant proportion of urban food producers and sellers, highlighting the gendered nature of urban agriculture as a livelihood strategy (Zezza and Tasciotti, 2010). In Dar es Salaam, urban agriculture provides informal employment opportunities for a substantial share of the urban population, contributing to food security and household income (Lee-Smith, 2010). Meanwhile, in Dhaka, Bangladesh, rooftop gardening has expanded, with surplus produce increasingly being marketed locally and supporting small-scale commercial enterprises (FAO, 2010). These dynamics indicate that urban agriculture is not only a coping mechanism but also a pathway to economic empowerment and urban poverty alleviation.

3.3.3.1 Subsistence vs. market-oriented urban agriculture

In the Global South, urban agriculture encompasses both subsistence-oriented and market-oriented practices. Subsistence UA primarily focuses on meeting household food needs, whereas market-oriented UA targets local or regional markets, generating income and contributing to urban food systems. Both forms are critical, but they differ in scale, resource use, and economic integration (see Table 3).

3.3.4 Structural barriers to scaling urban agriculture

3.3.4.1 Land tenure and governance constraints

The absence of formal recognition and secure land tenure for urban agriculture severely restricts its expansion. Many urban farmers cultivate unregistered or marginal lands, making them highly vulnerable to eviction, particularly as cities prioritize real estate development over food production. In cities such as Nairobi and Johannesburg, urban expansion and gentrification have increasingly displaced community gardens and informal farms, undermining local food systems (Lee-Smith, 2010; Thornton, 2008). Furthermore, urban agriculture is often omitted from municipal plans, and policy frameworks rarely provide access to subsidies, training, or extension services. This neglect hampers the sector's integration into broader urban sustainability agendas (FAO, 2010).

3.3.4.2 Environmental and climatic risks

Urban agriculture in the Global South is increasingly exposed to climate-induced stresses such as erratic rainfall, extreme heat, and water scarcity. In West Africa, changing weather patterns have already begun to reduce yields, threatening food security in low-income urban communities. A lack of access to climate-smart technologies such as efficient irrigation systems or resilient crop varieties further compounds the problem (Tambol et al., 2025).

3.3.5 Strategic pathways for scaling urban agriculture

Maximizing the impact of urban agriculture in the Global South requires integrated policy frameworks, technical innovation, and inclusive urban planning. A key strategy involves institutional integration, wherein urban agriculture is embedded within municipal development plans to ensure secure land rights and long-term viability. Expanding access to appropriate technologies such as vertical gardens, hydroponic systems, and grey water irrigation can significantly enhance productivity in space-constrained environments. Equally essential are capacity-building efforts and financial mechanisms that empower farmers through training, micro-financing opportunities, and improved market access. Community empowerment also plays a vital role, with support for farmer cooperatives and participatory governance structures enhancing representation, resilience, and collective resource management. While much of urban agriculture in the Global South operates informally, it holds transformative potential. With the right policy support and institutional backing, it can substantially strengthen urban food security, promote inclusive local economies, and foster climate-resilient urban development.

3.4 Urban agriculture in India

Urban agriculture (UA) in India plays a critical role in urban food security, livelihoods, and sustainable city development, addressing the pressures of rapid urbanization, rising demand for fresh produce, and limited access to affordable food. India presents a hybrid UA landscape, where high-tech rooftop hydroponics serve affluent consumers, while informal and peri-urban farms supply local markets and low-income households (FAO, 2006). Informal practices, such as slum gardening and community-managed plots, remain vital for household nutrition and income in low-income neighborhoods, providing food security and empowering marginalized groups.

TABLE 3 Comparison of subsistence urban agriculture and market-oriented peri-urban agriculture, highlighting key aspects, motivations, outputs, socio-economic roles, challenges, and examples.

Aspect	Subsistence urban agriculture (UA)	Market-oriented peri-urban agriculture
Definition	Small-scale, informal farming within cities for household consumption.	Medium- to large-scale farming on city fringes aimed at urban markets.
Scale & Location	Rooftops, courtyards, slums, vacant lots (intra-urban).	Peri-urban plots, cooperatives, village outskirts.
Primary Motivation	Food security, dietary diversity, survival strategy.	Commercial profit, supplying high-demand perishable goods.
Outputs	Vegetables, herbs, small livestock (poultry, goats).	Vegetables, dairy, poultry, flowers, fodder.
Socio-economic Role	Reduces household food expenditure, improves nutrition, resilience in crises.	Provides income, employment, and strengthens urban–rural food linkages.
Challenges	Insecure tenure, lack of policy support, pollution/wastewater risks.	Urban sprawl, land conversion, market volatility, weak farmland protection.
Examples	Slum gardening in Nairobi/Dhaka; household rooftop plots in Delhi.	Bengaluru peri-urban vegetable belt; Nairobi peri-urban dairy farms.

Source: Compiled by author.

3.4.1 Historical context and evolution

Urban farming in India has roots in subsistence cultivation, traditionally conducted on marginal lands, temple grounds, and household backyards. During the colonial period, urban agriculture primarily served subsistence needs for urban households (Beach, 2013). Post-independence, urban agriculture became more prominent due to population growth, rural-to-urban migration, and increasing urban food demand, particularly in cities such as Mumbai, Delhi, and Kolkata (FAO, 2010). Informal practices in slums and low-income settlements have consistently contributed to local food security, providing nutrition and livelihood opportunities (Zezza and Tasciotti, 2010). Informal practices in slums and low-income settlements, including grassroots community gardens, have consistently contributed to local food security and livelihoods (Zezza and Tasciotti, 2010).

3.4.2 Contemporary urban agriculture practices

3.4.2.1 Rooftop and hydroponic farming

High-tech initiatives in Delhi, Bangalore, and Pune have implemented rooftop gardens, vertical farms, and hydroponic system, optimizing space and resource use, supporting sustainable production, and improving access to fresh vegetables and leafy greens for urban consumers (Despommier, 2010; Mok et al., 2014). Rooftop hydroponics is generally capital-intensive, targeting affluent households or commercial markets.

3.4.2.2 Informal slum gardening and roadside farming

Informal UA remains crucial for low-income communities, where households cultivate vegetables on rooftops, courtyards, roadside strips, and vacant plots, often irrigated with greywater (FAO, 2006). These grassroots initiatives are low-input, subsistence-oriented, and rely heavily on local community participation for management and resource sharing. They contribute significantly to household nutrition, income generation, and women's empowerment (Zezza and Tasciotti, 2010; Beach, 2013).

3.4.2.3 Peri-urban and market-oriented agriculture

Peri-urban farms in cities like Delhi and Bengaluru provide a substantial share of leafy vegetables and other perishable crops to urban markets (FAO, 2006). These market-oriented UA initiatives often employ organic or hydroponic production techniques, providing income opportunities and linking urban households to local food systems. However, the scalability of informal and grassroots UA is constrained by factors such as insecure land tenure, water scarcity, limited technical support, and insufficient policy recognition. These challenges hinder replication of successful community-based models in other urban areas (Rocha and Lessa, 2009; World Future Council, 2015).

3.4.2.4 Grassroots vs. rooftop hydroponics

A notable tension exists between grassroots UA (informal slum gardens and peri-urban farms) and high-tech rooftop hydroponics. Grassroots practices focus on subsistence, community resilience, and inclusive livelihoods, while rooftop hydroponics targets affluent consumers and commercial markets (FAO, 2010; Mok et al., 2014). Both systems are valuable, but they differ in scale, inputs, economic integration, and visibility within policy frameworks. Integrating grassroots and high-tech approaches into urban planning requires policies that recognize informal farmers, secure land tenure, and provide technical and financial support to scale community-driven initiatives sustainably.

3.4.3 Policy and governance

Urban agriculture in India is largely informal, yet municipal and state-level policies increasingly support UA. Initiatives include rooftop gardens, school gardens, community allotments, and subsidy schemes with technical training promoted by horticulture departments in states such as Tamil Nadu and Maharashtra to popularize rooftop cultivation (FAO, 2010; Prain and Lee-Smith, 2010). Key challenges include insecure land tenure, limited water and input access, and lack of formal integration into urban planning. Supportive policies are essential to formalize grassroots initiatives without displacing vulnerable farmers, enhance access to resources, and create scalable pathways for community-driven UA.

3.4.4 Socio-economic and environmental impacts

Urban agriculture in India contributes to multiple socio-economic and environmental objectives. It enhances food security and nutrition by providing households with fresh vegetables and fruits, particularly in low-income settlements (FAO, 2006). At the same time, it supports livelihoods, especially for women and marginalized populations, by generating income through subsistence and market-oriented UA (Zezza and Tasciotti, 2010). Urban agriculture fosters community cohesion, as cooperative gardens, participatory resource management, and social networks strengthen local ties and encourage collective action (Beach, 2013). Grassroots initiatives demonstrate high social and economic value, but their replication across cities is limited by land scarcity, policy gaps, and resource constraints (Rocha and Lessa, 2009). Furthermore, these practices deliver environmental benefits, including mitigation of urban heat, improvement of air quality, and promotion of sustainable waste management through composting and water reuse (Mok et al., 2014; Despommier, 2010). Collectively, urban agriculture in India represents a multifunctional tool that simultaneously addresses food security, socio-economic empowerment, community resilience, and environmental sustainability.

3.5 Technological innovations in urban agriculture

Urban agriculture (UA) is experiencing a transformative shift due to technological advancements, which address critical challenges posed by urbanization, climate change, and limited space. As cities grow and land becomes increasingly scarce, traditional farming methods are no longer sufficient to meet the growing demand for food. To respond to these pressures, urban agriculture is moving toward high-tech, data-driven production systems that leverage precision tools, automation, and digital intelligence. This paradigm shift is leading to the emergence of innovations such as vertical farming, hydroponics, aeroponics, and artificial intelligence (AI), which enable space-efficient and resource-optimized food production in urban environments (Benke and Tomkins, 2017; Yousaf et al., 2023).

3.5.1 Vertical farming: a high-tech solution to urban food production

Vertical farming is one of the most groundbreaking innovations in urban agriculture, where crops are grown in stacked layers or vertically inclined surfaces within controlled environments such as indoor farms, greenhouses, or repurposed buildings. This method allows for high-density production in urban areas, utilizing LED lighting, automated nutrient delivery systems, and climate control mechanisms (Benke and Tomkins, 2017). Vertical farms are particularly well-suited for growing leafy greens, herbs, and microgreens, which require relatively small growing areas and a high turnover rate. Cities like New York, Tokyo, and Singapore have integrated vertical farming into their urban regeneration projects as part of their broader sustainability initiatives, reducing dependency on external food sources while increasing food security (Goldstein et al., 2016).

3.5.2 Hydroponics and aquaponics: soilless systems for urban farming

Hydroponics and aquaponics are increasingly popular soilless farming systems that are particularly well-suited to urban environments. Hydroponics uses a water-based solution to deliver nutrients directly to plants, eliminating the need for soil and enabling cultivation in confined spaces like rooftops, abandoned buildings, and vacant lots. Similarly, aquaponics combines hydroponics with aquaculture, where fish waste serves as natural fertilizer for the plants, and the plants help purify the water for the fish (Mok et al., 2014). These systems not only conserve water but also reduce the need for arable land, making them ideal for densely populated urban areas. For example, Singapore has adopted hydroponic farming as a solution to food security, with the government supporting the development of Agri-Food Tech Hubs to integrate hydroponics into urban infrastructure (Goldstein et al., 2016).

3.5.3 Artificial intelligence (AI) and IoT in urban agriculture

AI and the Internet of Things (IoT) are revolutionizing urban agriculture by providing smart farming solutions that optimize growing conditions, improve decision-making, and automate labor-intensive tasks. AI-driven systems utilize predictive analytics to optimize plant growth, nutrient management, and resource allocation. IoT devices such as temperature sensors, humidity controllers, and soil moisture detectors provide real-time data that supports more efficient farming practices (Kumar V. et al., 2024; Kumar C. S. et al., 2024). In cities like New York and Tokyo, AI and IoT technologies are being integrated into vertical farming, hydroponic systems, and community gardens, contributing to more sustainable and productive urban food systems (Mok et al., 2014). One successful example is Infarm, a Berlin-based company that deploys modular hydroponic units controlled by AI, enabling real-time adjustments to light, humidity, and nutrient levels, and thereby improving urban food resilience (Sanyé-Mengual et al., 2016).

3.5.4 Climate-smart solutions for urban agriculture

As climate change continues to impact food security, urban agriculture is incorporating climate-smart technologies that help mitigate the effects of climate disruptions. These technologies include drought-resistant crop varieties, efficient irrigation systems, and solar-powered pumps and rainwater harvesting systems (Redwood, 2009). In regions such as Sub-Saharan Africa and parts of Asia, where climate change-induced disruptions such as erratic rainfall patterns and extreme heat are common, these climate-adaptive solutions are crucial for ensuring food security. Cities like Nairobi, Kenya, and Accra, Ghana, have adopted climate-smart agricultural practices, enhancing water-use efficiency and building resilience against climate stress (McClintock, 2010). Furthermore, agroecology and organic farming methods have become increasingly popular in urban settings, restoring soil health and enhancing biodiversity, contributing to the long-term sustainability of urban food systems.

3.5.5 Challenges in technology-driven urban agriculture

While technological innovations in urban agriculture have shown great promise, several barriers hinder their widespread adoption. One significant constraint is the high capital investment required for setting up high-tech farming systems, which can be prohibitive for small-scale urban farmers and community-based initiatives (Grunewald et al., 2024). Energy consumption particularly from artificial lighting and HVAC systems is another concern, especially when renewable energy sources are not integrated into the infrastructure. Furthermore, technical skill gaps and digital literacy remain significant barriers, particularly in developing urban areas where access to education and training may be limited (Yousaf et al., 2023). To address these challenges, it is crucial to develop inclusive strategies that focus on affordability, accessibility, and capacity-building for urban farmers.

3.5.6 Future directions: scaling up technological innovations

The future of technological innovations in urban agriculture lies in scaling these technologies for broader adoption. To achieve this, policy incentives, financial support, and subsidies will be essential in lowering the entry barriers for small-scale and informal farmers. Governments, research institutions, and private enterprises must collaborate to create scalable and affordable solutions that can be integrated into urban policy frameworks (Redwood, 2009). Additionally, public-private partnerships and agritech incubators can play a catalytic role in driving innovation and enabling the deployment of scalable solutions. Renewable energy sources, such as solar power, should also be integrated into urban farming systems to enhance environmental sustainability. Capacity-building initiatives should prioritize skill development, particularly among youth and marginalized groups, to bridge the digital divide and ensure inclusive growth. Collaborative frameworks that involve academia, industry stakeholders, and municipal authorities are critical to embedding technology-driven urban agriculture into broader urban planning and food security strategies.

3.6 Policy and governance framework

Urban agriculture has evolved from being a grassroots or subsistence initiative to a formal strategy embedded in sustainable urban development. For urban agriculture (UA) to become scalable, resilient, and legally protected, comprehensive policy and governance frameworks are essential. These frameworks regulate land access, ensure food safety, promote environmental sustainability, and facilitate the integration of UA into broader urban planning systems (FAO, 2024). Governmental support, including zoning laws, financial incentives, and regulatory reform, plays a pivotal role in shaping the trajectory of urban agriculture both in the Global North and South.

3.6.1 Regulatory frameworks and legal recognition

Regulations, particularly those governing land use, zoning, and environmental safety, significantly influence the implementation and sustainability of UA initiatives. In cities like Toronto, Berlin, and Singapore, zoning laws have been revised to formally incorporate UA as part of urban land use planning. These legal reforms permit urban farming on rooftops, community plots, and vacant public lands, thereby legitimizing small-scale commercial ventures (Specht et al., 2014; Sasaki, 2025). Berlin, for instance, recognizes UA as part of its green infrastructure, leasing underutilized land for community gardens and educational farms (Specht et al., 2014). Conversely, in many cities in the Global South, such as Mumbai and Nairobi, UA often operates informally without land tenure security. Cultivators, lacking legal recognition, face eviction and limited access to credit or infrastructure. This legal invisibility deters long-term investment and undermines the sector's potential to contribute to food security and environmental goals.

3.6.2 Food safety and environmental regulations

Urban agriculture must comply with food safety protocols and environmental standards to ensure the health of consumers and urban ecosystems. In the United States and Europe, regulations mandate soil contamination testing, restrict pesticide usage, and enforce composting standards. These measures mitigate the risks of chemical exposure and pollution from urban farming activities (Paltseva et al., 2022). In contrast, cities in developing nations often lack such regulatory frameworks. In Indian and Nigerian cities, the use of untreated wastewater for irrigation has led to significant concerns regarding heavy metal contamination and health risks (Mohanty and Das, 2023; Hussaini et al., 2021). There is an urgent need for targeted policy reforms that ensure urban-grown food is both safe and environmentally sustainable.

3.6.3 Integration into urban planning systems

The institutionalization of UA within formal urban planning enhances its legitimacy and access to resources. Progressive urban centers have embedded UA in their climate adaptation and food resilience strategies. Paris's Parisculteurs initiative repurposes rooftops and public spaces for urban farms, while Milan's commitment to the Milan Urban Food Policy Pact (MUFPP) reflects the integration of food systems into municipal planning (Lohrberg et al., 2016; Van Tuijl et al., 2018). In Copenhagen, regulations now require green roofs and food gardens in new developments, linking UA to ecological urban design (Marini et al., 2023). Such integrative planning improves the multifunctionality of urban spaces, enhances biodiversity, and supports circular urban metabolism. However, mainstreaming UA in urban planning remains a challenge in many rapidly urbanizing cities due to competing land uses and fragmented governance.

3.6.4 Governmental programs and incentives

Government-led initiatives are essential to institutionalizing urban agriculture and incentivizing public participation. In the United States, the USDA's Urban Agriculture and Innovative Production Program offers grants and training to urban farmers. India's National Urban Horticulture Mission (NUHM) promotes rooftop and vertical farming technologies, aligning with smart city development (TNAU, 2023). Brazil's Belo Horizonte offers a pioneering example where municipal policies guarantee land access and provide inputs to low-income urban farmers, significantly enhancing food access and nutrition in underserved communities. Such public sector interventions underscore the state's role in creating enabling environments for UA through funding, infrastructure, and extension services.

3.6.5 Public-private partnerships and innovation support

Public-private partnerships (PPPs) have become instrumental in scaling urban farming innovations. In Germany, Infarm's modular hydroponic systems, supported by government grants, are deployed in retail stores, reducing food miles and enhancing transparency in food sourcing (European Investment Fund, 2018; Cointet et al., 2019). Similarly, Singapore's Sky Greens, a government-supported vertical farming enterprise, addresses space constraints through eco-friendly technologies (Wood, 2020). In India, startups like UrbanKisaan collaborate with local governments to deploy hydroponic systems in urban centers, reflecting the growing synergy between the state, private sector, and technology. These collaborations not only reduce the burden on public resources but also enhance technical innovation and market access for urban farmers.

3.6.6 Policy gaps and implementation challenges

Despite growing institutional support, several challenges hinder effective policy implementation in urban agriculture (UA). Urban land scarcity, bureaucratic inertia, and limited public awareness often result in UA being sidelined in favor of real estate development (Mougeot, 2010). Moreover, inadequate financing, fragmented governance, and lack of interdepartmental coordination pose systemic barriers. Climate risks, such as water shortages and heatwaves, further compound sustainability challenges (Sanyé-Mengual et al., 2016). To address these issues, cities must adopt inclusive governance approaches that prioritize community engagement, streamline intersectoral coordination, and develop city-specific policy tools tailored to local needs and ecological constraints (Morgan, 2009).

3.6.7 Successful policy models

3.6.7.1 Integrating informal practices into formal frameworks

In Belo Horizonte, the model emphasizes community engagement where informal farmers are not only included in planning but also empowered with secure land tenure. This model can be expanded by incorporating legal recognition for informal urban farmers through mechanisms such as land lease programs and zoning laws that allow them to maintain their operations while being formally recognized. This ensures continuity of access to land for informal farmers without displacing them in favor of larger development projects.

Milan's Urban Food Policy Pact integrates urban agriculture into formal urban planning, but the review can address how cities can balance formal and informal urban farming, such as providing legal support for informal practices like community gardens and rooftop farms, which often operate outside formal policies but provide critical food security to low-income urban communities (Van Tuijl et al., 2018; IPES-Food, 2017).

Toronto's Urban Agriculture Bylaws: Toronto's zoning regulations provide space for urban farms, but the inclusion of informal urban farmers in these frameworks is crucial. This could involve legalizing informal food production in informal sectors (e.g., slum areas or informal settlements) through pilot projects or pilot programs that offer temporary or conditional land tenure rights (City of Toronto, 2009).

3.6.8 Integration of informal urban agriculture

3.6.8.1 Informal urban agriculture and vulnerable farmers

In many cities across the Global South, informal urban agriculture is a lifeline for vulnerable populations. However, without formal recognition, these practices are at risk of being displaced as cities undergo rapid urbanization (Mougeot, 2010). To address this, urban policies should recognize the value of informal urban agriculture, integrating it into formal governance frameworks through the following approaches:

- Land Tenure Security: Cities must provide secure land tenure to informal farmers, such as long-term land leases or community land trusts, to protect them from eviction and ensure continued access to land for food production (Sanyé-Mengual et al., 2016). By doing so, vulnerable farmers can continue their practices without fear of displacement from property developers or urban expansion projects.
- Coexistence with Urban Development: The integration of informal practices does not necessarily mean removal of urban development projects. Through inclusive urban planning, informal farming can coexist with urban development by repurposing unused land (e.g., vacant plots, rooftops, and community spaces) for urban agriculture. Examples from Berlin and Toronto can be expanded to suggest how land-sharing models can be developed, where informal farmers are included in planning from the outset (Specht et al., 2014).
- Capacity-Building and Policy Support: As informal urban farmers often lack access to formal support networks (e.g., financial services, infrastructure, or training), policies should include capacity-building programs that empower informal farmers with the tools, skills, and support they need to transition toward more formalized agricultural practices, ensuring their livelihoods are sustained while contributing to the city's food security goals (Paltseva et al., 2022).
- Inclusive Governance: Engaging informal farmers in governance processes is crucial. Cities should invite informal farmers into decision-making processes related to urban agriculture. This could involve consultative processes where informal farmers are part of the policy-making dialogue, helping shape the policies that affect their livelihood while ensuring their rights and needs are considered.

By integrating informal urban farming practices into formal governance structures, cities can ensure sustainability while also supporting the vulnerable populations who rely on these informal practices. This not only helps prevent displacement but also boosts the resilience of urban food systems, making them more inclusive and adaptable (see Figure 4).

3.7 Social and economic impacts

Urban agriculture is increasingly recognized not only for its capacity to enhance food security and environmental resilience but also for its transformative role in promoting social and economic inclusion. Across both developed and developing contexts, UA contributes to household income generation, job creation, poverty alleviation, and community well-being. It offers critical pathways for marginalized populations, particularly women, youth, and the elderly, to engage in productive livelihoods, thereby supporting urban sustainability and equity agendas (Yuan G. N. et al., 2022; Azunre et al., 2019).

3.7.1 Livelihood opportunities and economic benefits

Urban agriculture provides diverse income-generating opportunities through food production, value addition, and small-scale agribusiness development. In low and middle-income countries, it serves as an essential coping strategy for urban poor communities, helping to mitigate unemployment and rising food costs. For example, urban farmers engage in the cultivation of vegetables, herbs, and medicinal plants, as well as animal husbandry activities such as poultry and fish farming (Azunre et al., 2019). These practices not only reduce household food expenditures but also create economic independence and financial resilience. Moreover, the rise of innovative models such as vertical farming, hydroponics, and rooftop gardens has introduced new employment avenues in high-tech agriculture, especially in rapidly urbanizing cities across Asia and Africa (Yuan G. N. et al., 2022). In some contexts, urban agriculture has also enabled entrepreneurship through the establishment of community-supported agriculture (CSA) schemes, organic produce markets, and farm-to-fork restaurant supply chains, thereby supporting local economic circuits and circular economy principles.

3.7.2 Gender inclusion and women's empowerment

Urban agriculture offers significant potential to address gender disparities by providing women with productive resources, leadership opportunities, and increased household decision-making power. Women often comprise a substantial share of urban farmers, especially in informal settlements, where they lead food production, marketing, and household-level processing activities (Hovorka, 2006). Engagement in urban agriculture has been linked to improved nutritional outcomes, greater income control, and enhanced self-esteem among women. In many cities, women's collectives and self-help groups have mobilized urban farming projects that double as platforms for skills development and social support. Such initiatives not only generate income but also strengthen women's agency in both

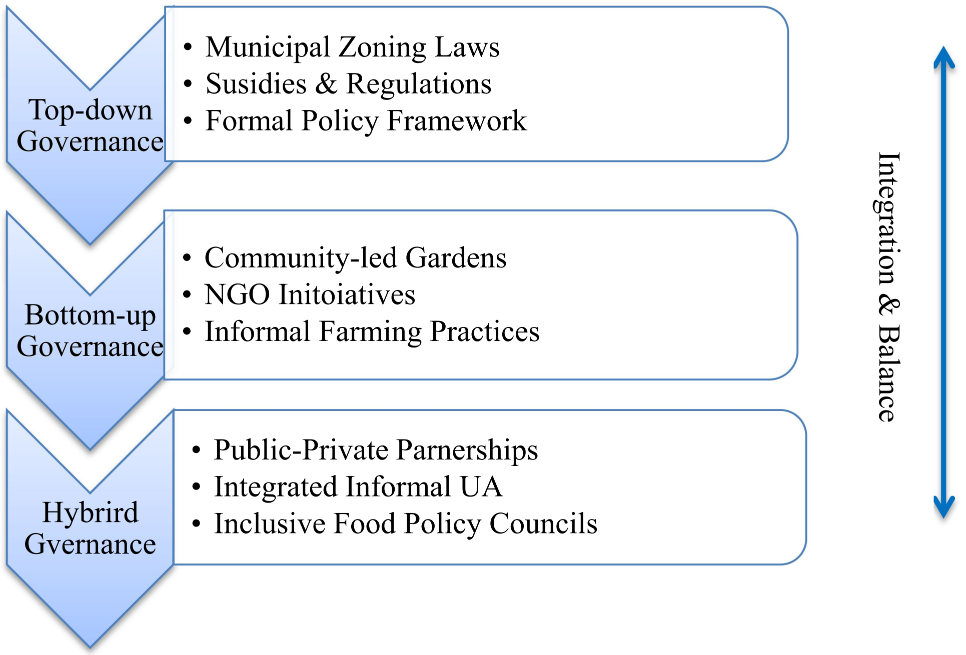

FIGURE 4
Governance models of urban agriculture. Diagram showing governance approaches for urban agriculture, including formal municipal frameworks, public-private partnerships, and community-led informal arrangements. Source: Compiled by author.

the domestic and public spheres. However, systemic barriers, including limited access to land, capital, and training, continue to constrain the full realization of gender-equitable outcomes. Thus, targeted policy measures and inclusive urban planning approaches are required to ensure that UA contributes meaningfully to women's empowerment and gender equity (Lemma and Sharma, 2024).

3.7.3 Community well-being and social capital

Beyond economic benefits, urban agriculture contributes significantly to social cohesion and mental well-being. Community gardens and cooperative farming initiatives create inclusive, multifunctional spaces where diverse groups interact, share knowledge, and build trust (Guitart et al., 2012). These spaces often serve as platforms for civic engagement, intergenerational learning, and cultural exchange, thereby strengthening social capital and fostering a sense of belonging among urban residents. Participation in urban farming has also been associated with mental health improvements, particularly through stress reduction, therapeutic horticulture, and opportunities for physical activity. Studies from cities in Europe, North America, and Asia have demonstrated the role of urban agriculture in improving psychological resilience, especially for the elderly and those experiencing social isolation (Yuan G. N. et al., 2022). Moreover, community-based UA projects have been instrumental in revitalizing neglected urban spaces, reducing crime, and enhancing neighborhood aesthetics, contributing to overall urban livability.

3.7.4 Towards inclusive and resilient urban communities

Urban agriculture, when supported by enabling institutional frameworks, can serve as a catalyst for socially inclusive and economically resilient urban development. Its cross-cutting benefits, spanning employment, gender equity, and social well-being, highlight its potential as a tool for achieving multiple Sustainable Development Goals (SDGs), including SDG 1 (No Poverty), SDG 5 (Gender Equality), SDG 11 (Sustainable Cities and Communities), and SDG 12 (Responsible Consumption and Production). To unlock these benefits at scale, policy interventions must prioritize marginalized communities, support women and youth through targeted training and financial mechanisms, and integrate UA into broader urban governance structures. Participatory models that emphasize co-creation and shared ownership are essential for ensuring that urban agriculture contributes equitably to inclusive growth and community resilience. However, risks of gentrification and exclusion of informal farmers persist, which could undermine the inclusivity of urban agriculture if not addressed through supportive policies and equitable land access.

3.8 Ecosystem services and sustainability

Urban agriculture provides a suite of ecosystem services that contribute significantly to urban environmental sustainability. Amid increasing urbanization, climate change impacts, and ecological degradation, the integration of food-producing green spaces into cities offers vital ecological functions such as climate regulation, biodiversity support, waste recycling, and enhanced urban resilience.

3.8.1 Climate resilience and urban microclimate regulation

Empirical studies from cities like Tokyo, New York, and Paris demonstrate that rooftop gardens, when integrated into building designs, significantly contribute to thermal insulation and stormwater regulation. For instance, research in Tokyo's Sumida ward highlights the role of green roofs in moderating urban heat islands and managing stormwater (Aleksejeva et al., 2022). Similarly, studies in New York and Paris have shown that green roofs can reduce building energy consumption and mitigate urban flooding (Getter and Rowe, 2006; Oberndorfer et al., 2007). In addition, Takebayashi and Moriyama (2007) demonstrated that green roofs can effectively mitigate urban heat island effects by lowering surface temperatures, contributing to cooling in densely urbanized areas. Beyond structural benefits, urban farms play a crucial role in enhancing atmospheric quality through carbon sequestration and pollutant filtration. Vegetation in urban food systems captures carbon dioxide and improves air quality by absorbing nitrogen oxides and particulate matter, thereby contributing to climate mitigation and public health benefits (Rowe, 2011; Speak et al., 2012).

3.8.2 Biodiversity conservation and ecological habitat creation

Urban agriculture contributes significantly to the conservation of urban biodiversity by establishing microhabitats for pollinators, beneficial insects, birds, and soil biota. Through crop diversification and the use of ecological practices such as polycultures, composting, and organic pest control, urban farms help mitigate the adverse effects of urbanization on local ecosystems. For instance, empirical research from Berlin has shown that community gardens with diverse and native vegetation promote wild bee diversity and functional traits, supporting ecological resilience (Felderhoff et al., 2023). Similarly, studies in London highlight how allotment gardens foster pollinator richness and improve ecological connectivity by serving as green stepping stones within fragmented urban landscapes (Haase and Gaeva, 2023). Agroecological practices in urban agriculture also support soil microbial diversity and ecological resilience. Techniques such as composting, green manuring, and intercropping reduce the reliance on synthetic inputs, restore soil health, and enhance biotic interactions within urban ecosystems (Mougeot, 2010). These biodiversity benefits underscore the multifunctionality of urban agriculture as both a food production and ecological restoration strategy.

3.8.3 Waste reduction and circular resource management

Urban agriculture contributes to sustainable urban metabolism by closing nutrient loops and reducing organic waste. Many urban farms incorporate composting facilities, converting household and food market waste into organic fertilizers that enrich soils and reduce municipal landfill burdens (Siegner et al., 2018). Cities such as Amsterdam, Toronto, and San Francisco have integrated food waste diversion policies with urban agriculture programs, resulting in measurable reductions in municipal solid waste streams. Water-saving technologies are also central to urban farming's environmental value. Hydroponic and aquaponic systems reuse nutrient-rich water in closed-loop systems, drastically lowering water consumption compared to conventional agriculture. Greywater recycling and rainwater harvesting practices further augment water efficiency in cities facing drought risks, such as Chennai, Cape Town, and Los Angeles. Additionally, the use of renewable energy solar panels, LED grow lights, and energy-efficient climate control enhances the low-carbon footprint of controlled-environment urban agriculture (Benke and Tomkins, 2017).

3.8.4 Advancing ecological sustainability through policy and innovation

Although urban agriculture contributes significantly to ecosystem services, its broader ecological potential can only be realized through enabling policies, institutional integration, and multisectoral collaboration. Urban planning frameworks should prioritize the inclusion of food-producing landscapes as a key component of green infrastructure, fostering ecological restoration, enhancing climate resilience, and promoting resource efficiency (Mougeot, 2010). Advancing these goals involves embedding biodiversity targets within urban land-use policies, incentivizing composting and circular waste-to-resource systems, and encouraging research on agroecological practices and green infrastructure design. Furthermore, fostering partnerships between environmental agencies, municipalities, and urban agriculture networks can amplify impact, while investments in education and skill-building programs are crucial to equip urban farmers with sustainability-oriented practices.

3.8.5 Energy trade-offs: vertical farms vs. grassroots

In addition to the environmental benefits, there are significant energy trade-offs between high-tech vertical farming systems and grassroots urban agriculture. While vertical farms powered by technologies such as hydroponics, artificial lighting, and climate control systems maximize space and resources, they often require substantial energy inputs, particularly for lighting and environmental regulation (Grunewald et al., 2024). If not paired with renewable energy sources, vertical farming could have a higher carbon footprint than traditional farming systems. In contrast, grassroots urban agriculture, such as community gardens and rooftop farming, tends to be more energy-efficient, relying on natural light and less energy-intensive systems. However, these systems may require more land area for the same output, highlighting the trade-off between energy use and land efficiency in urban agriculture.

3.9 Urban agriculture and sustainable development goals (SDGs)

Urban agriculture (UA) is a multidimensional strategy addressing food insecurity, environmental challenges, and socio-economic inequalities in cities. It contributes to multiple Sustainable Development Goals (SDGs) by providing fresh, nutritious produce, promoting social inclusion, and enhancing urban resilience. Table 4 summarizes the relevant SDGs, associated aspects of UA, impacts, and example initiatives.

While UA can significantly improve access to vegetables, fruits, and small-scale livestock products, it cannot replace large-scale production of staple crops such as rice, maize, or wheat due to space and resource limitations. UA should therefore be seen as a complement to rural agriculture, enhancing urban food security and dietary diversity rather than substituting conventional food systems. Large-scale reliance on UA would require changes in dietary habits, including reduced consumption of staple carbohydrates and animal products, to meet urban food demands sustainably.

Integrating UA into urban planning and policy requires coherent, multisectoral frameworks, including supportive zoning regulations, green infrastructure planning, and climate adaptation strategies (Kumar et al., 2025). Incentives for youth and women's participation, secure land tenure,

TABLE 4 Contributionsof urban agriculture towards SDGs, associated aspects, impact areas, and supporting initiatives.

SDG	Relevant aspects of urban agriculture	Impact/contribution	Example initiatives	References
SDG 2: Zero Hunger	Urban farming and controlled-environment agriculture enhance food security.	Increased local food production improved access to nutritious foods.	Vertical farms and rooftop gardens in U. S. cities.	Pradhan et al. (2024); Kumar et al. (2025)
SDG 11: Sustainable Cities and Communities	Integration of food systems into urban planning and green infrastructure.	Sustainable land use; improved urban resilience and livability.	Building-integrated agriculture in Germany.	Pradhan et al. (2024); Kumar et al. (2025)
SDG 12: Responsible Consumption and Production	Adoption of sustainable agricultural practices and circular food systems.	Waste reduction; resource-efficient food production models.	Aquaponics and hydroponics projects.	Pradhan et al. (2024); Kumar et al. (2025)
SDG 13: Climate Action	Implementation of climate-resilient urban agriculture practices.	Reduced food miles; carbon footprint mitigation.	Community gardens employing sustainable methods.	Pradhan et al. (2024); Kumar et al. (2025)
SDG 8: Decent Work and Economic Growth	Urban farming as a source of livelihood and entrepreneurship.	Job creation; local economic empowerment.	Small-scale urban farm enterprises in U. S. cities.	Pradhan et al. (2024)
SDG 10: Reduced Inequalities	Promotion of equitable food access through community-based agriculture.	Enhanced food distribution equity among underserved populations.	Low-income urban gardening initiatives.	Pradhan et al. (2024)

Source: Compiled by author.

and financial and technical support are essential for scaling up UA initiatives. Public awareness and participatory governance further strengthen community engagement and long-term sustainability.

By complementing rural agriculture, UA contributes to diversified and resilient food systems, particularly in food deserts and underserved areas, increasing access to fresh and nutritious foods while mitigating the impact of climate change and supply chain disruptions. Nature-based approaches in UA can support both human and planetary health, reinforcing its role in urban food security (Ebenso et al., 2022).

3.10 Cross-cutting debates

Urban agriculture (UA) is increasingly recognized as an important tool for urban resilience, food security, and sustainability. However, several key debates need to be addressed to better understand its role, challenges, and future potential in urban systems. These debates revolve around issues of economic viability, scalability, and governance asymmetry.

3.10.1 Economic viability and sustainability

One of the major debates in the field of urban agriculture concerns its economic viability. While urban farming presents clear benefits in terms of food security and community resilience, questions remain about its ability to operate profitably, particularly in densely urbanized areas with high land costs. Some vertical farming systems have reported profitability, especially in affluent urban areas with a high demand for locally grown produce (Yuan G. N. et al., 2022). However, other systems face challenges, particularly related to the high energy costs associated with maintaining indoor farming environments, such as artificial lighting and climate control (Yuan G. N. et al., 2022). The costs associated with setting up and maintaining urban farms, especially high-tech solutions like vertical farms, hydroponics, and aquaponics, can be prohibitively high. Many urban farming initiatives struggle to achieve economic sustainability without external support, such as grants, subsidies, or philanthropic investment. Thus, the challenge remains to develop business models that are both economically sustainable and scalable to benefit broader urban populations.

3.10.2 Scalability and replicability

Scalability is another key concern when it comes to the broader adoption of urban agriculture. Grassroots urban agriculture (UA) practices are effective in building resilience in local communities, but they are often constrained by issues such as land tenure insecurity, lack of formal recognition, and limited access to resources. High-tech urban agriculture, on the other hand, has greater scalability, with the ability to replicate and expand across urban areas. However, these technologies are often inaccessible to vulnerable groups, creating a divide in access and equity (Aubry et al., 2012). While high-tech UA systems may be economically viable in certain contexts, they often exclude marginalized populations who lack the capital or technical knowledge to participate in these initiatives. Therefore, scaling urban agriculture in an inclusive and equitable way requires models that balance the benefits of technological advancements with the needs of grassroots and informal agricultural practices.

3.10.3 Governance asymmetry and policy support

Governance asymmetry is a crucial issue that affects the effectiveness and success of urban agriculture. In many cities, UA operates in a policy vacuum, with little formal support or recognition from local governments. Policies often favor formal, high-tech urban farming solutions while neglecting the contributions of informal actors. In the Global South, urban farmers often lack secure land tenure, access to technical support, and inclusion in urban planning processes, leading to informal and precarious farming practices. Conversely, in developed nations, urban agriculture is often seen as a niche activity supported by a select group of urban dwellers and businesses, while informal farmers often from marginalized communities are excluded from policy and governance frameworks. Effective governance can foster the integration of UA into cities' sustainability agendas and ensure its long-term viability. It is essential that policies address the needs of both formal and informal urban farmers, ensuring inclusive participation and equal access to resources.

By addressing these debates economic viability, scalability, and governance asymmetry urban agriculture can better contribute to the achievement of the SDGs and play a transformative role in creating more sustainable, resilient, and inclusive cities.

3.11 Future directions

As urban agriculture continues to evolve as a solution for sustainable urban food systems, several research priorities must be addressed to enhance its long-term impact. The following five areas are critical for advancing the field:

1. Longitudinal research on climate resilience
   Future studies should focus on longitudinal research to assess how urban agriculture can adapt to and mitigate the impacts of climate change over time. This will help identify the long-term benefits of different urban farming systems in enhancing food security, climate resilience, and community sustainability.

2. Cost–benefit analyses of high-tech urban agriculture in low-income contexts
   High-tech urban agriculture system, such as vertical farming and hydroponics, show promise in resource-efficient food production. However, there is a need for in-depth cost–benefit analyses, particularly in low-income urban contexts, to evaluate their economic feasibility, scalability, and ability to address food insecurity without exacerbating socio-economic disparities.

3. Comparative Governance Models Integrating Informal Urban Agriculture
   While many urban agriculture policies prioritize formal, high-tech farming initiatives, informal urban agriculture plays a significant role in food security, especially in the Global South. Research should explore governance models that integrate both formal and informal urban agriculture systems to create inclusive, resilient, and sustainable food policies.

4. Greater Focus on Nutrition Outcomes
   While urban agriculture's role in food production is widely acknowledged, its impact on nutrition outcomes, particularly in urban food deserts and low-income neighbourhoods, remains under-explored. Future research should focus on the nutritional benefits of urban farming, examining how it can contribute to improved diet quality and reduced rates of malnutrition and obesity.

5. Gender and youth in urban agriculture policy
   Urban agriculture offers significant opportunities for empowerment, especially for marginalized groups such as women and youth. Research should explore how urban agriculture policies can be tailored to support gender equity and youth participation, focusing on strategies to remove barriers to their involvement and create inclusive opportunities for leadership and skill development.

These research priorities provide a roadmap for future studies that will deepen our understanding of urban agriculture's potential and strengthen its integration into sustainable urban food systems. Addressing these areas will help policymakers, practitioners, and researchers create more resilient, inclusive, and equitable urban food environments.

4 Conclusion

Urban agriculture has evolved from a localized, subsistence-oriented activity into a key strategy for addressing global urban sustainability challenges. This review has synthesized diverse perspectives and identified crucial themes in the development of urban agriculture across various global contexts. By examining its role in food security, climate resilience, and urban development, the review underscores the growing importance of integrating urban farming into broader urban planning frameworks.

Urban agriculture's multifaceted nature means it contributes significantly to social, economic, and environmental objectives. In the Global South, it serves as a critical strategy for food access, poverty alleviation, and community resilience. Meanwhile, in developed regions, it increasingly aligns with environmental sustainability, circular economy models, and technological innovations, such as vertical farming and hydroponics. These innovations not only address space limitations but also optimize resource use and promote sustainability.

India, situated at the intersection of rapid urbanization and persistent food insecurity, presents a unique case for the implementation of peri-urban agriculture and citizen-led innovations. The country's diverse urban landscapes highlight both the challenges and opportunities for scaling urban agriculture, especially in low-income and informal contexts. However, significant gaps remain, particularly in policy integration, equitable land access, and the scalability of advanced technologies in resource-constrained environments.

Looking ahead, five critical research priorities must guide the future of urban agriculture: (1) long-term studies on climate resilience, (2) cost–benefit analyses of high-tech urban agriculture in low-income areas, (3) comparative governance models that integrate informal farming practices, (4) research focusing on nutrition outcomes, and (5) gender- and youth-sensitive policies. Addressing these research gaps will provide essential insights into the sustainable scaling of urban agriculture.

Strengthening institutional support, fostering cross-sectoral collaborations, and ensuring inclusive participation will be key to positioning urban agriculture as a transformative solution for sustainable food systems. As cities strive for greater resilience and equity, urban agriculture holds the potential to drive both food and environmental justice, helping cities to meet their Sustainable Development Goals (SDGs) while creating more livable, equitable urban environments.

Author contributions

RS: Writing – review & editing, Writing – original draft, Software, Formal analysis, Resources, Conceptualization, Methodology, Investigation. AP: Project administration, Supervision, Validation,

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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