

Review

# Integrating Urban Agriculture and Stormwater Management in a Circular Economy to Enhance Ecosystem Services: Connecting the Dots

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**Abstract:** Due to the rapid urbanization in the context of the conventional linear economy, the vulnerability of the urban ecosystem to climate change has increased. As a result, connecting urban ecosystem services of different urban land uses is imperative for urban sustainability and resilience. In conventional land use planning, urban agriculture (UA) and urban stormwater management are treated as separate economic sectors with different-disconnected-ecosystem services. Furthermore, few studies have synthesized knowledge regarding the potential impacts of integration of UA and stormwater green infrastructures (GIs) on the quantity and quality of urban ecosystem services of both economic sectors. This study provides a detailed analysis of the imperative question—how should a city integrate the developments of both urban agriculture and stormwater green infrastructure to overcome barriers while enhancing the ecosystem services? To answer this question, we conducted an extensive literature review. The results show that integrating UA with GIs can enhance urban food production while protecting urban water quality. This paper provides an initial context and mechanisms for future researchers and city planners regarding the manner in which the synergies between UA and stormwater GIs can create greater value for the wellbeing of urban ecosystems and resilience in the circular economy.

**Keywords:** aquaponic; bioretention; gardening; green roof; hydroponic; rainwater harvesting; urban resilience; urban runoff; urban sustainability; water quality



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## 1. Introduction

As most of the world's population lives in urban areas, managing urban food insecurity and stormwater runoff is increasingly challenging globally due to the combined effects of climate change, rapid urban development, and fast population growth [1]. To address these challenges, sustainable urban agriculture (UA) and stormwater green infrastructures (GIs) have been considered to be alternative solutions to the conventional centralized agriculture practices and gray stormwater infrastructure [2–5]. Although sustainable urban agriculture can provide stormwater management benefits, it is often considered to be a separate sector from others, including stormwater management, in traditional urban land use planning and policy. Similarly, although stormwater green infrastructure may be able to produce food while managing stormwater, connecting the two economic sectors is not common, nor it is considered in current stormwater management policies.

Consequently, urban agriculture faces various barriers, including zoning limits, restricted land use planning, and a lack of funding for this non-integrated approach [6]. Although some of these challenges were addressed by the recently implemented 2018 US Farm Bill, sectoral-based and unsustainable urban farming practices may result in

unintended consequences, such as increasing demand for water supply and degradation of urban freshwater resources [7–9]. As the global population is becoming increasingly urbanized, expanding urban agriculture using limited water supply can exacerbate problems related to the water security of cities. This requires innovative water resource management techniques, such as the use of non-traditional sources of water for urban agriculture, including stormwater runoff and reclaimed water. This indicates that the expansion in UA must occur in conjunction with advances in urban water resource management, including rainwater harvesting, stormwater retention, and water reuse [10]. In addition, UA and stormwater management must be integrated to enhance the ecological benefits of the two sectors in various ways, including via water reuse and resource recovery in a circular economy.

In conventional city planning and management, urban agriculture and stormwater management are operated by two departments with different primary objectives. Urban agriculture is mainly adopted for food production and aesthetic values, whereas stormwater management practices focus on managing stormwater quantity and quality. Since both food security and urban stormwater management are integral to most urban issues, addressing these challenges requires a holistic approach that creates synergy by enhancing ecosystem services.

To enhance urban social and environmental resilience, it is of paramount importance to integrate urban agriculture and stormwater green infrastructure. In addition, the number of publications that discuss stormwater or urban agriculture has increased since 2005 [11], but the literature related to the integration of the two systems to improve ecosystem services has remained limited. Finally, urban agriculture is becoming a popular practice in addressing urban food insecurity; however, the inability of urban agriculture to feed city populations as expected and land scarcity are current challenges and will remain so in the future. This study aimed to investigate both theoretical and practical means to address these challenges by fostering cross-collaboration among various urban land-use sectors. The objective of this study was to identify mechanisms by which cities should integrate UA and stormwater GIs developments to advance urban farming while enhancing the ecosystem services via the synergetic effects of the two systems. To address this specific objective, we conducted a detailed literature review on integrated UA and stormwater GIs systems, such as bio-retention cells and green roofs. The findings from this study provide adequate support for the integration of UA and stormwater GIs in building resilient cities and the circular economy.

The outcomes of the literature review are summarized in three categories. First, the findings related to best practices for urban agriculture and stormwater management circularity are discussed. Secondly, a significant part of the review is dedicated to evaluating the ecosystem-based approach of the available best practices, including the reduction or elimination of the waste externality of urban agriculture and stormwater management, resource recovery, reclaimed water reuse, stormwater retention and reuse, and associated ecosystem benefits, and to identify data or knowledge gaps and areas where further attention is warranted. Additionally, a review of possible mechanisms for integrating UA and stormwater GIs in a circular economy is summarized and compiled in a schematic diagram. Overall, the findings of this manuscript provide insights to the benefit of researchers, planners, and sustainability managers, for making urban environments more resilient.

## 2. Materials and Methods

In this study, an extensive literature search was conducted using digital databases, such as Science Direct, PubMed, Google Scholar, Web of Sciences, and ResearchGate to obtain information reported in English-only peer-reviewed studies published from 1997 until 2021. Table 1 illustrates the search terms and term description for articles identification and study screening. Based on inclusion and exclusion criteria, the synthesis was made based on Science Direct and ResearchGate as the only sources. Table 2 indicates inclusion and exclusion criteria. The review was performed using the combination of the primary

terms or keywords: urban agriculture and stormwater green infrastructure, which can be stated as urban agriculture AND stormwater management OR circular economy OR green infrastructure OR bioretention cell OR stormwater pollution OR integrated water resources management OR integrated environmental management OR integrated landscape planning OR ecosystem service OR biobased circular economy. The search concluded on 30 April 2021.

**Table 1.** Review primary terms, term description, and search terms used for literature identification and screening.

	Primary Term	Term Description	Search Terms
Population	Urban Agriculture	Economic sector of interest	Urban farming, rooftop gardening, hydroponic, aquaponic, composting, and reclaimed water reuse
	Stormwater Green Infrastructure	Environmental management of interest	Bioretention cell; green roof; rain garden; rainwater harvesting; urban trees; stormwater gray infrastructure; stormwater green Infrastructure
	Ecosystem Services	Environmental and socio-economic benefits of UA and GI	Ecosystem; Urban Ecosystem, Ecosystem Services
Outcome	Urban ecosystem services	Environmental and socio-economic benefits of interest	Urban food production; stormwater retention; water quality improvement;
Agent	Water quality parameters	Water quality parameters of interest	Total nitrogen; total phosphorus; total suspended solids; trace metals
	Fresh Produces	Urban food production of interest	Vegetable

**Table 2.** Inclusion and exclusion criteria.

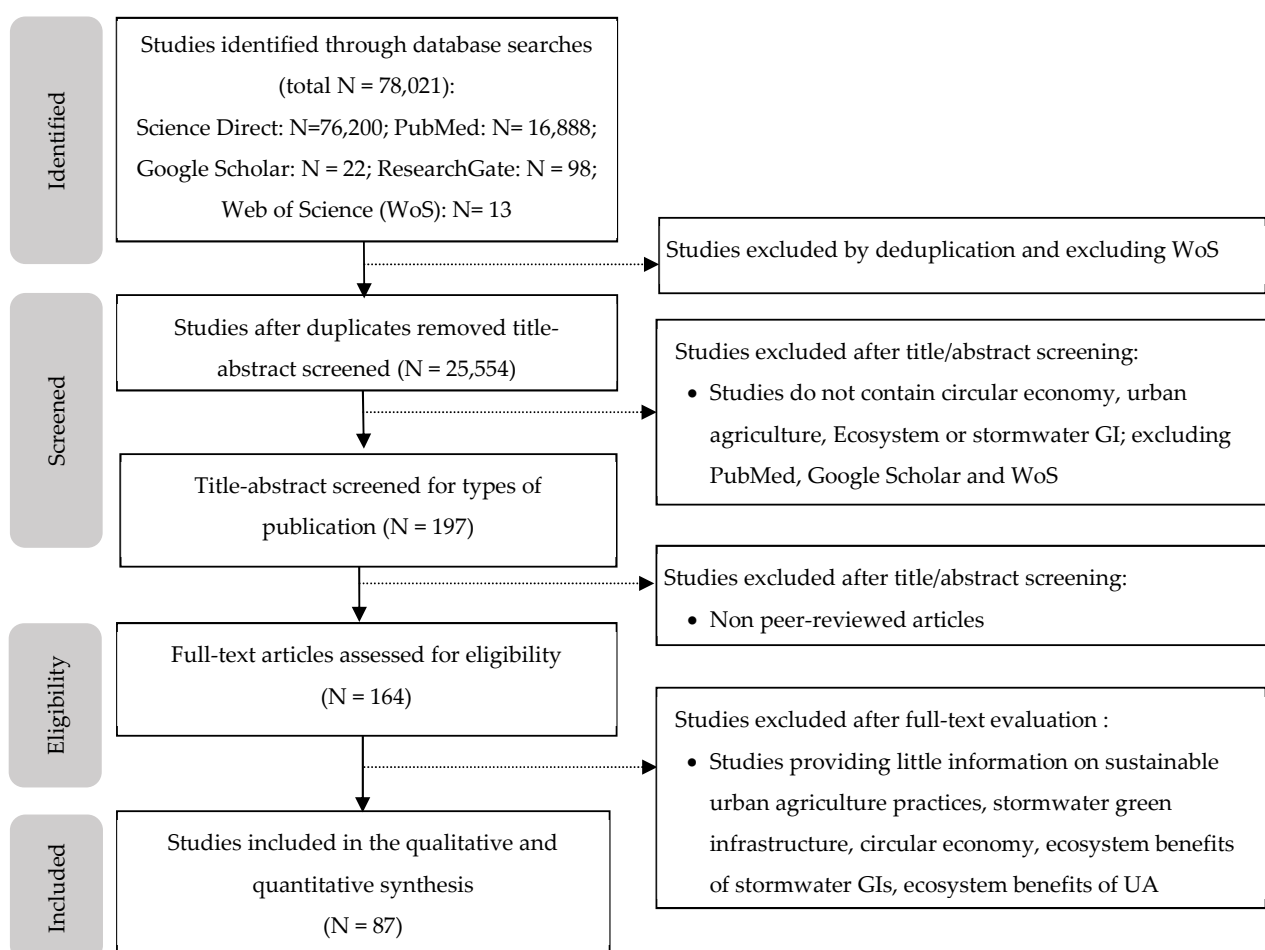
	Inclusion Criteria	Exclusion Criteria
Study type	Review articles; Research articles, conference abstract; book chapters, discussion, editorial	Encyclopedia
Language	English	Non-English
Population	Urban ecosystem services (Urban Agriculture, Urban stormwater Management, Circular economy, Gray and Green Infrastructure, Ecosystem)	Non-Urban ecosystem services
Outcomes	Sustainable urban agriculture practices as means to provide food, reduce stormwater runoff or Green infrastructures as ways to produce food, retain stormwater runoff, and provide socio-economic benefits in a circular economy.	Non-urban agricultural or non-urban green stormwater infrastructure.
Study Period	1997–2021	Pre-1997

The workflow of the literature search and screening is illustrated in Figure 1. In the databases, 78,021 article titles and abstracts published between 1997 and 2021 were identified by searching the two keywords—urban agriculture, and water management.

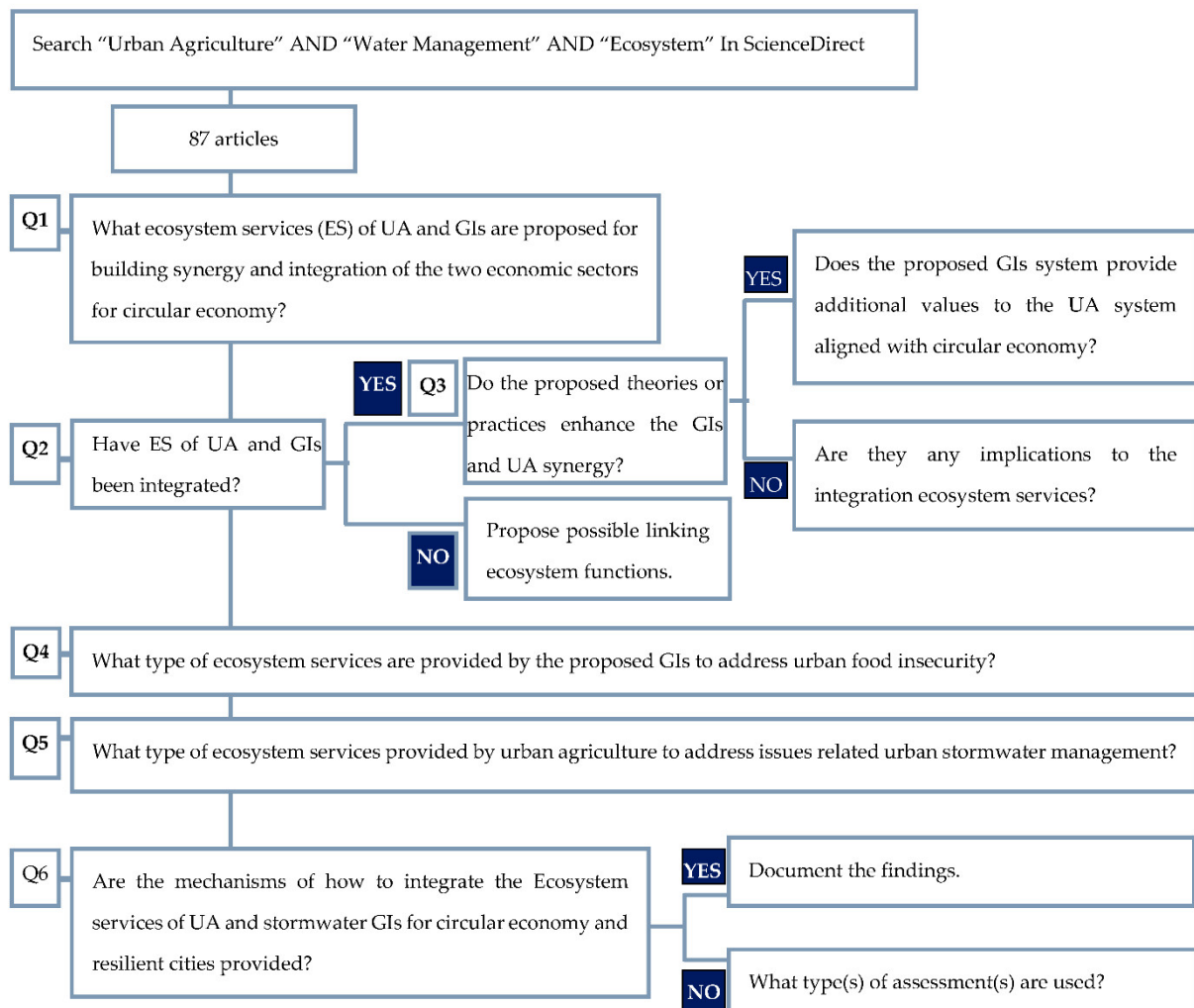
After excluding duplicates, we screened 25,554 abstracts and titles, which were then further screened to 197 studies excluding studies that do not contain these three terms—urban agriculture, ecosystem, and stormwater GIs. Excluding non-peer-reviewed publications, 197 full-text studies were filtered for relevance and eligibility. Subsequently, 164 full-text studies were assessed for eligibility based on questions illustrated in Figure 2. Finally, 87 full-text studies were included in the quantitative and qualitative synthesis.

As illustrated in Figure 2, for each full-text publication included in the analysis, a similar search strategy to that presented by Ronchi [12] was adopted. In this example, six key questions were applied to evaluate each publication for the ecosystem-based integration of UA and stormwater GIs:

1. What ecosystem services of UA and stormwater GIs are proposed for building synergy and integration of the two economic sectors (Q1)? This question is key to investigating how different stormwater GIs and UA contribute to the enhancement of ecosystem services while addressing urban food insecurity and urban stormwater management.
2. Have the ecosystems of UA and stormwater GIs been integrated (Q2)? This question is linked to question #3 (Q3). Both questions were applied to further analyze and synthesize the integration of ecosystem services for different urban land uses.
3. Do the proposed theories or practices enhance the stormwater GIs and UA synergy (Q3)? This is a follow-up question to question #2 (Q2) for an in-depth analysis of specific ecosystem services in view of building urban resilience.
4. What type of ecosystem services are provided by the proposed stormwater GIs to address urban food insecurity (Q4)? This question identifies alternative yet innovative approaches for integrating UA and stormwater GIs for the practical application of urban planning.
5. What type of ecosystem services are provided by urban agriculture to address issues related to urban stormwater management (Q5)? This additional question helps to examine the proposed findings in view of building urban resilience against the effects of extreme events due to climate change, e.g., flooding and water scarcity.
6. Are the mechanisms provided for the integration of the ecosystem services of UA and GIs for the circular economy and resilient cities (Q6)? This final question is for further analysis and exploration of alternative solutions to identify sustainable means of integrating the two economic sectors for future resilient cities while creating synergy between their ecosystem services.



**Figure 1.** Flowchart of literature selection and screening. N represents the number of studies (articles); WoS = Web of Science.



**Figure 2.** Questions applied for title screening and eligibility assessment.

### 3. Results

#### 3.1. Urban Resilience and Ecosystem Services

The findings of this extensive literature study indicate that the resilience of urban ecosystems determines the sustainability and resilience of the urban environment. In other words, urban sustainability and resilience depend on the resilience of connected urban ecosystem services provided by different environmental and economic sectors [13]. Ecosystem services are benefits provided to humans through the transformations of resources into a flow of essential goods and services, such as provisional (food and water supply), cultural (recreation aesthetic values), regulating (water purification, erosion control), and supporting services (nutrient cycling, water cycling) [14]. The resilience of urban ecosystems depends on the ecosystem's biodiversity quality and quantity, including plants, animals, and microbial organisms [15]. Further, the diversity of urban organisms is the direct source of urban ecosystem services. It must be noted that an urban ecosystem is a human-modified ecosystem that requires continuous maintenance and management intervention to provide the intended services [16]. In planning urban green infrastructure development, the significance of the network and multifunctional connectivity of the green infrastructure is highlighted in recent studies [17,18].

This implies that strategic integration of ecosystem services is needed in urban planning related to urban stormwater management using green infrastructure. The need for

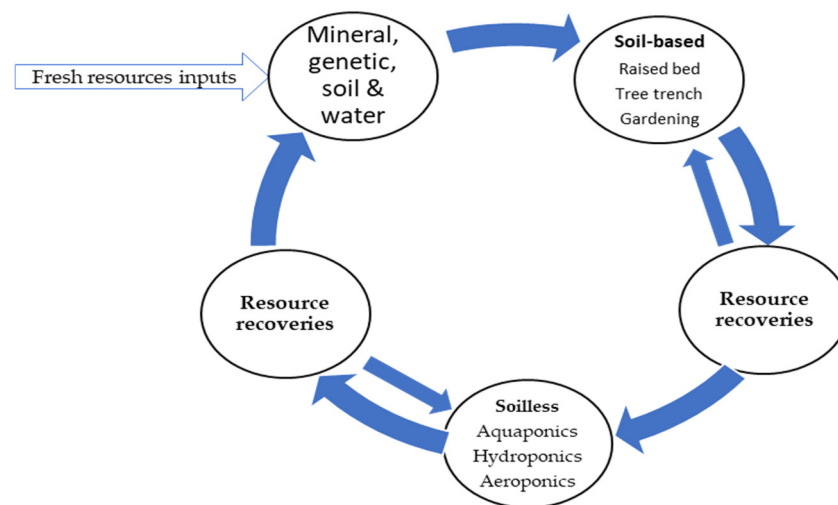
strategic integration has been recognized to reduce inequality in the distribution of green infrastructure and associated ecosystem services in the disadvantaged socio-demographic and socio-economic areas of cities [19]. In addition, urban ecosystem functioning changes over space and time; this is also the case for the quality and quantity of ecosystem services, in addition to their demand and production [20]. Many researchers have recognized the importance of careful consideration of ecosystem services in urban planning, design, policy, and management [18,21,22]. Nevertheless, there is a lack of studies about the integration of expanding urban farming with stormwater green infrastructure in a circular economy in a manner that maintains nutrient and water circularity while providing synergetic effects of ecosystem services. In this study, we explored means of enhancing locally produced ecosystem services, such as the provision of fresh food and supporting services of stormwater retention and water purification, through the integration of sustainable urban agriculture and stormwater green infrastructure. In sustainable cities with a circular economy, assessing the need and mismatch of ecosystem services must be considered in urban planning and management. This shows the importance of identifying an approach to the strategic integration of urban agriculture and stormwater management.

### *3.2. Urban Agriculture in a Circular Economy*

Sustainable urban agriculture can play a significant role in the circular economy and circular cities in various ways. For example, sustainable urban agriculture provides foods and fibers to the city while reducing stormwater runoff and the combined overflow of sewers in a circular economy. Sustainable urban agriculture is considered to be a sustainable solution to address not only urban food insecurity, but also to reduce stormwater runoff [23]. In addition, converting impervious areas to urban gardens reduces surface runoff and flooding [2]. Finally, rainwater harvesting can be used to supplement urban irrigation water demand [24–26]. Due to this ecological benefit, urban agriculture is expanding and is considered to be a form of green infrastructure [27,28].

Sustainable urban agriculture is consistent with circular economy principles. The circular economy requires the utilization and reuse of natural resources and the release of by-products into the environment after treatment of waste. Sustainable urban agriculture practices include environmental wellbeing and social equity while benefiting the ecosystem. In these sustainable practices, many researchers have documented the use of organic fertilizer, compost, and biosolids to reduce nutrient runoff from agricultural sites while reducing the load on landfills by using organic waste [29–33]. Further, avoiding synthetic pesticides is imperative to reducing the tradeoff of chemical pesticide control. Finally, safe urban farming practices can be applied to the greening and revitalization of brownfields [33].

It should also be noted that the circularity of urban agriculture relates to resource recovery or waste reuse. Figure 3 shows the conceptual circularity of urban agriculture systems, including soil-based and soilless agriculture [34,35]. Water lies at the center of both soil-based and soilless agricultural systems, including aeroponic, hydroponic, and aquaponic. In this sustainable model, fresh resources are reused via resource recovery, including that of water and plant nutrients [36].



**Figure 3.** A Circular Urban Agriculture.

### 3.3. Stormwater Management in a Circular Economy

By 2050, two-thirds of the global population is expected to live in cities. This will significantly increase the consumption of natural resources and waste production, which may damage ecosystems [37]. Rapid urban development, in addition to the increase in impervious areas, can make cities vulnerable and prone to stormwater-related damages, including flooding and disruption of aquatic ecosystems [38]. This problem may exacerbate the challenge of conventional urban stormwater infrastructure, also known as gray infrastructure [39]. The gray approach is designed to move stormwater away as quickly as possible from urban areas via pipes and conduits with a limited capacity, which can be overwhelmed during the wet season, thus contaminating local waterways. This centralized stormwater infrastructure applies a “Take-Use-Dispose” strategy, which is similar to the “Take-Make-Dispose” strategy of the linear economy. Traditional gray stormwater management follows a linear economic model and does not provide as many benefits as green infrastructure. This externality of stormwater gray infrastructure can be addressed by stormwater green infrastructures, such as bioretention cells, green roofs, tree trenches, retention ponds, or pervious pavements.

In contrast to the gray infrastructure, stormwater green infrastructure is a distributed model that treats stormwater runoff close to the source. It enhances locally produced ecosystem benefits by reducing stormwater runoff, recharging groundwater, reducing flooding, and increasing stormwater water filtration and source water protection [2,40]. Despite these benefits, limited studies have addressed the role and challenges associated with expanding stormwater green infrastructure to support the mission of sustainable cities with a circular economy.

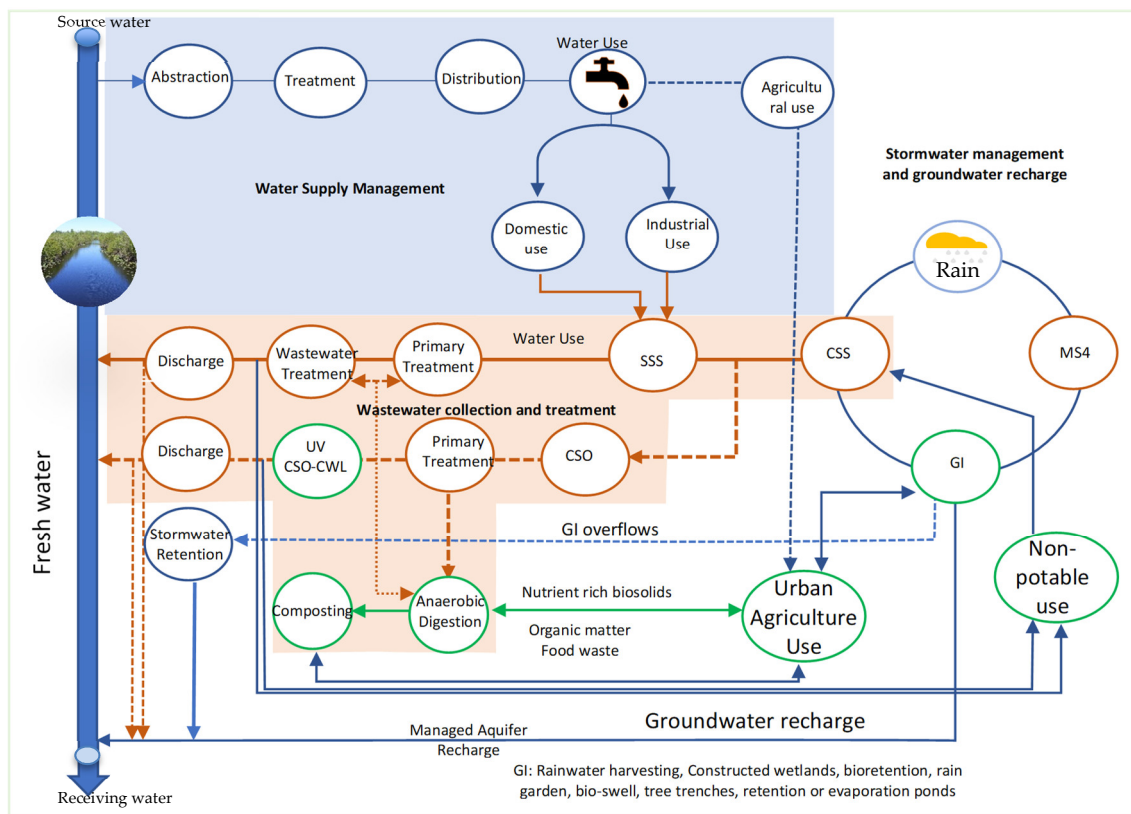
Several studies have recognized that water is central to the circular economy and that the circularity of water resource management is crucial for building sustainable cities [41]. Stormwater green infrastructure addresses all three principles of circular economy [42]: (1) designing waste externalities by optimizing consumptive use of stormwater for use in agricultural or evaporative cooling; (2) keeping resources in use by optimizing resource yields within water systems; and (3) regenerating natural capital by preserving and enhancing natural capital, such as river restoration, pollution prevention, reduction of energy use, and reduction of combined sewer overflows. Table 3 provides examples of stormwater green infrastructure that enhances water circularity. The result shows that stormwater GIs can address all three core principles of the circular economy.

**Table 3.** Aligning stormwater green infrastructure activities with the principles of the circular economy.

Circular Economy Principles [40]	Water Systems Management	Examples of Stormwater Green Infrastructure	References
Principle 1: Design out waste externalities	<ul style="list-style-type: none"> <li>Optimize consumptive use of water within sub-basin in relation to adjacent sub-basins (e.g., use in agriculture or evaporative cooling)</li> <li>Optimize the amount of energy, minerals, and chemicals use in the operation of water systems in concert with other systems.</li> </ul>	<ul style="list-style-type: none"> <li>Bioretention cell, rain gardens, retention ponds, constructed wetlands</li> </ul>	[43–48]
Principle 2: Keep Resources in Use	<ul style="list-style-type: none"> <li>Optimize resource yields (water use and reuse, energy, minerals, and chemicals) within water systems.</li> <li>Optimize energy or resource extraction from the water system and maximize their reuse.</li> <li>Optimize value generated in the interfaces of the water system with other systems.</li> </ul>	<ul style="list-style-type: none"> <li>Using municipal biosolids for the growing media of bioretention, urban gardening, tree trenches, and landscaping.</li> <li>Producing biogas and fertile organic fertilizer using an anaerobic digester</li> </ul>	[30–32]
Principle 3: Regenerate Natural Capital	<ul style="list-style-type: none"> <li>Maximize environmental flows by reducing consumptive and non-consumptive uses of water.</li> <li>Preserve and enhance the natural capital (e.g., river restoration, pollution prevention, quality of effluent, etc.)</li> <li>Ensure minimum disruption to natural water systems from human interactions and use.</li> </ul>	<ul style="list-style-type: none"> <li>Managed groundwater recharge</li> <li>Water use in some beautification ponds and fish hatcheries when the outflow is returned to the point of diversion,</li> </ul>	[49–51]

Based on this review, a conceptual model of a circular water system is proposed. Figure 4 illustrates a conceptual model of an integrated circular water management (ICWM) system. The components of ICWM include source water and receiving water (rivers), water supply management (industrial, domestic, and agricultural uses), wastewater collection and treatment, and stormwater management and groundwater recharge. In the integrated system, each of the three main water resources categories is addressed, including potable water, stormwater, and wastewater collection and treatment. The wastewater collection and treatment systems include a municipal-separate-storm-sewer system (MS4), separate sewer system (SSS), combined sewer system (CSS), and wastewater treatment. The primary focus of the proposed ICWM is to reduce waste while maximizing reuse by linking all major components of urban water and wastewater systems within a single complex ecosystem. This proposed complex system provides the maximum benefit, including reduced sewer overflows, stormwater, or rainwater reuse, reduced demand for water supply, and grey and recycled water reuse. In the integrated approach, stormwater GIs plays an essential role in maintaining water circularity in the urban setting. This implies that stormwater GIs can serve as a tool for stormwater retention and treatment for runoff from UA and can also provide wastewater retention and treatment for combined sewer overflows (CSOs). The water treated by stormwater GIs can be reused for non-potable water uses, including irrigation, cooling, and groundwater recharge [52–54].





**Figure 4.** Conceptual framework for integrated urban water, wastewater, stormwater system management circularity: GI—Green infrastructure; CSO-CWL—Combined sewer overflow constructed wetlands, CSO—Combined sewer overflows, CSS—Combined sewer system, SSS—Separate sewer system, MS4—Municipal separate storm sewer system, UV—Ultraviolet light wastewater treatment.

This implies that stormwater GIs can have a multifunctional role in a circular wastewater management approach and can have a significant role in addressing the impact of CSOs on the global aquatic ecosystem. Combined sewer overflows have been reported to be responsible for degrading urban aquatic ecosystems globally by discharging untreated raw sewage directly into the receiving waters. Combined sewer overflow constructed wetlands (CSO-CWLs) have been proposed to address this challenge. According to several researchers, CSO-CWLs can effectively purify CSOs [52–55]. According to Tonderaab [54], this type of stormwater GI can remove 85% of ammonia and carbonaceous Biochemical Oxygen Demand (BOD).

In addition, CSO-CWLs can remove 70% of micropollutants and pharmaceutical products [56]. According to Ruppelta et al. [57], this type of stormwater GIs can remove 80–91% BOD, 60–85% Chemical Oxygen Demand (COD), and 80–95% Total Suspended Solids (TSS). Further, in areas where stormwater GIs is not possible, end-of-pipe systems can be applied, such as primary settling tanks, dynamic rotating belt filters, adsorption on granular activated carbon, and UV disinfection steps for further CSOs treatment [58].

Furthermore, anaerobic digestion is a key part of wastewater management circularity because it uses waste to generate renewable energy and biogas and to provide wastewater stabilization for land application. Nutrient-rich biosolids can be used for urban agriculture, including urban trees. Food waste and organic matter from urban agriculture can provide carbon sources for anaerobic digestion. In addition, anaerobic digestion can be applied to treat solid waste generated by primary and secondary wastewater treatment systems designed to purify wastewater received from CSOs and SSS.

Rainwater harvesting is also important in the integrated cycle of water management and provides benefits such as reducing CSOs to improve wastewater treatment, reducing

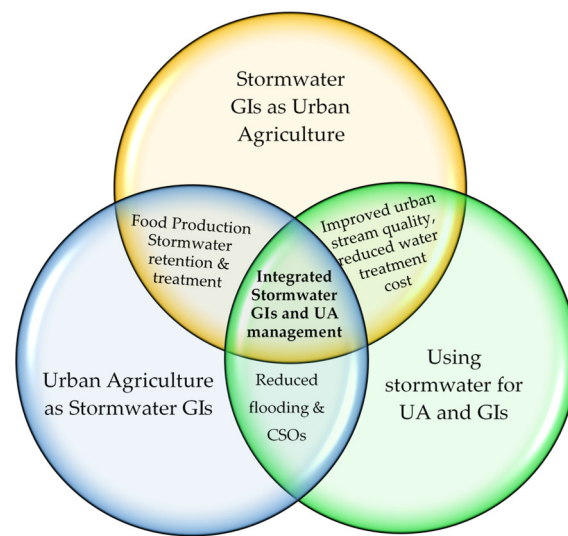
the cost of damage caused by floods, decreasing water demand, reducing the cost of drinking water production, aquifer recharging, and improving stream base flows [26,59]. A recent study demonstrated that rainwater harvesting can provide up to 25% of the water that is used for washing and flushing, with no treatment, in India [45]. In Australia, rainwater harvesting can satisfy up to 100% of toilet flushing and laundry use [60] and 97% of drinking water demands [61]. In China, the integration of rainwater harvesting, and drip irrigation can increase apple fruit production by 54% [25]. In the State of Florida, rainwater harvesting can reduce flooding by 20% [26]. It must also be noted that if rainwater harvesting is used to reduce flooding and CSOs, the water captured from impervious areas, including roofs in cisterns, should be used for some appropriate purpose before the next significant rain event [62]. Overall, the literature study shows that rainwater harvesting is an important part of sustainable urban water resource management and urban farming in a circular economy.

### 3.4. Stormwater Management in a Circular Economy

Stormwater GIs can be designed to reduce runoff and flooding while providing local fresh foods. They are considered to be more adaptive strategies for both short- and long-term urban stormwater management planning than gray infrastructure [63]. Nevertheless, integration of stormwater management and urban agriculture (ISMUA) is not part of conventional urban land use planning. In addition, there is also limited field data related to appropriate methods for implementing ISMUA. There is a knowledge gap and a lack of policy regarding the successful implementation of the ISMUA system. This study focused on possible means of implementing ISMUA for the maximum ecosystem benefit of the integrated system while highlighting approaches to reduce tradeoffs.

Based on an extensive literature study, three means of implementing ISMUA were identified: (1) use of stormwater GIs as food-producing systems; (2) use of urban agriculture as urban stormwater GIs; and (3) non-consumptive and consumptive use of harvested stormwater for urban agriculture and stormwater GIs. Figure 5 illustrates ISMUA. Previous studies have examined applying stormwater GIs for food production, such as green roofs or rooftop gardening, which are commonly used to retain stormwater and can be used for rooftop gardening. Recent literature studies [34,64,65] extensively discussed how stormwater GIs can address urban food insecurity and energy conservation while retaining stormwater during peak flows. This approach focuses on the water–energy–food–ecosystem security nexus approach to contribute to the sustainable and resilient development of cities. The environmental benefits of green roofs are well recognized as mitigating the effects of urban heat islands and stormwater runoff management. According to Berardi et al. [66], green roofs can reduce heat flow by up to 90% in summer and up to 30% in winter. In addition, green roofs can contribute to urban food production. For example, in Singapore, green roofs have produced about 35% of the domestic food demand [65].

Nevertheless, the capacity of food-producing green roofs to mitigate stormwater quantity and quality must be verified using controlled field data. For example, adding compost to the growing media of GIs in the case of productive green roofs may have mixed effects on mitigating stormwater quality. Using growing media or soil mix with excessive plant nutrients and the application of mineral fertilizer could result in the potential leaching of nitrogen and phosphorus [67–70]. In contrast, the addition of compost was reported to be a potential absorbent or treatment method for heavy metals from industrial and landfill stormwater [71]. The substrate or growing media of green roofs is critical for the success of the system as a tool for stormwater quality and quantity management. In contrast to the most commonly used lightweight substrates for mitigating urban heat islands, and stormwater quantity and quality, sustainable food production on green roofs requires a greater quantity of organic matter and an optimum level of plant nutrients. This demonstrates the need to balance the effect of the green roof substrate by using stable compost materials. The addition of locally available recycled materials, such as biochar, perlite, and zeolites, are reported to reduce nutrient leaching [69,72].



**Figure 5.** Integrated stormwater green infrastructure and urban agriculture (ISMA).

In addition, stormwater GIs can provide food production services while mitigating stormwater quality and quantity. Several studies have demonstrated that vegetable gardens can reduce stormwater runoff while providing good food yields [43,48]. This indicates that characterization of GIs is important prior to using them to treat stormwater because stormwater carries a range of contaminants including, total suspended solids (TSS), heavy metals, polycyclic aromatic hydrocarbons (PAHs), nitrogen, and phosphorous compounds.

Furthermore, the benefit of stormwater for urban agriculture can be described in two ways. First, urban agriculture can provide the benefit of stormwater retention by reducing runoff during peak flows [73]. Second, water harvesting in appropriate containers during rain or peak flows can be used to irrigate urban agriculture and for other consumptive uses.

Finally, other noticeable benefits of urban agriculture include purifying reclaimed wastewater and revitalization of brownfields [34,40]. Treating wastewater using a hydroponic system allows nutrient recovery and reuse while producing food [74,75]. Another study shows that wastewater supplemented with artificial lighting improved nitrogen removal [76].

### 3.5. Enhancement of Ecosystem Services

Ecosystem services are a crucial component of urban sustainability and resilience. They are the processes that directly or indirectly contribute to sustainable human wellbeing, and thus they are considered to be “natural capital” [77]. Table 4 illustrates examples of ecosystem services provided by integrated systems of UA and stormwater GIs. The quality and quantity of ecosystem services depend on biodiversity, which is a key component of the environmental benefits of urban agriculture. As indicated in Table 4 and Figure 4, integrated stormwater GIs and urban agriculture management help cities to overcome the existing barriers related to urban agriculture and focus on the synergies of the ecological benefits of the two sectors. Integration of stormwater management and urban agriculture reduces, if not eliminates, possible sectoral disservices. For example, urban agriculture may result in ecosystem disservices, including nutrient runoff and competition for water from other services [78]. Table 4 depicts possible enhancements of ecosystem services provided by integrating urban agriculture and stormwater management. This indicates, in addition to providing and regulating services, the integrated system can have a significant contribution to the creation of cultural, economic, and educational opportunities for a city.

**Table 4.** Ecosystem services and examples of integrated stormwater management and urban agriculture.

	Ecosystem Services	Example of Integrated Stormwater Management and Urban Agriculture	References
Provision:	Food supply	Food-producing rain gardens and green roofs, urban fruit trees, urban food forest	[4,9,23,79,80]
	Water supply (non-potable use for consumptive uses: harvested or reclaimed water)	Graywater reuse through bioretention, rainwater harvesting, using harvested water for agriculture to reduce water supply/demand.	[10,61,81]
	Wood and fiber	Urban forest	[82]
Regulating:	Drinking water quality enhancement	Stormwater retention and filtration	[2,26,83]
	Flood control	Bioretention, rainwater harvesting, using harvested water for agriculture	[2,26,83]
	Wastewater purification	Using hydroponic for food production and wastewater treatment	[40]
	Stormwater quality enhancement (N, P, coliform, total suspended solids)	Bioretention	[23,79]
	Air purification/air quality regulation	Urban trees, urban forest	[2,84,85]
	Carbon sequestration	Urban trees, urban forest	[84–87]
	Temperature regulation	Urban trees, urban forest	[2]
	Cultural:	Esthetic value	Urban fruit trees, green roofs, Bioretention, Tree trenches
Recreation		Bioretention, Tree trenches	[2]
Educational opportunities		Green roofs, Bioretention, Tree trenches	[2,4]

Nevertheless, the selection of an appropriate type of stormwater GIs is imperative to efficiently treat stormwater quality. Table 5 illustrates typical examples of bioretention cells with treatment efficiency for different water contaminants. Based on this example, the removal rate of total nitrogen (TN) and total phosphorous (TP) by the bioretention cell can range from 30% to 90%, and 67% to 95%, respectively. According to Jay et al. [88], bioretention cells can remove more than 80% of polycyclic aromatic hydrocarbons (PAHs). There is limited data available for the PAHs removal. Overall, one should note that the removal rate of bioretention depends on various factors including soil mix, design, depth of saturated zone [79–91].

**Table 5.** Summary of stormwater quality treatment efficiency (%) of GIs based on the literature review.

References	TN	TP	TSS	PAHs	Type of Study and Country	Addition of Enhancing Materials
	Removal Efficiency (%)					
[79]	82	95	94		Laboratory; Artificial rainfall, USA	
[80]	51	67	70		Field Study, USA	
[81]	90				Field Study, USA	Wood chips
[82]	86				Laboratory	
[83]	64	89			Field Study, China	
[84]	56				Field Study, USA	
[84]	95	94			Laboratory, China	Fe-biochar
[86]	80	95	95		Field study, China	Zeolites
[87]		90	95		Laboratory, Sweden	
[89]				84 to 100%		
[91]	29.8–123.0				Laboratory	

Another typical example of integrated stormwater GIs and UA is rooftop farming, also known as a productive green roof. It is often referred to as the food-water-energy nexus [62,63]. This type of integrated system provides multiple ecosystem services, including stormwater management, food production, energy conservation, education, aesthetics, recreation, economic and social benefits. Brooklyn Grange of urban rooftop farm in the New York City [92], and the Farm at Mill Creek in the city of Mill Creek, Philadelphia [93] are among many such integrated rooftop farms in the USA. Furthermore, rooftop farming is popular in developing countries [94].

## 4. Discussion

### 4.1. Enhancement of Ecosystem Services

Our findings were compared with two other different perspectives pertaining to environmental management in urban areas. First, most authors focus on a separate land-use approach in addressing urban food insecurity and urban stormwater management, rather than cross-agency collaboration in planning and management. The separate approach describes various ways of addressing a single environmental or urban land issue rather than the holistic approach. For example, van der Wielab [28] and others [30–34] focused on sustainable practices, including nutrient recycling, and reusing biowastes to address food insecurity. Conversely, Nilson et al. [38] and others [39–42] emphasized the distributed approach of urban stormwater management, which does not necessarily include urban agriculture. In this review, both theoretical and technical concepts for the mechanism of integration of UA and GSI are elaborated (Figures 3 and 4).

The second comparison is related to integrated environmental management (IEM) and integrated water resource management. In this approach, there are a significant number of publications regarding general theories and practices that provide guiding principles to achieve the priority goals while minimizing the negative impacts of other activities on the individual elements of the environment. However, these do not specifically address current and future issues related to urban stormwater management and urban agriculture as an integrated approach. For example, Posivakova et al. [95] discuss the characterization of selected IEM approaches in a broader context, identifying the questions of “what” and “how”, and examining theories that are key to planning and implementation of holistic environmental management tools. In the current literature regarding IEM approaches, linking urban agriculture and stormwater management theory and practices, in particular, is missing. For example, Biswas et al. [96] and other similar studies [95,97] emphasized water resource and ecosystem management, and they did not specifically address competing land-use practices of urban agriculture and other urban practices.

Furthermore, several literature reviews demonstrate the significance of ecosystem services in urban resilience, and some even propose that ecosystem services should be included in urban planning processes [15–18,21,22,98]. Nevertheless, there are limited studies that provide detailed perspectives regarding the strategic integration of UA and stormwater GIs economic sectors. To enhance the ecosystem services of these two economic sectors, strategic integration of both ecosystem benefits is critical. Many studies recognize the importance of careful consideration of ecosystem services in urban planning, but they are limited in the details provided for how to expand UA to address urban food insecurity without affecting urban water resources. In our findings, a limited number of studies show that sustainable urban agriculture can be designed to both provide provisional ecosystem services, such as food supply, and regulate water supply and urban stream water quality [23–26].

Similarly, we also evaluated the circular economy literature studies. These studies are also very broad and do not specifically provide an alternative to address issues related to urban agriculture [43–51,98,99]. For example, Sreeharsha et al. [98] focuses on the energy, water, and resource recovery in a broader context but does not specifically address the role of urban agriculture to address urban food insecurity and nutrient recycling. Nevertheless, the circularity of urban agriculture and stormwater management requires

resource recovery or waste reuse. In both soil-based and soilless urban agriculture, water is an integral component of the circularity of urban agriculture. As indicated in Figure 2, which shows the circular urban agriculture model, freshwater resources, including water, plants, and nutrients, are reused. It must be noted that the construction of resilient cities requires the integration of sustainable practices, including sustainable urban agriculture and urban stormwater management. Separating urban agriculture from other land uses cannot address key urban issues related to food insecurity and land scarcity.

This study shows that providing an in-depth analysis of the ecosystem service-based integration of UA and GSI is crucial for the fast-growing and urbanizing world. A considerable number of studies have recommended the integration of ecosystem services into urban planning from general perspectives but do not specifically provide guidelines for linking or integrating the multiple functions of ecosystem services of different land uses. For example, Marino et al. [93] and others [92,100] focus on the importance of the integration of ecosystem services and green infrastructure at multiple scales in a broader context. This paper also emphasizes ecosystem services but addresses the “what” and “how” questions relating to the theories and practices for city planners or regulators. This analysis provides insights pertaining to ecosystem-based adaptation and has the potential to help cities meet various environmental, social, and economic objectives, including resilience to climate change [92–94,100,101]. In addition, this paper specifically discussed the possible means of linking ecosystem services of the two economic sectors, i.e., UA and stormwater GIs.

Finally, in the integrated system, the selection of appropriate stormwater GIs is vital. As illustrated in Table 5, a wide range of variability was noted in the removal rate of water contaminants in bioretention cells. This variation is attributed to the difference in the design, soil mix, and nutrient management practices. Overall, further studies are necessary for key stormwater GIs, including bioretention cells, and extensive and intensive green roofs.

#### 4.2. Limitation of the Study

The findings of this study should be considered in light of its limitations. The limitations of this study depend on the parameters set for the literature review, which are arbitrary and could limit the inclusion of other articles that may be of interest to the aims of the research. Other forms of publication, such as conference reviews and book chapters, were excluded. The research methodology consciously limited the selection of articles in an attempt to focus on the quality of the content with explicit reference to urban agriculture and green stormwater infrastructure, rather than the number of articles investigated.

A possible improvement could be made by integrating a new combination of keywords as parameters for the literature review, and the collection of additional water quality and quantity data that represent a longer time period. This could include the integration of environmental planning and urban agriculture to verify approaches for the integration of sustainable urban agriculture with other environmental management practices. Similarly, urban planning for agriculture, adaptive environmental management, and urban farming, or urban agriculture and urban resilience, may provide additional perspectives on how to integrate urban agriculture with other environmental management practices for future resilient cities.

### 5. Conclusions

Based on this study, it can be concluded that there are various approaches to integrating the ecosystem services of urban agriculture and stormwater green infrastructures for the construction of resilient cities with a circular economy. Overall, the results show that integrating urban agriculture with stormwater bioretention can enhance urban food production while protecting urban water quality. Urban agriculture can be designed not only to address urban food insecurity but also to manage stormwater runoff and prevent combined sewer overflows. Increased optimization of design and materials to remove total nitrogen and total phosphorous, in addition to a collection of adequate performance

data of bioretention during different rain events and agricultural activities, can provide additional insights for such integration. Finally, the findings of this study are useful for researchers, urban planners, and environmental managers. These findings improve our understanding of the mechanisms used to integrate the ecosystem services of urban agriculture and stormwater green infrastructure management to enhance the resilience of future cities, thereby addressing growing concerns regarding urban food insecurity and urban stormwater-related issues. Therefore, the proposed sustainability practices and ways of integrating urban agriculture and stormwater green infrastructure would benefit societies at local and global levels in the exploration of mechanisms for adaptation to extreme events related to climate change.

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