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Perspective

Untangling the Food-Water-Soil Nexus through the Lens of Ecosystem Services and Disservices in Urban Gardens

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Abstract: Nexus thinking is crucial for sustainable resource management, but existing frameworks often fail to capture the complexities of urban nature-based solutions, such as urban gardens. Specifically, the prevailing Water-Energy-Food nexus is often unsuitable for low-energy cultivated systems, sidelining the foundational role of soil and overlooking the co-production of ecosystem disservices (EDS) alongside ecosystem services (ES). This perspective paper addresses these gaps by proposing the Food-Water-Soil (FWS) nexus, analyzed through the dual lens of ES and EDS, as a more robust framework for assessing these systems. We argue that ES and EDS are not mere outputs but are the core mediating functions that define the system's potential and its limits. Central to this framework is the conceptualization of soil as a living infrastructure whose dynamic properties are altered by management, thereby governing the trade-offs and synergies between food production and water dynamics. We conclude by demonstrating that adopting this FWS-ES/EDS perspective has important implications for urban governance and adaptive management. It enables a more complete understanding of system dynamics, fosters more inclusive stakeholder dialogue by making both benefits and nuisances visible, promotes coherent cross-sectoral policy, and supports a culture of long-term ecological stewardship.

Keywords: Food-Water-Soil; urban nexus; urban garden; urban nature-based solutions; ecosystem services and disservices

1. Introduction

Ecosystem services (ES) refer to the direct and indirect benefits that humans derive from the functions of ecosystems, which are essential to human well-being [1,2]. Recognized as vital components within our social-ecological systems, these services highlight the crucial role of nature in supporting life and development. In urban environments, the concept of ESs has gained prominence for emphasizing the importance of urban nature and nature-based solutions (NbS) in promoting citizen well-being and sustainable development [3–5]. ESs are increasingly incorporated into nexus concepts to clarify and address the trade-offs in policies and planning, as ESs themselves are the result of complex linkages and feedback mechanisms in social-ecological systems [6], which encompass nexus dimensions. Current nexus frameworks, however, often struggle with this deep integration. Ecosystems are frequently relegated to the periphery, being treated either as an additional, co-equal node in the system, an endpoint for assessing the environmental impacts of nexus policies [7], or an external driver influencing adaptation strategies [8]. The ES-centric framework proposed by Sambo and colleagues represents a significant step in centering ecosystems within the Water-Energy-Food (WEF) nexus [9]. It clarifies the complex interactions among multiple nexus sectors and the pressures and responses of WEF to the ecosystem processes and functions that deliver their services. However, this framework does not offer the integration of the ecosystem disservices (EDS) generated alongside the benefits [10,11]. It is essential to acknowledge that nuisances and harms are inherent to human–ecosystem interactions. Further research into EDS is crucial, as it can help identify ways to mitigate or eliminate disservices without compromising ecosystem integrity [11,12].

Emerging nexus conceptualizations are often fundamentally unfit for soil-based systems, especially urban gardens, which are a specific type of NbS that needs a customized approach and makes use of limited amounts of energy. Within urban gardens, ES and EDS are the tangible outputs of the Food-Water-Soil (FWS) nexus. Food provisioning and biomass production are mediated by soil fertility, while water infiltration and retention in the soil regulate local hydrology and support plant growth. While holding the foundational role of cultivated systems, the soil dimension is under-theorized in the nexus research landscape [13,14], often treated as a passive substrate or a static variable in spatial models. Recognizing the central role of soil in urban gardens (e.g., community gardens, green corridors, school gardens) and urban agriculture, there is a global interest in soil and its functions for assuring a healthy living environment within the urban context. Programs like the "Mission 'A Soil Deal for Europe'" explicitly advocate for addressing challenges of soil health and land use [15], which are fundamental to the viability of cultivated nature systems. These initiatives recognize that the complexities of cultivated NbS - spanning spatial constraints, circular economy principles, and social equity- demand a multi-stakeholder and adaptive approach to innovation [16]. Integrating soil dimension into nexus thinking, such as the FWS nexus, would provide a holistic, transdisciplinary, and sustainable approach to resource management and allocation. Therefore, this paper proposes the concept of the FWS nexus and its necessity in urban gardens assessment and planning, utilizing ES and EDS as analytical lenses. We do not propose the FWS nexus as a universal replacement for the established WEF nexus, which remains indispensable for evaluating macro-scale, energy-intensive agricultural paradigms. Rather, the FWS nexus is an adaptation designed for low-input, soil-centric urban cultivated systems where energy is often a negligible input, but soil plays the foundational role in mediating system resilience. Our contribution lies in adapting nexus thinking for these soil-dependent systems by utilizing the dual ES/EDS lens to capture soil states, ultimately informing adaptive urban governance. We begin by illustrating and clarifying the relationships between ES, EDS, and FWS nexus using urban gardens as the operational sphere. We conclude the discussion with recommendations for operating a functional FWS framework for urban gardens assessment and governance.

2. Food-Water-Soil Nexus Thinking in Urban Gardens

Urban gardens incorporate practices that utilize natural processes to enhance agricultural productivity sustainably, while also promoting soil health, effective water management, and biodiversity conservation within the urban environment [17,18]. On the other hand, in many places, urban gardens still rely on artificial inputs [19], such as synthetic fertilizers and pesticides. An increased reliance on these agrichemicals is a primary driver of EDSs, such as nutrient runoff, soil degradation, and food residue risks. It is at this critical interface of natural assets and human well-being that our FWS framework becomes operational. Urban gardens can be understood as a form of cultivated natural capital, a hybrid system that is neither entirely natural nor purely an artifact of human creation [20]; it requires the deliberate intersection of human management and ecological processes. Urban gardens, such as allotments or communal gardens, require minimal energy input for production [21]. In contrast, soil is the foundational medium where critical interactions occur, and managing soil health through sustainable agricultural practices is of significant importance for long-term urban resilience [17], therefore, soil should be placed at the center of nexus thinking, especially in planning and evaluating the effectiveness of soil-based NbS.

The FWS nexus is best understood by characterizing the distinct but interdependent roles of its components. Water serves as the dynamic medium, facilitating primary flow and nutrient transport, which in turn supports plant growth. Food, or more broadly biomass, represents the productive output and the principal objective of management interventions. At the core sits soil, the foundational living infrastructure of the system. Soil is a capital asset [22] whose function is determined by its health and functional state (e.g., physical, chemical, and biological properties) that govern the system's overall capacity to provide a continuous flow of services. We can distinguish between its inherent properties (e.g., texture, mineralogy), which define the system's baseline capability, and its dynamic properties (e.g., soil organic carbon, aggregate stability, biota), which reflect its current health and are directly modified by management [23]. It is the management interventions targeting food production that alter these dynamic properties, thereby mediating the soil's relationship with water. For example, a decision to apply compost to increase crop yield enhances the dynamic property of soil organic carbon, which in turn improves the soil's capacity to store water, demonstrating a synergy between the food, water, and soil dimensions. It is these changes in soil-mediated functions, driven by the interactions between food, water, and soil, that ultimately manifest as the ecosystem services and disservices valued by society.

3. FWS Nexus through the Lens of ES and EDS

A crucial insight from ecological economics is that while the biophysical structures of a landscape exist passively, the realization of cultural ecosystem services, such as aesthetics, is a co-produced process requiring human perception, access, cultural framing, and social interaction to manifest as a tangible benefit [24]. In other words, services and disservices are co-produced through the dynamic interaction between the cultivated nature capital (in this paper, it is viewed as urban gardens) and the other three capital stocks: social, human, and built. Figure 1 establishes the key assets and actors – the four capitals – involved in this co-production [25].

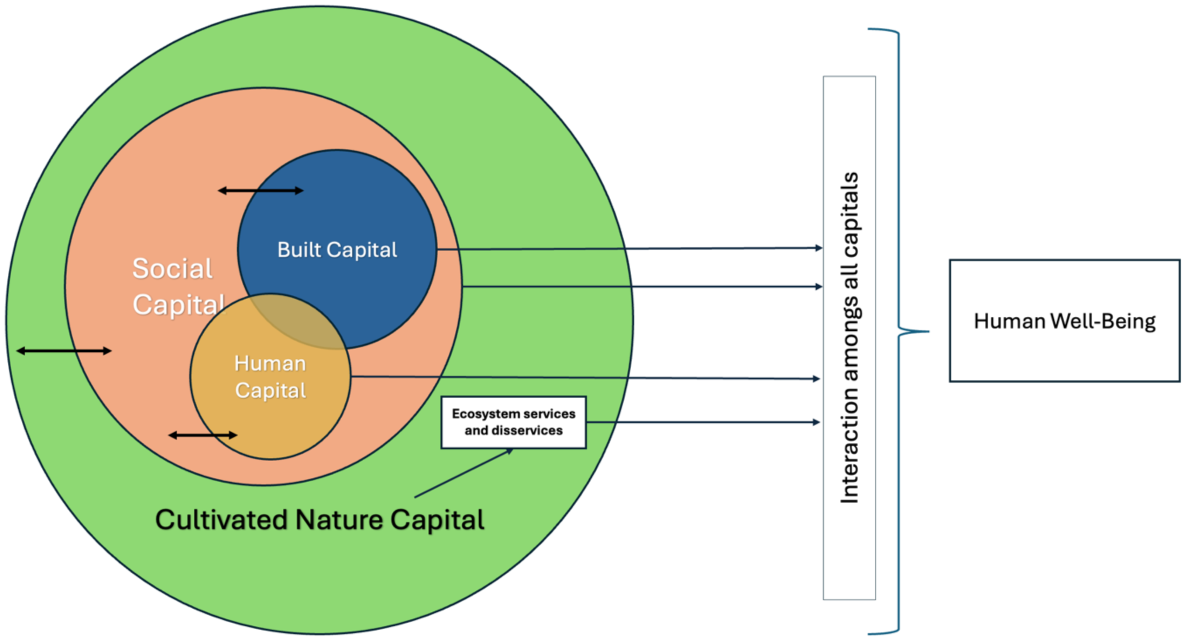

Figure 1. Interactions between nature capital and social capital affecting human well-being. Modified from Sangha et al., 2022 [25].

Let us consider the provisioning of food. The natural capital of urban gardens (i.e., soil, biodiversity, and climatic conditions) holds the potential to generate produce. This potential is only realized through the application of human capital (a gardener's knowledge and physical labor), which is aided by built capital (tools, irrigation systems, raised beds), and often structured by social capital (community garden rules, shared knowledge networks, and trust among members). The resulting harvest is a co-produced ecosystem service. Conversely, the very same interactions can generate ecosystem disservices. A gardener's lack of knowledge (human capital) combined with an overreliance on external inputs (built capital) can deplete soil organic matter, resulting in nutrient runoff and pollution of local waterways.

In contrast, a successful garden that enhances well-being can build social capital (stronger community ties) and human capital (new gardening skills). Thus, the ultimate contribution of the urban gardens to human well-being is the net outcome of these complex, co-produced services and disservices, which are mediated by the constant interplay of all four forms of capital. It thus becomes clear that ES and EDS are not an 'add-on' but rather the enabling and disabling features that define the nexus system's potential and its limits. ES and EDS emerge at the dynamic interface between the managed ecology of an urban food garden and the surrounding urban social system [26], and represent the ultimate locus of interaction among the food, water, and soil dimensions of this nexus.

The intention of clarifying the FWS framework through the ES and EDS lenses in this paper is rooted in the dynamic and systemic perspective. Quantitative assessments, such as material flow analysis, often work best with resources that are easily quantified in standardized units (e.g., cubic meters of water, tonnes of grain, gigajoules of energy). Soil, however, defies such straightforward accounting. Unlike water flowing through a pipe or stored in buckets, many of soil's most critical functions are services rather than physical flows. The "flow" of nitrogen mineralization or disease suppression is a biological process rate that govern complex mass transfer in the traditional sense of material flow analysis. While soil mass can erode and be transported (as in material flow), this represents a system degradation rather than a managed resource flow. The critical resource we aim to manage is not soil mass, but rather soil health or soil quality–a complex, multi-attribute characteristic that encompasses physical, chemical, and biological properties [27]. A single metric, such as tonnes or joules, cannot capture this quality. Hence, soil is often overlooked in traditional urban nexus assessments that prioritize engineered infrastructure. By framing the functions of soil, water, and plants as services and disservices, we shift the analytical focus from a simple accounting of material stocks to an assessment of the performance of the urban gardens as a living, multifunctional piece of infrastructure. The degradation of this infrastructure incurs real costs, not just in lost productivity, but in diminished regulatory capacity (e.g., stormwater management) and resilience. A significant health disservice stems from historical soil contamination. Urban soils serve as reservoirs for legacy pollutants like lead and arsenic. Mitigating these exposure risks requires adaptive management responses, such as rigorous soil screening and the construction of raised beds utilizing clean, imported soil [28].

Following this framing, we argue that both ES and EDS must be incorporated into the center of the FWS nexus as the implicit functions that mediate the links between its components, rather than as simple outputs. The role of ES/EDS in facilitating synergies and, more critically, in exposing trade-offs becomes explicit when considering the system's underlying biophysical state [27]. The soil's biophysical structure and microbial processes are the foundation that underpins ecosystem functions. These functions are essential for delivering services valued by urban dwellers, such as fresh food, aesthetic beauty, or microclimate regulation. Figure 2 illustrates the FWS nexus as a continuous socio-ecological feedback loop utilizing an ES/EDS cascade model. In this cascade model, the cycle begins with the *Ecosystem Structure* (dynamic soil and water properties), which drives biophysical *Functions* (e.g., plants' evapotranspiration or carbon accumulation). When intersecting with human needs, these functions manifest as *Ecosystem Services* (e.g., biomass yields, air purification) or *Ecosystem Disservices* (e.g., toxic dust, pest outbreaks). Crucially, these outputs are not static endpoints; they are evaluated through societal *Values*. For example, experiencing the disservice of insect bites prompts communities to re-evaluate the land as a public health liability, triggering adaptive *Responses*, ranging from localized gardener interventions (e.g., applying pesticides) to municipal policies (e.g., new regulations). These management responses loop back to physically alter the baseline *Ecosystem Structure* for the next cycle. Ultimately, Figure 2 demonstrates that FWS nexus management is an ongoing, adaptive dialogue between ecological functions and urban governance, rather than a linear extraction of resources.

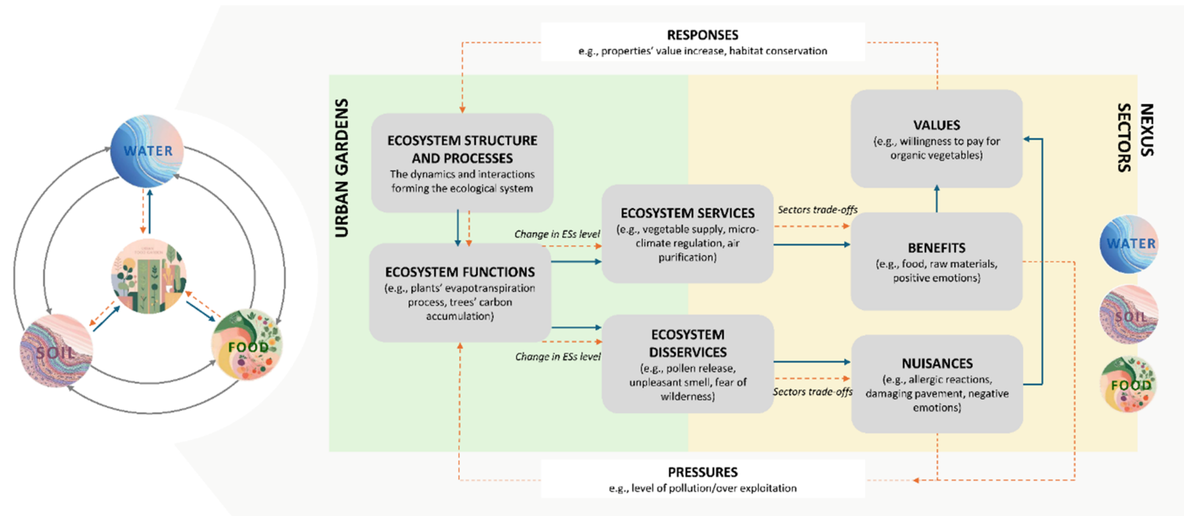

Figure 2. Integrating the ES and EDS model in the FWS nexus framework. Adapted from Sambo et al., 2024 [9].

4. Implications for Nexus Governance and Adaptive Management

Urban gardens are often considered a type of NbS [29,30]. Adopting a dual ES and EDS perspective is fundamental to navigating the complexities of the FWS nexus and achieving sustainable outcomes in urban gardens. Rather than simply maximizing benefits, this balanced lens aims to optimize the net contribution of these systems to urban well-being.

First, this approach offers a far more comprehensive and accurate understanding of the garden's internal dynamics. The goal of FWS nexus thinking is to develop integrated management practices that recognize the profound interdependence of food production, water use, and soil health. The soil, in particular, acts as a living ledger or ecological memory; its health is a direct reflection of past management choices, environmental conditions, and disturbances, serving as a predictor of future potential. Spatially and temporally mapping the flows of both services (e.g., food provision, stormwater infiltration) and disservices (e.g., potable water consumption, nutrient runoff) allows us to identify critical interdependencies and time-lag effects. For example, the decision to maximize yield in one season through intensive irrigation and fertilization can create a "yield drag" in subsequent years by degrading soil structure and depleting organic matter, thus reducing its water-holding capacity [14]. The FWS lens makes this causality visible, transforming our management from a series of isolated actions into a conscious dialogue with the garden's ecological memory [31]. This means utilizing historical markers, such as the legacy of industrial lead contamination, to dictate specific adaptive interventions (e.g., the mandatory construction of raised beds with clean, imported soil to ensure food safety).

To operationalize this nexus for cultivated NbS without overburdening municipal governments, the theoretical FWS framework lays the groundwork for indicator-based assessments, such as those adapted from the participatory MESMIS methodology [32,33]. This involves evaluating both biophysical data (e.g., soil sampling) and social data at the community garden scale through a process of participatory co-creation. Such a shared governance model fosters cross-sectoral collaboration and can leverage community science programs to decentralize periodic soil monitoring, empowering local gardener associations while breaking down administrative silos. Urban gardens can be governed as Urban Living Labs, a collaborative space where municipal experts, researchers, and citizens engage in joint environmental monitoring and co-design solutions [34]. These spaces can facilitate transparent communication between technical experts and the general public.

Second, the ES/EDS perspective fosters a more rational and inclusive dialogue among stakeholders. All too often, urban greening initiatives are promoted with a uniformly positive narrative that can obscure real-world conflicts and trade-offs. The FWS framework provides a common, transparent language that makes not only the benefits but also the potential risks and nuisances of urban gardens visible and debatable. This moves the conversation beyond green aesthetics, enabling gardeners, residents, and city planners to openly address conflicts over issues like water rights, pest management strategies, the risk of allergens, or even gentrification pressures associated with new green spaces [35]. By quantifying and qualifying both sides of the ledger, we encourage evidence-based negotiation and the co-design of solutions that reflect the shared goal of minimizing harms while securing benefits. This process enhances the legitimacy of urban greening policies and fosters a more resilient social fabric surrounding them [36].

Furthermore, this dual perspective is a powerful antidote to the fragmented, siloed governance that plagues most municipalities. Acknowledging that urban gardens co-produce a wide array of services and disservices reveals their deep entanglement with multiple domains of urban policy [37]. The FWS framework allows different city departments to understand the interconnected impact of a single garden, e.g., *public health* (nutrition vs. allergens), *urban hydrology* (infiltration vs. contaminated runoff), *waste management* (composting vs. green waste & odor), and planning and development (community building & aesthetic improvement vs land-use conflicts).

Finally, this approach is crucial for moving beyond a mindset of resource extraction and toward a culture of ecological stewardship. It reorients our ultimate goal from simply "*producing food*" to "*maintaining the health and functionality of the garden as a long-term urban asset*". Assessing the outcomes of different management practices on the net provision of ES over EDS provides a direct feedback loop for continuous learning and improvement. By making the costs of disservices clear, it justifies investments in knowledge, skills, and infrastructure (i.e., human and built capital). This perspective helps us value the garden not just for the harvest it provides, but for its ongoing capacity to function [29]. It aligns with the "One Health" concept, recognizing that the health of soil, plants, and people is deeply interwoven and indivisible. Ultimately, governing urban gardens through an FWS-ES/EDS lens is an act of foresight – commitment to managing these vital urban spaces not for a single season's yield, but for their enduring contribution to a resilient and livable city for generations to come.

5. Conclusions

As urban environments increasingly rely on cultivated nature-based solutions to build resilience, the frameworks we use to assess them must evolve. The prevailing WEF nexus, while valuable at macro scales, often overlooks the foundational role of soil in low-input urban gardens. By transitioning to an FWS nexus evaluated through the dual lens of ES and EDS, this perspective recenters soil not as a passive substrate, but as a dynamic capital asset and a living archive of past ecological and anthropogenic interactions.

Meaningful progress in sustainability science requires a critical revision of fundamental claims before attempting rigid operationalization. This approach makes explicit the vital trade-offs inherent in urban agriculture – balancing the synergies of biomass production against the severe disservices of legacy soil contamination. While transitioning this conceptual FWS nexus into municipal application presents inherent complexities, establishing a robust theoretical foundation is a necessary first step. Rather than prescribing rigid, universal indicators that risk marginalizing local socio-ecological nuances and community-driven practices, this framework provides the conceptual architecture needed to guide future policy. By embracing participatory, co-created assessment methodologies, urban planners and local communities can collaboratively translate this FWS perspective into context-specific practices, moving beyond simple resource extraction toward a culture of long-term ecological stewardship.

Author Contributions

P.T.K.: conceptualization, formal analysis, writing—original draft preparation, writing—reviewing and editing, visualization; B.B.: conceptualization, formal analysis, writing—original draft preparation, validation, supervision, project administration; L.J.-S.: conceptualization, formal analysis, writing—original draft preparation, supervision; H.L.T.T.: conceptualization, writing—original draft preparation, supervision; B.D.-G.: conceptualization, formal analysis, writing—original draft preparation, supervision. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

Use of AI and AI-Assisted Technologies

No AI tools were utilized for this paper.

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