Towards Resilient and Carbon-Neutral Philippine Cities: A Systematic Literature Review of Blue-Green Plumbing Infrastructure and Registered Master Plumbers' Role in Climate Resilience and Urban Sustainability

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ABSTRACT

Rapid urbanization, climate-related hazards, and increasing pressure on freshwater resources have intensified concerns regarding the sustainability of urban infrastructure systems in the Philippines. Many cities continue to experience recurring flooding, water supply challenges, inadequate wastewater management, aging utility infrastructure, and fragmented governance arrangements that complicate integrated planning and service delivery. These conditions highlight the need for innovative approaches that can simultaneously improve climate resilience and support low-carbon urban development. This study aimed to examine the potential of Blue-Green Plumbing Infrastructure (BGPI) as a sustainable urban water management strategy and assess its contribution to the development of resilient and carbon-neutral Philippine cities. A Systematic Literature Review (SLR) was conducted using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework. Relevant international and Philippine studies were analyzed to evaluate the technical, environmental, institutional, and professional dimensions of BGPI implementation. Particular attention was given to the role of Registered Master Plumbers (RMPs) in the planning, design, operation, maintenance, and regulatory compliance of sustainable water infrastructure systems. The findings demonstrate that BGPI offers multiple environmental and operational benefits. These include improved water conservation, reduced dependence on potable water supplies, lower energy requirements for water treatment and distribution, enhanced stormwater management, increased ecological value, and greater resilience to climate-related risks. The review also indicates that BGPI can support carbon-neutral development by improving water-use efficiency and reducing the energy intensity of urban water systems. However, its broader adoption remains constrained by institutional fragmentation, limited policy integration, financial barriers, insufficient technical standards, and capacity gaps among stakeholders. The study concludes that integrating BGPI into urban planning, building regulations, and water governance frameworks can significantly strengthen urban resilience and sustainability in the Philippines. Achieving wider implementation will require stronger regulatory support, enhanced professional capacity, and greater collaboration among government, industry, and academic institutions.

Keywords: Blue-Green Plumbing Infrastructure, Carbon Neutrality, Climate Resilience, Sustainable Cities, Urban Water Management, Registered Master Plumber

INTRODUCTION

Climate change has emerged as one of the most significant challenges confronting contemporary cities, requiring governments, industries, and communities to develop infrastructure systems that simultaneously reduce greenhouse gas (GHG) emissions and enhance resilience to climate-related hazards. Across the globe, cities are increasingly pursuing carbon-neutral development pathways to align with international commitments such as the Paris Agreement and the Sustainable Development Goals (SDGs). Urban areas play a critical role in this transition because they account for a substantial share of global energy consumption, resource use, and carbon emissions generated from buildings, transportation systems, water infrastructure, and other urban services. Consequently, the creation of resilient and low-carbon cities has become a central objective of sustainable urban development. Within this context, planners, engineers, policymakers, and infrastructure professionals are being challenged to develop integrated solutions that not only address environmental sustainability but also strengthen urban adaptation to the growing impacts of climate change.

The urgency of this transition is particularly evident in developing countries, where rapid urbanization often outpaces the capacity of existing infrastructure systems (Sun et al., 2020). In the Philippines, increasing population growth, expanding urban development, and climate variability have intensified pressures on water, sanitation, and drainage systems (Raza et al., 2019). Numerous urban centers continue to experience recurring flooding, water shortages, environmental degradation, and declining ecosystem services (Koop & Leeuwen, 2016). These challenges are compounded by aging infrastructure, inadequate wastewater treatment facilities, fragmented institutional responsibilities, and limited integration of climate considerations into infrastructure planning and governance (Molinos-Senante et al., 2024). Moreover, the absence of comprehensive city-level emissions inventories and localized monitoring systems creates difficulties in evaluating the effectiveness of climate mitigation and adaptation initiatives (Bai et al., 2023). As a result, the need for innovative infrastructure approaches that support both resilience and carbon neutrality has become increasingly important in the Philippine urban context.

Traditionally, urban water management has relied heavily on gray infrastructure systems, including centralized water supply networks, sewerage systems, concrete drainage channels, and engineered flood control structures (Chiu et al., 2021). While these approaches have provided essential public services, they often face substantial maintenance requirements and inadequate capacity to address increasingly complex environmental challenges (Bartos et al., 2017). Furthermore, gray infrastructure typically addresses individual problems in isolation, restricting opportunities to generate broader environmental and social benefits (Kabisch et al., 2017). Recognizing these limitations, researchers and practitioners have increasingly advocated for nature-based and integrated approaches that work with natural processes rather than against them (Hamel & Tan, 2021). These developments have contributed to the emergence of Blue-Green Infrastructure (BGI), which integrates water-sensitive urban design, ecological restoration, green spaces, and sustainable water management strategies to enhance environmental performance and urban resilience (Pochodyła et al., 2021).

Among these emerging approaches, decentralized blue-green water management represents a particularly promising but often overlooked component of sustainable urban development (Pille & Säumel, 2021). Decentralized blue-green water management extends the principles of blue-green infrastructure to building-scale and neighborhood-scale plumbing systems by integrating engineered water services with nature-based and decentralized water management technologies (Almaaitah et al., 2021). Examples include rainwater harvesting systems, greywater recycling systems, decentralized wastewater treatment facilities, constructed wetlands, green roofs, rain gardens, permeable landscapes, and smart water-monitoring technologies (Chen et al., 2024). Unlike conventional plumbing systems that primarily focus on delivering potable water and removing wastewater, decentralized blue-green water management promotes circular water management through conservation, reuse, resource recovery, and environmental enhancement (Larsen et al., 2016). By reducing potable water demand and improving local water management, these decentralized systems can contribute simultaneously to climate adaptation, water security, environmental protection, and greenhouse gas reduction (Larsen et al., 2016).

The relevance of BGPI is closely associated with the water-energy-climate nexus, which recognizes the interconnected relationship between water use, energy consumption, and carbon emissions. Substantial energy is required for water extraction, treatment, pumping, distribution, collection, and wastewater treatment. Consequently, strategies that reduce water demand or promote local reuse can also reduce the energy required to operate water systems, thereby decreasing associated greenhouse gas emissions. Rainwater harvesting systems, for example, reduce dependence on centralized water supplies, while greywater reuse systems allow treated wastewater to be reused for non-potable applications such as irrigation and toilet flushing. Similarly, constructed wetlands and nature-based treatment systems can improve water quality while requiring less energy than conventional treatment facilities. Through these mechanisms, BGPI transforms plumbing infrastructure from a passive utility service into an active contributor to climate mitigation and adaptation strategies.

In the Philippine setting, the need for integrated water management solutions is becoming increasingly urgent. Major metropolitan areas such as Metro Manila, Cebu, and Davao face growing challenges associated with flooding, water scarcity, groundwater depletion, land subsidence, and pollution of receiving water bodies (ADB, 2014). At the same time, urban growth continues to increase demand for reliable water and sanitation services. Reports from national and international organizations have consistently highlighted deficiencies in water infrastructure, including inadequate wastewater treatment coverage (Jegatheesan et al., 2022). In addition, wastewater management facilities in many developments continue to experience difficulties in maintaining compliance with environmental regulations (Lantaca, 2024), highlighting gaps in operational capacity, monitoring systems, and institutional support. These conditions underscore the limitations of conventional approaches and illustrate the need for more sustainable and resilient infrastructure alternatives capable of addressing multiple urban challenges simultaneously.

Despite growing international interest in blue-green infrastructure and nature-based solutions, the specific role of plumbing infrastructure within sustainable urban development remains insufficiently examined. Existing research has primarily focused on stormwater management, urban greening, flood mitigation, and ecosystem restoration, while comparatively little attention has been given to the contribution of plumbing systems in supporting climate-resilient and carbon-neutral cities. Within the Philippine context, there remains limited understanding of how rainwater harvesting, greywater reuse, decentralized wastewater management, and other plumbing-based interventions can contribute to broader climate and sustainability objectives. Furthermore, implementation efforts continue to face a range of technical, economic, institutional, and regulatory barriers. Fragmented governance structures, overlapping agency mandates, the absence of harmonized technical standards, and limited policy incentives have constrained the widespread adoption of blue-green infrastructure technologies despite their demonstrated benefits (Orale et al., 2025).

An additional but often underappreciated aspect of BGPI implementation is the role played by Registered Master Plumbers (RMPs). As professionals responsible for the design, installation, operation, maintenance, and regulatory compliance of water and sanitation systems—critical components of climate-resilient urban infrastructure—RMPs are well-positioned to facilitate the adoption of sustainable plumbing technologies. Their technical expertise enables the translation of blue-green concepts into functional infrastructure systems that support water conservation, resource efficiency, and environmental sustainability. Beyond their traditional responsibilities, RMPs increasingly serve as key actors in climate-responsive infrastructure planning and urban resilience initiatives. Understanding their role is therefore essential to identifying pathways through which BGPI can be effectively integrated into urban development strategies.

Given these circumstances, a comprehensive synthesis of existing knowledge is necessary to better understand the opportunities and challenges associated with BGPI implementation in Philippine cities. While international studies provide valuable insights into the technical and environmental benefits of integrated water management systems, there remains a significant knowledge gap regarding the applicability, effectiveness, and governance requirements of wastewater management systems within the local context (Corpuz, 2025)(Castro et al., 2026). A systematic review can help bridge this gap by identifying best practices, evaluating implementation barriers, assessing institutional readiness, and examining the role of professional stakeholders in facilitating adoption. Such knowledge is essential for policymakers, urban planners, engineers, and infrastructure professionals seeking to develop evidence-based approaches for sustainable urban transformation.

Therefore, this study conducts a systematic literature review to examine the contribution of Blue-Green Plumbing Infrastructure to resilient and carbon-neutral urban development in the Philippines. Specifically, the study investigates global best practices and technological innovations, evaluates the climate mitigation and adaptation benefits of BGPI, identifies implementation challenges and opportunities, assesses the strategic role of Registered Master Plumbers, and develops recommendations for integrating BGPI into urban planning, governance frameworks, and infrastructure policies. Ultimately, the study seeks to contribute to the growing body of knowledge on sustainable urban water systems and provide a practical foundation for advancing resilient and carbon-neutral Philippine cities.

METHODOLOGY

Research Design

This study employed a Systematic Literature Review (SLR) approach to synthesize and critically evaluate existing knowledge on Blue-Green Plumbing Infrastructure (BGPI), climate resilience, carbon-neutral urban development, and the role of Registered Master Plumbers (RMPs) in sustainable urban water management. A systematic review was selected because it provides a transparent, rigorous, and replicable method for identifying, screening, assessing, and synthesizing available evidence from multiple sources. Unlike traditional narrative reviews, systematic reviews minimize selection bias through structured search procedures, predefined inclusion and exclusion criteria, and documented screening protocols. The approach is particularly suitable for emerging interdisciplinary fields such as BGPI, where relevant studies are distributed across engineering, environmental planning, sustainability science, water resources management, urban studies, and climate adaptation literature. The methodology adopted in this study was designed to identify current knowledge, evaluate research trends, determine implementation barriers and opportunities, and generate evidence-based recommendations relevant to the Philippine context.

Review Framework

The review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework, which is widely recognized as a best-practice guideline for reporting systematic reviews (Page et al., 2021). The PRISMA framework provides a structured process for documenting the identification, screening, eligibility assessment, and inclusion of studies (Page et al., 2021). Applying PRISMA enhanced the transparency and reproducibility of the review while allowing readers to understand how studies were selected and evaluated. The framework facilitated a systematic examination of literature related to blue-green infrastructure, sustainable plumbing systems, water-sensitive urban design, climate resilience, urban sustainability, and carbon-neutral development. The review process consisted of four primary stages: identification of relevant publications, screening of retrieved records, assessment of eligibility, and inclusion of studies meeting the established selection criteria. This structured approach ensured consistency and methodological rigor throughout the review process.

Search Strategy

A comprehensive literature search was conducted to identify peer-reviewed journal articles, conference papers, technical reports, and relevant institutional publications concerning Blue-Green Plumbing Infrastructure and related fields. Multiple academic databases were consulted to maximize coverage and reduce publication bias. These databases included Scopus, Web of Science, ScienceDirect, SpringerLink, Google Scholar, Wiley Online Library, Taylor & Francis Online, and MDPI Sustainability. Additional sources were identified through backward and forward citation tracking and through the review of publications from international organizations such as the United Nations Environment Programme (UNEP), the Intergovernmental Panel on Climate Change (IPCC), the World Bank, the Asian Development Bank (ADB), and other institutions involved in urban sustainability and climate resilience research.

Search strings were developed using combinations of keywords related to the study objectives. Boolean operators such as “AND,” “OR,” and “NOT” were employed to improve search accuracy and retrieve relevant publications. Examples of search terms included “Blue-Green Infrastructure” AND “Climate Resilience,” “Blue-Green Plumbing Infrastructure,” “Rainwater Harvesting” AND “Urban Sustainability,” “Greywater Reuse” AND “Carbon Reduction,” “Nature-Based Solutions” AND “Water Management,” “Sustainable Plumbing Systems,” “Carbon-Neutral Cities,” “Water-Energy-Climate Nexus,” “Registered Master Plumbers” AND “Sustainability,” and “Philippines” AND “Urban Water Management.” The search focused primarily on literature published between 2015 and 2026 to capture current developments in climate adaptation, sustainable infrastructure, and urban water management. Seminal studies published before 2015 were also considered when they provided foundational concepts relevant to blue-green infrastructure and sustainable urban planning.

Inclusion and Exclusion Criteria

To ensure relevance and quality, predefined inclusion and exclusion criteria were established before the screening process. Studies were included if they: (1) were published in peer-reviewed journals or reputable conference proceedings; (2) addressed blue-green infrastructure, sustainable water management, decentralized water systems, climate resilience, carbon-neutral urban development, or related themes; (3) contained empirical findings, case studies, technical analyses, policy evaluations, or systematic reviews; and (4) were available in English. Publications focusing on rainwater harvesting, greywater recycling, green roofs, constructed wetlands, urban stormwater management, water reuse systems, smart water monitoring technologies, and climate-adaptive infrastructure were also considered relevant to the scope of the review.

Studies were excluded if they: (1) lacked sufficient methodological detail; (2) were opinion articles, editorials, newsletters, or non-scholarly publications; (3) focused exclusively on unrelated infrastructure sectors with no connection to water systems or urban resilience; (4) were duplicate records identified during database searches; or (5) were inaccessible in full-text format. Excluding irrelevant and low-quality sources improved the reliability and validity of the synthesized findings.

Study Screening and Selection

The study selection process followed the PRISMA protocol. Initially, all records retrieved from the database searches were exported and compiled into a reference management system. Duplicate records were identified and removed prior to screening. The titles and abstracts of the remaining publications were then reviewed to determine their relevance to the research objectives. Studies that clearly failed to meet the inclusion criteria were excluded at this stage.

The full texts of potentially relevant studies were subsequently retrieved and evaluated in greater detail. During this eligibility assessment stage, publications were reviewed against the predefined inclusion and exclusion criteria. Particular attention was given to the relevance of the studies to BGPI concepts, climate mitigation and adaptation outcomes, urban sustainability, regulatory considerations, and professional practice implications. The final set of selected studies formed the evidence base used for data extraction and thematic synthesis. This structured screening procedure ensured that only high-quality and directly relevant literature informed the conclusions of the review.

Data Extraction and Analysis

Data from the selected studies were extracted using a standardized review matrix developed specifically for this research. The matrix captured key information including the publication year, study location, research objectives, methodologies employed, types of BGPI interventions examined, environmental outcomes, climate resilience benefits, carbon reduction mechanisms, implementation barriers, governance considerations, and implications for professional practice.

Following data extraction, a thematic synthesis approach was employed to analyze and integrate findings across studies. Similar concepts, themes, and patterns were grouped into broader analytical categories. The analysis focused on identifying recurring themes related to: (1) BGPI technologies and practices; (2) climate adaptation benefits; (3) carbon mitigation mechanisms; (4) water conservation and resource efficiency outcomes; (5) institutional and regulatory challenges; (6) economic and technical barriers; and (7) the role of Registered Master Plumbers in sustainable urban development. This approach enabled the integration of evidence from diverse disciplinary perspectives and facilitated the development of a comprehensive understanding of BGPI within the context of resilient and carbon-neutral cities.

Reliability and Quality Assurance

To enhance the credibility of the review, multiple quality assurance measures were incorporated throughout the research process. Selected studies were evaluated based on relevance, methodological rigor, clarity of findings, and contribution to the research objectives. Preference was given to peer-reviewed publications and widely cited studies from reputable journals and institutions. Triangulation was achieved by comparing findings across different geographic regions, disciplines, and research methodologies. Furthermore, evidence from international case studies was critically examined in relation to Philippine urban conditions to assess applicability and contextual relevance.

Through the application of a systematic review methodology guided by the PRISMA framework, this study provides a comprehensive and evidence-based assessment of Blue-Green Plumbing Infrastructure as a pathway toward resilient and carbon-neutral Philippine cities. The resulting synthesis offers a foundation for understanding current knowledge, identifying research gaps, and informing future policy, planning, and professional practice initiatives related to sustainable urban water management.

RESULTS

The systematic review revealed that Blue-Green Plumbing Infrastructure (BGPI) is an emerging but increasingly important component of resilient and carbon-neutral urban development. Across the reviewed literature, BGPI is generally positioned at the intersection of sustainable water management, climate adaptation, carbon reduction, urban resilience, and sustainable infrastructure practice. Unlike conventional plumbing systems, which are primarily designed to supply potable water and convey wastewater away from buildings, BGPI emphasizes more circular and integrated water systems. These systems include rainwater harvesting, greywater reuse, decentralized wastewater treatment, constructed wetlands, green roofs, rain gardens, permeable surfaces, and smart monitoring technologies. The reviewed studies consistently suggest that these interventions can reduce water demand, lower energy use related to water treatment and pumping, improve stormwater management, and strengthen the adaptive capacity of cities facing climate-related hazards. This finding is consistent with the conceptual direction of the study, which identifies BGPI as a practical pathway for linking building-level plumbing systems with broader goals of climate resilience and carbon-neutral urban development.

The review also showed that the relevance of BGPI is particularly strong in countries such as the Philippines, where urban areas face simultaneous pressures from rapid urbanization, flooding, water scarcity, wastewater pollution, infrastructure limitations, and fragmented governance. The review identifies Manila as experiencing wastewater management challenges (Jegatheesan et al., 2022) and Cebu as experiencing environmental pressures caused by rapid urbanization, intense rainfall, and inadequate drainage (Demegillo et al., 2025). These pressures highlight the need for infrastructure solutions that can provide multiple benefits rather than address one problem at a time. In this context, BGPI appears not merely as a technical innovation but as a planning approach that can support water security, disaster risk reduction, environmental compliance, and low-carbon development (Orale et al., 2025).

Global trends in Blue-Green Plumbing Infrastructure

A major finding of the review is the increasing global recognition of blue-green and nature-based infrastructure as an alternative or complement to conventional gray infrastructure (Palmer et al., 2015). The literature indicates that cities are moving away from purely centralized and hard-engineered systems toward more distributed, flexible, and ecologically integrated solutions (Andersson et al., 2022). This shift is driven by the need to address the combined effects of climate change, urban flooding, and rising infrastructure costs (Browder et al., 2019). Blue-green systems are valued because they can perform several functions at the same time, including collecting rainwater, reducing runoff, treating stormwater, cooling urban environments, improving biodiversity, and enhancing public spaces (Li et al., 2023; Nguyen et al., 2022). Within this broader movement, BGPI gives specific attention to the building and plumbing scale, where many water-use decisions and infrastructure interventions are implemented.

The reviewed literature identifies rainwater harvesting as a recognized BGPI-related practice (Nguyen et al., 2022). Rainwater harvesting systems capture and store rainfall from rooftops and other catchment surfaces for later use in non-potable applications such as outdoor uses (Quon & Jiang, 2023). From a climate resilience perspective, these systems help reduce dependence on centralized water supply networks, especially during periods of water shortage. From a stormwater management perspective, they can reduce the volume of runoff entering drainage systems during heavy rainfall events. From a carbon-related perspective, lower demand for centrally treated and pumped water may reduce associated energy consumption and emissions. In the

Philippine context, where intense rainfall and urban flooding occur alongside seasonal water stress, rainwater harvesting represents a practical and highly relevant intervention.

Greywater reuse was also identified as a significant BGPI strategy (Quon & Jiang, 2023). Greywater systems typically collect wastewater from showers and hand washing for non-potable reuse, though classification can vary depending on the inclusion of kitchen or laundry sources. The reviewed literature suggests that greywater reuse can reduce potable water consumption, decrease wastewater discharge, and support more efficient resource circulation within buildings or developments. This is particularly relevant for high-rise residential, institutional, commercial, and mixed-use buildings, where daily water demand is high. In urban areas with limited sewerage coverage or wastewater treatment capacity, greywater reuse also offers a decentralized option for reducing pressure on conventional treatment facilities. However, the review also indicates that successful greywater reuse depends on proper design, treatment, monitoring, maintenance, and clear regulatory standards to ensure health and environmental safety.

Nature-based treatment systems, including constructed wetlands and other green infrastructure, were likewise found to be important components of BGPI (Ruangpan et al., 2020). These systems use vegetation, soils, microbial processes, and natural filtration mechanisms to manage water quality and quantity. Constructed wetlands can support decentralized wastewater treatment, while rain gardens and bioswales can intercept runoff and improve infiltration. Green roofs can capture rainfall, reduce roof surface temperature, and contribute to urban cooling. These approaches are particularly valuable because they create co-benefits that conventional infrastructure often does not provide. Aside from their water management function, they may contribute to biodiversity improvement, urban heat reduction, aesthetic enhancement, and ecological restoration. For cities exposed to flooding and heat stress, these co-benefits strengthen the case for integrating BGPI into urban planning and building design.

Table 1. Common BGPI technologies and observed contributions

BGPI technology	**Main function**	**Climate resilience contribution**	**Carbon-neutral development contribution**
Rainwater harvesting (Nguyen et al., 2022)	Captures and stores rainfall for reuse	Reduces pressure on drainage and water supply systems	Lowers demand for centrally treated and pumped water
Greywater reuse (Walle et al., 2023)	Treats and reuses non-potable wastewater	Improves water security during periods of scarcity	Reduces potable water demand and related energy use
Constructed wetlands (Stefanakis, 2019)	Provides decentralized wastewater treatment	Improves water quality and supports local adaptation	Offers lower-energy treatment potential compared with conventional systems
Green roofs (Siehr et al., 2022)	Retains rainfall and reduces heat absorption	Supports stormwater management and urban cooling	May reduce building cooling demand
Rain gardens and bioswales (Sharma & Malaviya, 2021)	Filters and infiltrates stormwater	Reduces runoff and localized flooding	Supports ecosystem-based urban sustainability
Smart water monitoring (Pradyumna & Hegde, 2024)	Tracks water use, leakage, and system performance	Improves operational reliability and early detection	Enhances efficiency and resource optimization

Carbon reduction mechanisms of BGPI

The review indicates that BGPI contributes to carbon-neutral urban development primarily through indirect but important carbon-reduction pathways. Water conservation through rainwater harvesting, greywater reuse, efficient fixtures, and decentralized reuse offers significant potential for carbon reduction. By reducing potable water demand, these practices decrease the energy required to abstract, treat, pump, and distribute water, thereby lowering overall energy consumption and associated greenhouse gas emissions. This relationship reflects the water-energy-climate nexus discussed in the literature, where water use, energy demand, and greenhouse gas emissions are closely connected.

Another mechanism is the reduction of wastewater volume requiring centralized treatment. Where greywater reuse or decentralized treatment systems are properly designed and maintained, part of the wastewater stream can be managed locally. This may reduce hydraulic loading on sewer networks and treatment plants, especially in dense urban areas. Constructed wetlands and other nature-based treatment systems may also provide lower-energy alternatives for selected wastewater treatment applications (Ogden, 2013). While the magnitude of carbon reduction depends on local system design, treatment efficiency, energy source, and operational practices, the literature supports the general finding that integrated water reuse systems can contribute to resource efficiency and emission reduction.

BGPI may also contribute to carbon neutrality objectives through urban cooling and reduced energy demand. Green roofs, vegetated surfaces, and blue-green landscapes can help moderate urban heat by providing shading, evapotranspiration, and reductions in surface temperature. In buildings and urban districts, reduced heat absorption may lower cooling requirements, particularly in tropical climates. Although the reviewed literature varies in terms of quantifying these benefits, the overall finding is that BGPI can support climate mitigation not only through water savings but also through energy-related co-benefits linked to urban thermal regulation. This is especially relevant for Philippine cities, where hot and humid conditions increase the importance of passive cooling and climate-sensitive design.

Climate adaptation and resilience benefits

The review found that the strongest and most immediate contribution of BGPI is related to climate adaptation and urban resilience. In the Philippine context, flooding remains one of the most recurring urban hazards, particularly in heavily developed areas with limited drainage capacity and extensive impervious surfaces (Tan, 2021). BGPI technologies such as rainwater harvesting systems, green roofs, rain gardens, bioswales, and permeable landscapes can reduce runoff volume, delay peak discharge, and improve localized water retention (Boongaling et al., 2026). Although these systems cannot replace all major flood control infrastructure, they can complement drainage networks and reduce pressure on existing systems when applied across buildings, subdivisions, campuses, and districts.

Water security is another major resilience benefit. The review indicates that Philippine urban areas experience increasing pressure on water resources due to population growth, seasonal variability, groundwater extraction, and inefficient management practices (ADB, 2014; Siringan, 2012). BGPI can help improve water security by diversifying water sources at the building and community level (Mason et al., 2017). Rainwater harvesting and greywater reuse can supply non-potable water for applications that do not require treated drinking water. This reduces dependence on limited potable supplies and can improve continuity of use during shortages or service interruptions. In highly urbanized areas, these decentralized systems may become important supporting measures for climate adaptation planning.

The review also points to environmental resilience benefits. Constructed wetlands, rain gardens, and other vegetated systems can improve water quality before runoff or treated wastewater reaches rivers, lakes, or coastal ecosystems (Castro et al., 2026). This is important because untreated or poorly treated wastewater contributes to environmental degradation and public health concerns. By integrating treatment, retention, and ecological functions, BGPI can help reduce pollution loads and support healthier urban ecosystems. These benefits demonstrate that BGPI operates beyond the narrow function of plumbing distribution and drainage; it supports a broader environmental management role within cities.

Role of Registered Master Plumbers

A key finding of the review is that Registered Master Plumbers occupy a strategic position in the implementation of BGPI. The study's source document emphasizes that successful implementation of blue-green technologies requires specialized professional expertise in system design, installation, operation, maintenance, and regulatory compliance. Registered Master Plumbers are directly involved in many of these functions, making them important actors in translating sustainability concepts into practical building-level systems.

The literature suggests that RMPs can contribute to BGPI implementation in four major ways. First, they can support design integration by ensuring that rainwater harvesting, greywater reuse, wastewater treatment, and water-efficiency measures are properly incorporated into plumbing layouts and building systems. Second, they can improve installation quality by applying technical standards and ensuring that systems are safe, functional, and maintainable. Third, they can support operation and maintenance, which is critical because BGPI systems require regular inspection, cleaning, monitoring, and performance checks. Fourth, they can assist in compliance by helping developers, building owners, and local governments align plumbing systems with applicable environmental, sanitation, and building regulations (Persily et al., 2020).

This finding highlights the need to expand the roles of plumbing practitioners and engineers toward climate-responsive and sustainability-oriented practice, necessitating additional competencies in green building systems, water reuse, and environmental compliance (Berro, 2025).

Barriers to implementation

The review identified several barriers that limit the wider adoption of BGPI in Philippine cities. The first barrier is technical capacity. Although rainwater harvesting, greywater reuse, and nature-based treatment systems are already known internationally, their successful application requires site-specific design, proper sizing, treatment controls, monitoring, maintenance, and user awareness. Poorly designed or poorly maintained systems may produce limited benefits or create health and operational risks; therefore, technical guidance and professional training are necessary to support effective implementation.

The second barrier is economic feasibility. Many BGPI systems require higher initial capital investment compared with conventional plumbing or drainage systems. Although long-term benefits may include water savings, reduced energy use, improved resilience, and environmental gains, these benefits are not always immediately visible to developers, building owners, or decision-makers. The lack of clear life-cycle cost assessment and incentive mechanisms may reduce willingness to adopt BGPI technologies. This finding supports the need for financial tools, green building incentives, and evidence-based cost-benefit analysis to demonstrate long-term value (Researcher & Thakran, 2021).

The third barrier is institutional fragmentation, as the Philippine water and infrastructure sectors are characterized by fragmented governance arrangements, overlapping institutional mandates, and limited coordination (Enriquez et al., 2021). Responsibilities for water supply, sanitation, building regulation, environmental compliance, land-use planning, and climate action are distributed across different institutions. This can create uncertainty about who should regulate, approve, monitor, or promote BGPI systems. Without coordinated policy frameworks, implementation may remain project-based rather than mainstreamed into urban development practice.

The fourth barrier is regulatory limitations. Regulatory frameworks often struggle to provide comprehensive guidance for decentralized water reuse systems, smart water technologies, and nature-based plumbing solutions. The review indicates that some policy proposals have begun to recognize the importance of Low Impact Development and sustainable urban water management, but many remain at the proposal or early integration stage. This suggests that the policy environment is evolving, but further regulatory harmonization is needed to support widespread BGPI adoption.

Readiness of Philippine cities

The review suggests that readiness for BGPI implementation varies across Philippine cities. Highly urbanized areas such as Metro Manila, Cebu, and Davao face strong demand for BGPI because of flooding, water demand, wastewater management issues, and rapid development. However, these same cities may also face the greatest implementation challenges due to dense land use, aging infrastructure, institutional complexity, and

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high development pressure. This means that while the need for BGPI is high, implementation will require strong policy support, technical standards, professional capacity, and inter-agency coordination.

Emerging urban centers provide opportunities for earlier integration of BGPI into planning and development controls, as new developments offer more flexibility than retrofitting congested metropolitan areas (Ahmed et al., 2019). However, readiness will depend on local government capacity, availability of technical expertise, financing mechanisms, and alignment with national building and environmental regulations (Koohestani et al., 2025). The review therefore suggests that BGPI should not be treated as a single technology package but as a scalable framework that can be adapted to different urban contexts (Kelkar et al., 2025).

Table 2. Summary of key results from the systematic review

Thematic area	Main finding	Implication for Philippine cities
BGPI technologies	Rainwater harvesting, greywater reuse, constructed wetlands, green roofs, and rain gardens are the most relevant systems (Castro et al., 2026)	These can be integrated into buildings, subdivisions, campuses, and urban districts
Carbon reduction	BGPI reduces water and energy demand through conservation and reuse	Supports carbon-neutral development through indirect emission reduction pathways
Climate adaptation	BGPI improves flood management, water security, and environmental quality (Castro et al., 2026)	Strengthens urban resilience against rainfall extremes and water stress
Professional practice	RMPs are essential in design, installation, operation, maintenance, and compliance	Professional training and expanded green competencies are needed
Governance	Fragmented mandates and limited standards constrain implementation (Castro et al., 2026)	Policy harmonization and inter-agency coordination are necessary
Regulation	Current frameworks remain more oriented toward conventional gray infrastructure	Building and plumbing regulations should integrate BGPI provisions
Urban readiness	Large cities show strong need, while emerging cities offer planning opportunities	BGPI implementation should be context-specific and phased

Synthesis of findings

Overall, the results show that BGPI can serve as a multidimensional strategy for advancing resilient and carbon-neutral Philippine cities. Its value lies not in any single technology but in the integration of water conservation, wastewater reuse, stormwater control, ecosystem enhancement, energy efficiency, and professional practice. The findings suggest that BGPI can help address several urban challenges at once, including flooding, water scarcity, wastewater pollution, infrastructure inefficiency, and climate-related vulnerability. However, the review also shows that technical innovation alone is insufficient. Successful implementation requires supportive policy, harmonized regulations, professional capacity, institutional coordination, and long-term investment planning.

The results further confirm that plumbing infrastructure should be recognized as a strategic part of climate action. In many urban sustainability discussions, plumbing systems are treated mainly as building utilities. However, the findings of this review show that plumbing systems influence water demand, energy use, wastewater generation, environmental compliance, and climate resilience (Bilal et al., 2026). For this reason, Registered Master Plumbers should be included more actively in conversations on green buildings, sustainable cities, climate adaptation, and carbon-neutral development. By positioning RMPs as technical implementers and sustainability partners, BGPI can become more practical, scalable, and locally grounded within the Philippine urban context.

DISCUSSION

Contribution of Blue-Green Plumbing Infrastructure to Carbon-Neutral Urban Development

The findings of this review demonstrate that Blue-Green Plumbing Infrastructure (BGPI) has significant potential to contribute to carbon-neutral urban development by addressing the interconnected challenges of water management, energy consumption, greenhouse gas emissions, and climate resilience. Although plumbing systems have traditionally been viewed as utility infrastructure primarily concerned with water delivery and wastewater disposal, the findings suggest that they can also serve as important climate-action mechanisms when integrated with blue-green and nature-based approaches. Rainwater harvesting, greywater reuse, decentralized wastewater treatment systems, and smart water-management technologies contribute to reducing potable water demand and associated energy requirements for water extraction, treatment, pumping, and distribution (Engström et al., 2017). In this way, BGPI supports climate mitigation through indirect but measurable carbon-reduction pathways. These findings reinforce the increasing recognition of the water-energy-climate nexus, which emphasizes that more sustainable water management practices can simultaneously improve resource efficiency and reduce greenhouse gas emissions.

The findings further indicate that BGPI aligns closely with international sustainability agendas and carbon-neutral city initiatives. Globally, cities are increasingly adopting integrated approaches that combine engineered infrastructure with ecological systems to achieve environmental, social, and economic benefits. Unlike conventional gray infrastructure, which often addresses individual problems through centralized engineering solutions, BGPI promotes multifunctionality by generating multiple benefits from a single intervention. A rainwater harvesting system, for example, can reduce water demand, lower stormwater runoff, decrease energy consumption, and contribute to climate adaptation (Steffen et al., 2013). Similarly, green roofs and constructed wetlands can improve water quality, enhance biodiversity, reduce urban heat island effects, and support carbon reduction objectives (Cascone et al., 2018; Mihalakakou et al., 2023). These multifunctional characteristics suggest that BGPI can play an important role in helping cities transition toward more sustainable and low-carbon development pathways.

In the Philippine context, this contribution is particularly relevant because national climate commitments increasingly emphasize both mitigation and adaptation strategies (Roldan, 2022). While most discussions regarding carbon neutrality focus on energy systems, transportation, and land-use planning (Khaffaf et al., 2024), the results of this review suggest that urban water infrastructure represents an underrecognized but important opportunity for climate action. Through improved water efficiency, resource recovery, and decentralized management approaches, BGPI can help cities achieve emissions reductions while simultaneously strengthening resilience against climate-related hazards. Therefore, the integration of BGPI within city-level development plans may offer a practical means of advancing carbon-neutral objectives while addressing persistent infrastructure challenges.

Integration with Climate Resilience Frameworks

A second major finding emerging from this review is the strong alignment between BGPI and climate resilience objectives. The results indicate that climate resilience benefits are often more immediate and visible than carbon reduction outcomes, particularly in highly urbanized environments vulnerable to flooding, water scarcity, and environmental degradation. Across the reviewed literature, blue-green systems consistently demonstrated the capacity to improve stormwater management, increase local water availability, support ecosystem health, and reduce exposure to climate-related risks. These functions align closely with contemporary resilience frameworks that emphasize adaptability, redundancy, flexibility, and ecosystem-based approaches to risk reduction.

Flooding represents one of the most significant climate-related challenges facing Philippine cities (WorldBank, 2022). Rapid urbanization has replaced permeable surfaces with roads, buildings, and pavements, increasing runoff volumes and reducing infiltration (Öztürk et al., 2024). Traditional drainage infrastructure often struggles to accommodate increasingly intense rainfall events associated with climate change (Zevenbergen et al., 2018). BGPI offers an alternative approach by encouraging water retention, infiltration, and decentralized management through systems such as rain gardens, bioswales, constructed wetlands, green roofs, and rainwater harvesting technologies. Rather than relying solely on the rapid conveyance of stormwater, these systems seek to slow, store, and utilize water more effectively. Consequently, BGPI supports a transition from reactive flood management toward more adaptive and resilient urban water strategies.

The review also highlights the importance of BGPI in improving urban water security. Philippine cities experience competing pressures from water depletion, increasing demand, and institutional challenges (Corong et al., 2012). The adoption of Blue-Green Infrastructure systems, which can supplement water supplies, enhances resilience against water shortages and supply disruptions (Nguyen et al., 2022). These decentralized approaches diversify water sources and reduce dependence on centralized infrastructure systems, thereby increasing the capacity of urban communities to respond to environmental uncertainties. Such findings support international research suggesting that decentralized water systems represent an important adaptation strategy in water-stressed and climate-vulnerable regions.

In addition, BGPI contributes to broader ecological resilience. Constructed wetlands, vegetated treatment systems, and green urban landscapes improve water quality, support biodiversity, restore ecological functions, and enhance environmental conditions within cities (Stefanakis, 2019). These ecosystem services strengthen urban resilience by improving the capacity of natural systems to absorb shocks and recover from disturbances. Consequently, BGPI should not be viewed solely as water infrastructure but rather as a component of integrated climate resilience planning.

Implications for Urban Infrastructure Planning

The findings suggest that BGPI requires a significant shift in how urban infrastructure is planned, designed, and managed. Conventional infrastructure planning typically treats water supply, drainage, wastewater treatment, and environmental management as separate systems governed by different institutions. However, the results of this study indicate that sustainable and resilient urban development depends increasingly on integrating these functions into holistic and interconnected infrastructure frameworks. BGPI reflects this integration by linking water efficiency, stormwater management, environmental protection, resource recovery, and climate adaptation within a single planning approach.

For Philippine cities, this implies that water-sensitive urban planning principles should be incorporated more comprehensively into land-use planning, building design, infrastructure development, and environmental management programs. New urban development offers opportunities for integrating rainwater harvesting systems, greywater recycling facilities, green roofs, permeable landscapes, and decentralized wastewater treatment technologies from the earliest stages of project design. In contrast, highly urbanized areas may benefit from retrofitting existing infrastructure through targeted blue-green interventions that improve resilience while optimizing resource efficiency. The review therefore suggests that BGPI should be considered throughout the entire urban development lifecycle rather than as a supplementary environmental measure.

The results further indicate that planning decisions should recognize the long-term value of multifunctional infrastructure. Although some BGPI interventions may involve higher initial capital costs, they can generate multiple environmental, operational, and resilience-related benefits over time (Hallegatte et al., 2019). These findings support a life-cycle planning perspective that evaluates infrastructure investments based on cumulative economic, social, and environmental performance rather than short-term construction costs alone. Such an approach is particularly important for rapidly growing cities seeking sustainable alternatives to conventional gray infrastructure expansion.

Role of Registered Master Plumbers in Climate Governance and Sustainable Development

One of the most important findings of this review is the emerging strategic role of Registered Master Plumbers (RMPs) in climate-responsive infrastructure development. Existing literature frequently examines climate adaptation and sustainable infrastructure from the perspectives of planners, engineers, environmental managers, and policymakers. However, comparatively little attention has been given to the role of plumbing professionals despite their direct involvement in water-system design, installation, operation, maintenance, and regulatory compliance (Hamilton, 2026). The findings of this review suggest that RMPs represent a critical professional group capable of translating sustainability objectives into practical infrastructure solutions.

Traditional plumbing practice has primarily focused on ensuring the safe and reliable provision of water and sanitation services. However, the growing adoption of BGPI expands the professional responsibilities of RMPs beyond conventional functions. Effective implementation of rainwater harvesting systems, greywater reuse technologies, decentralized wastewater treatment facilities, and smart water-monitoring systems requires specialized technical knowledge and ongoing operational oversight (Green, 2010; Khajvand et al., 2022). Consequently, RMPs increasingly occupy a central position in achieving water-efficiency goals, promoting resource conservation, and supporting climate adaptation strategies. Their expertise allows them to serve not only as technical practitioners but also as sustainability advocates and climate-action partners.

These findings have important implications for professional development and education. The successful scaling of BGPI in the Philippines will likely require strengthened institutional coordination and harmonized policies to advance green plumbing technologies, water reuse systems, nature-based treatment approaches, and climate-resilient infrastructure design (Castro et al., 2026),(Orale et al., 2025).

Policy and Regulatory Implications

The review highlights that technical feasibility alone is insufficient to ensure widespread adoption of BGPI. Despite the demonstrated environmental and climate-related benefits of blue-green approaches, implementation remains constrained by institutional fragmentation, regulatory limitations, and governance challenges (Valerio, 2024). The findings indicate that water supply, sanitation, environmental protection, land-use planning, and building regulation responsibilities are distributed across multiple agencies, often resulting in overlapping mandates and coordination difficulties. These institutional arrangements can create barriers to innovation and slow the adoption of integrated infrastructure solutions.

Current regulatory frameworks also appear to remain heavily oriented toward traditional gray infrastructure systems (Seidu et al., 2025). Existing standards often provide limited guidance regarding nature-based treatment technologies and other alternatives to traditional infrastructure (Saarinen et al., 2025). Consequently, designers, developers, regulators, and local governments frequently lack the clear policy direction necessary to support implementation (Saarinen et al., 2025). This finding suggests that regulatory modernization may be one of the most important factors influencing future BGPI adoption. Updating technical standards, building regulations, plumbing codes, and environmental policies to accommodate sustainable water-management practices would help create an enabling environment for innovation.

The review further suggests that stronger integration between climate policy and infrastructure planning is needed. Rather than treating water management, environmental protection, and climate action as separate policy domains, BGPI demonstrates the benefits of coordinated and interdisciplinary approaches. National agencies, local government units, professional organizations, academic institutions, and the private sector all have important roles in facilitating this transition. Encouraging collaboration among these stakeholders may help overcome implementation barriers and support mainstream adoption of blue-green practices.

Synthesis of Findings

Overall, the discussion demonstrates that Blue-Green Plumbing Infrastructure represents far more than a collection of individual technologies. Rather, it constitutes an integrated framework capable of advancing climate mitigation, climate adaptation, water security, environmental sustainability, and urban resilience simultaneously. The findings reveal that BGPI can address several pressing urban challenges faced by Philippine cities while supporting broader carbon-neutral development objectives. However, successful implementation will depend not only on technical solutions but also on institutional reforms, professional capacity development, regulatory modernization, and cross-sectoral collaboration.

Most importantly, the results suggest that plumbing infrastructure should be recognized as an active contributor to sustainable urban transformation rather than merely a supporting utility service. By integrating water conservation, reuse, ecosystem services, and climate-responsive design into urban development strategies, BGPI offers a practical pathway toward resilient and carbon-neutral Philippine cities. The challenge now lies in translating this potential into policy, practice, and professional action capable of supporting long-term sustainability outcomes.

Proposed Blue-Green Plumbing Infrastructure Framework for Resilient and Carbon-Neutral Philippine Cities

Conceptual Foundation of the Framework

The findings of this systematic literature review demonstrate that achieving resilient and carbon-neutral urban development requires a more integrated approach to water infrastructure planning and management. While existing urban sustainability initiatives frequently emphasize renewable energy, transportation systems, and green buildings, the review revealed that building-level plumbing infrastructure represents a significant but underutilized opportunity for climate mitigation, climate adaptation, and resource efficiency. The proposed Blue-Green Plumbing Infrastructure (BGPI) Framework is therefore developed to address this gap by integrating technical, environmental, institutional, and professional dimensions into a single implementation model. The framework recognizes that sustainable urban water systems cannot be achieved solely through technological innovation or policy reform. Instead, successful implementation requires coordinated interaction among infrastructure systems, governance institutions, environmental objectives, and professional stakeholders.

The framework is designed particularly for the Philippine context, where cities face persistent challenges associated with flooding, water scarcity, wastewater management deficiencies, fragmented governance, and increasing climate risks (Castro et al., 2026; Nunn et al., 2021). It seeks to provide a practical roadmap for incorporating blue-green infrastructure principles into plumbing systems while supporting broader goals of climate resilience, carbon reduction, and sustainable urban development. By positioning plumbing infrastructure as an active component of climate action rather than a passive utility service, the framework expands the role of water systems in achieving low-carbon and resilient cities.

The proposed BGPI Framework was developed from the major themes that emerged from the systematic literature review. These themes include decentralized water technologies, climate adaptation benefits, carbon-reduction mechanisms, governance barriers, regulatory limitations, and the professional role of Registered Master Plumbers. By organizing these themes into technical, environmental, institutional, and professional dimensions, the framework provides a structured model for translating the findings of the review into a practical implementation pathway for Philippine cities.

Technical Dimension

The technical dimension represents the physical and operational components of the framework. It focuses on the integration of decentralized, resource-efficient, and nature-based water management technologies within buildings, communities, and urban districts. Literature identifies technologies such as rainwater harvesting, greywater reuse, decentralized wastewater treatment, constructed wetlands, green roofs, and other nature-based solutions as relevant interventions for achieving sustainability and resilience objectives (Namratha & Gaonkar, 2026; Oral et al., 2020).

Rainwater harvesting systems function as supplementary water sources that reduce dependence on centralized water supply networks while simultaneously mitigating stormwater runoff , and greywater reuse systems support circular water management for non-potable applications. Constructed wetlands provide decentralized wastewater management while enhancing environmental quality, while smart water monitoring technologies enable real-time monitoring, leak detection, and operational optimization. Together, these technologies create an integrated water management system capable of improving efficiency, reliability, and resilience while reducing environmental impacts.

The framework emphasizes that these technologies should not be implemented as isolated infrastructure components. Rather, they should function as interconnected systems capable of maximizing water conservation, energy efficiency, resource recovery, and climate adaptation benefits throughout the entire urban water cycle.

Environmental Dimension

The environmental dimension reflects the contribution of BGPI to climate mitigation, ecosystem health, resource efficiency, and environmental sustainability. Findings from the review indicate that blue-green plumbing systems generate environmental benefits through several pathways. First, they reduce potable water demand and wastewater generation. Second, they lower the energy requirements associated with water abstraction, treatment, pumping, and distribution, improve water quality through natural treatment processes, and enhance urban ecological functions.

A fundamental concept underlying this dimension is the water-energy-climate nexus. Water consumption and energy use are closely linked, meaning that improvements in water efficiency can produce corresponding reductions in energy consumption and greenhouse gas emissions (Retamal et al., 2010). Rainwater harvesting, greywater recycling, and nature-based treatment systems contribute to carbon reduction by decreasing demand for centralized systems and requiring lower energy inputs than conventional facilities (Retamal et al., 2010),(Cardoso et al., 2021). These reductions, while indirect, support broader carbon-neutral development objectives.

The environmental dimension also incorporates climate adaptation outcomes. Green roofs, rain gardens, wetlands, and permeable landscapes improve stormwater retention, reduce urban heat exposure, enhance biodiversity, and increase ecological resilience (Staddon et al., 2018). Consequently, BGPI contributes simultaneously to both climate mitigation and climate adaptation, providing a comprehensive approach to environmental sustainability.

Institutional Dimension

The review identified fragmented governance arrangements as one of the most significant barriers affecting BGPI implementation in the Philippines. Water management, environmental regulation, urban planning, infrastructure development, and climate action responsibilities are frequently distributed across multiple agencies with overlapping mandates and limited coordination. As a result, many innovative water-management technologies struggle to gain institutional support despite demonstrated technical feasibility.

To address this challenge, the institutional dimension of the framework emphasizes multi-agency coordination and integrated governance. This dimension promotes collaboration among local government units, water utilities, environmental agencies, planning offices, building regulators, academic institutions, and professional organizations. Rather than operating independently, these stakeholders should work through shared planning mechanisms that align infrastructure development with climate resilience and sustainability objectives.

Regulatory modernization also forms a critical component of this dimension. The framework recognizes the need to update building codes, plumbing standards, environmental regulations, and urban planning policies to provide explicit guidance for rainwater harvesting, greywater reuse, decentralized water systems, and other BGPI technologies. The integration of Low Impact Development (LID) principles and water-sensitive urban design concepts into policy frameworks would further support mainstream adoption. Through these reforms, governance structures can transition from fragmented and reactive approaches toward more coordinated and climate-responsive infrastructure management systems.

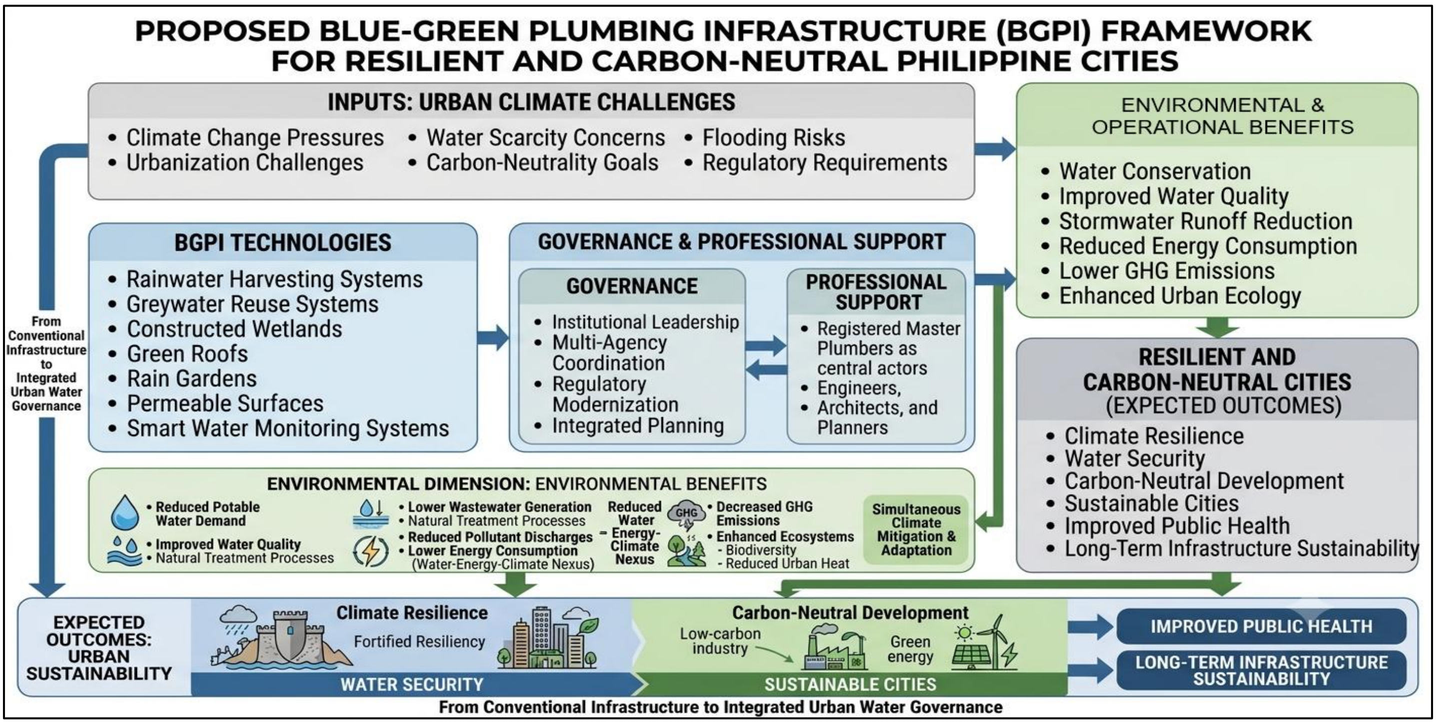
Professional Dimension

One of the most significant contributions of this study is the recognition of Registered Master Plumbers (RMPs) as central actors in resilient and carbon-neutral urban development. Although discussions of climate adaptation and sustainable infrastructure frequently focus on planners, engineers, architects, and environmental professionals, the findings indicate that plumbing professionals play a uniquely important role because of their direct responsibility for water-system implementation and operation.

The professional dimension therefore positions RMPs as the primary technical implementers of BGPI systems. Their role extends beyond traditional plumbing functions and includes sustainability planning, water-efficiency design, resource recovery implementation, environmental compliance support, system monitoring, and long-term operational management. Because many BGPI interventions occur at the building and neighborhood scales, RMPs occupy a critical interface between sustainability policy and practical infrastructure implementation.

The framework further recommends strengthening professional competencies through enhanced education, technical training, certification programs, and continuing professional development. Key areas of capacity building include rainwater harvesting design, greywater treatment systems, decentralized wastewater management, nature-based solutions, digital monitoring technologies, climate resilience planning, and sustainable infrastructure assessment. By expanding professional competencies in these areas, RMPs can become effective climate-action partners and sustainability leaders within the built environment sector.

Figure 1. Proposed Blue-Green Plumbing Infrastructure (BGPI) Framework for Resilient and Carbon-Neutral Philippine Cities



The proposed framework was developed by synthesizing the recurring themes identified in the literature review, particularly the technological, environmental, institutional, and professional dimensions that influence BGPI implementation in Philippine cities.

Expected Outcomes of the Framework

The proposed BGPI Framework is expected to produce multiple interconnected outcomes that support resilient and carbon-neutral cities. At the infrastructure level, it promotes more efficient water management systems capable of improving supply reliability, reducing wastewater generation, and enhancing operational performance. At the environmental level, it contributes to lower carbon emissions, improved ecosystem services, reduced environmental pollution, and increased climate resilience. At the institutional level, it encourages stronger coordination among agencies and promotes policy alignment across water, environmental, and urban planning sectors. At the professional level, it strengthens the role of Registered Master Plumbers as sustainability practitioners capable of implementing innovative water-management solutions.

Most importantly, the framework supports a transition from conventional infrastructure planning toward integrated urban water governance. Rather than treating water supply, wastewater management, stormwater control, and climate adaptation as separate concerns, it combines these functions into a unified strategy that advances both sustainability and resilience objectives. By doing so, the proposed BGPI Framework provides a practical pathway for integrating plumbing infrastructure into broader efforts to create resilient, resource-efficient, and carbon-neutral Philippine cities.

Limitations of the Study

This study is subject to several limitations. First, the findings are derived from a systematic review of existing literature and therefore rely primarily on secondary sources rather than field-based evidence obtained from actual BGPI implementations in Philippine cities. While the review provides a comprehensive synthesis of current knowledge, it does not include direct performance measurements, operational monitoring data, or case-study evaluations that could validate the effectiveness of BGPI under local climatic, institutional, and socio-economic conditions. Consequently, the applicability of some international findings to Philippine urban settings should be interpreted with caution.

Second, although numerous studies report environmental and operational benefits associated with rainwater harvesting, greywater reuse, decentralized wastewater treatment, and nature-based infrastructure, the magnitude of these benefits may vary considerably depending on site-specific factors such as climate, population density, regulatory conditions, maintenance practices, and infrastructure design. The review was not intended to quantify these variations through empirical analysis.

Third, the discussion of carbon-neutral development is based largely on the water-energy-climate nexus identified in the literature. While improved water efficiency and reduced energy consumption can contribute to greenhouse gas mitigation, these measures alone do not necessarily result in full carbon neutrality. Achieving carbon-neutral urban development requires complementary interventions across multiple sectors, including energy, transportation, buildings, waste management, and land-use planning. Therefore, BGPI should be viewed as a supporting component of broader urban decarbonization efforts rather than a standalone solution for achieving carbon neutrality.

CONCLUSION AND RECOMMENDATIONS

Based on the synthesis of existing studies, Blue-Green Plumbing Infrastructure emerges as a viable framework for promoting sustainable urban development within the Philippine context. Its capacity to improve water resource efficiency, mitigate climate-related risks, and contribute to emissions reduction objectives underscores its relevance in supporting the country's transition toward climate-resilient and carbon-conscious cities. The synthesis of literature revealed that BGPI extends the traditional function of plumbing systems beyond water supply and wastewater conveyance by integrating rainwater harvesting, greywater reuse, decentralized wastewater treatment, constructed wetlands, green roofs, rain gardens, and smart water-management technologies into a comprehensive urban sustainability strategy. Through these integrated approaches, BGPI contributes to water conservation, stormwater management, environmental protection, resource efficiency, and climate resilience while simultaneously reducing the energy demands associated with centralized water and wastewater systems. These findings confirm that plumbing infrastructure can serve as a strategic component of climate mitigation and adaptation efforts rather than merely as a supporting utility service.

Findings from the review further reveal that the contribution of BGPI to carbon-neutral urban development extends beyond water management benefits alone. Through its influence on the water–energy–climate nexus, improved water-use efficiency can reduce the energy requirements associated with water extraction, treatment, distribution, and wastewater management, ultimately supporting greenhouse gas mitigation efforts. The review also suggests that BGPI advances climate-resilient and low-carbon urban development by reducing reliance on centralized water infrastructure and promoting resource-efficient alternatives. Through the adoption of water reuse practices and nature-based treatment technologies, cities can improve water security while simultaneously lowering energy demand and associated environmental impacts. In addition to environmental benefits, these systems strengthen urban resilience by reducing flooding risks, enhancing water security, improving ecosystem services, and promoting adaptive capacity in the face of climate-related hazards. These multifunctional benefits highlight BGPI as an effective framework for addressing multiple urban challenges simultaneously.

The findings suggest that Blue-Green Plumbing Infrastructure (BGPI) can contribute meaningfully to climate-resilient and lower-carbon urban development through improved water-use efficiency, decentralized resource management, reduced pressure on centralized infrastructure systems, and enhanced ecosystem services. However, the review also indicates that the contribution of BGPI to carbon mitigation should be interpreted within the broader context of urban sustainability. While reductions in water-related energy consumption may lower greenhouse gas emissions, such improvements alone are insufficient to achieve complete carbon neutrality. Rather, BGPI should be considered one component of an integrated urban climate strategy that works alongside renewable energy deployment, sustainable transportation, energy-efficient buildings, and other decarbonization measures. Future empirical studies and life-cycle carbon assessments are necessary to quantify the actual contribution of BGPI to emissions reduction in Philippine cities.

A key finding of this study is the crucial role of Registered Master Plumbers (RMPs) in advancing sustainable urban development. The implementation of BGPI requires specialized expertise in system design, installation, operation, maintenance, monitoring, and regulatory compliance. Consequently, RMPs are uniquely positioned to translate sustainability objectives into practical and operational infrastructure solutions. Their involvement is essential not only in the technical implementation of BGPI systems but also in promoting innovation, ensuring environmental compliance, and supporting climate-responsive development practices. The findings therefore suggest that the future role of RMPs must evolve beyond traditional plumbing functions toward broader responsibilities in sustainable infrastructure management and climate resilience planning.

Notwithstanding the documented benefits of BGPI, several structural and institutional challenges continue to impede its widespread application (Orale et al., 2025). Addressing fragmented governance systems, clarifying agency roles and responsibilities, strengthening technical standards, enhancing policy frameworks, expanding financial support mechanisms, and developing professional expertise will be essential to facilitate broader implementation and maximize the long-term benefits of BGPI in the Philippines. Such challenges indicate that the successful mainstreaming of BGPI will require not only technological solutions but also institutional reforms, capacity-building initiatives, and stronger policy integration across sectors. Addressing these constraints is critical for unlocking the full environmental, social, and economic benefits of blue-green infrastructure systems.

Recommendations

Based on the findings of this study, several recommendations are proposed to support the wider adoption and effective implementation of Blue-Green Plumbing Infrastructure in Philippine cities.

First, national and local government agencies should strengthen policy and regulatory frameworks by integrating BGPI principles into building codes, plumbing regulations, environmental policies, and urban development plans. Regulatory support for rainwater harvesting, greywater reuse, decentralized wastewater treatment, and nature-based solutions can provide greater clarity and encourage broader implementation.

Second, local government units should incorporate BGPI strategies into climate action plans, disaster risk reduction programs, water security initiatives, and sustainable urban development policies. Pilot projects and demonstration sites can serve as practical examples of successful implementation and provide evidence for scaling up blue-green infrastructure interventions.

Third, professional organizations, academic institutions, and industry stakeholders should expand training and capacity-building programs focused on sustainable plumbing systems, water reuse technologies, nature-based infrastructure, and smart water management. Strengthening the competencies of Registered Master Plumbers and other built-environment professionals will be critical for ensuring the successful design, operation, and maintenance of BGPI systems.

Furthermore, infrastructure investments should be evaluated based on their performance over the entire project life cycle rather than solely on initial capital requirements. Although the adoption of decentralized infrastructure projects in the Philippines may involve high capital costs (Selerio, 2024), its potential to generate environmental, economic, and social benefits over time supports its consideration as a sustainable long-term development strategy.

Finally, future research should move beyond conceptual analyses and systematic reviews by conducting empirical case studies, pilot implementations, life-cycle cost assessments, and performance evaluations of BGPI systems within Philippine cities. Additional studies examining carbon reduction potential, regulatory readiness, stakeholder perceptions, and implementation barriers at the local level would further strengthen the evidence base for policy and practice.

In conclusion, the transition toward resilient and carbon-neutral Philippine cities will require integrated and innovative approaches to infrastructure development. Blue-Green Plumbing Infrastructure provides a practical and scalable pathway for achieving these objectives by linking water management, climate adaptation, carbon reduction, and urban sustainability into a unified framework. By strengthening policies, institutions, professional competencies, and implementation mechanisms, Philippine cities can leverage BGPI as a key enabler of sustainable and climate-resilient urban transformation.

Future Research Directions

Future research should move beyond literature-based assessments and focus on empirical investigations of Blue-Green Plumbing Infrastructure (BGPI) under Philippine conditions. Pilot projects, building-scale assessments, and stakeholder surveys are recommended to evaluate the real-world performance, feasibility, and acceptance of BGPI technologies in different urban settings. Such studies would provide locally grounded evidence regarding the effectiveness of rainwater harvesting systems, greywater reuse systems, decentralized wastewater treatment facilities, green roofs, and other nature-based water management solutions.

Researchers should examine measurable performance indicators, including water-use reduction, energy savings, maintenance requirements, life-cycle costs, environmental benefits, and long-term operational performance. Quantitative monitoring of these indicators would help validate the environmental and economic benefits identified in the literature and support evidence-based policy development.

Additionally, comparative studies between conventional plumbing systems and BGPI-integrated systems are strongly encouraged. Such research could assess differences in resource efficiency, operational costs, carbon emissions, resilience to climate-related hazards, and overall sustainability performance. Comparative analyses would generate stronger empirical evidence for planners, policymakers, developers, and infrastructure professionals, thereby supporting informed decision-making regarding the adoption and scaling of BGPI in Philippine cities.

Finally, future studies should include life-cycle carbon assessments and broader sustainability evaluations to determine the extent to which BGPI contributes to urban decarbonization objectives. While existing literature suggests that improved water efficiency and reduced energy consumption can lower greenhouse gas emissions, further local research is needed to quantify the actual carbon-reduction potential of BGPI and its contribution within broader climate-neutral urban development strategies.

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REFERENCES

1. Ahmed, S., Meenar, M., & Alam, A. (2019). Designing a Blue-Green Infrastructure (BGI) Network: Toward Water-Sensitive Urban Growth Planning in Dhaka, Bangladesh. Land, 8(9), 138–138. https://doi.org/10.3390/land8090138
2. Almaaitah, T., Appleby, M., Rosenblat, H., Drake, J., & Joksimovic, D. (2021). The potential of Blue-Green infrastructure as a climate change adaptation strategy: a systematic literature review. Blue-Green Systems, 3(1), 223–248. https://doi.org/10.2166/bgs.2021.016
3. Andersson, E., Haase, D., Kronenberg, J., Langemeyer, J., Mascarenhas, A., Wolff, M., & Elmqvist, T. (2022). Based on nature, enabled by social-ecological-technological context: deriving benefit from urban green and blue infrastructure. Ecology and Society, 27(4). https://doi.org/10.5751/es-13580-270418
4. Bai, X., Dodman, D., Hayward, B., Lwasa, S., Seto, K. C., Abid, H., Thakur, J., Khatiwada, D., Bauner, D., Abino, A., Castillo, J., Lee, Y., Acakpovi, A., Abubakar, R., Asabere, N., Majeed, I., Acuto, M., Leffel, B., Acuto, M., … Zscheischler, J. (2023). Urban Systems and Other Settlements. In Cambridge University Press eBooks (pp. 861–952). Cambridge University Press. https://doi.org/10.1017/9781009157926.010
5. Bank, A. D. (2014). Asian Development Bank (ADB), Republic of the Philippines National Urban Assessment. https://doi.org/10.22617/rpt146356
6. Bartos, M., Wong, B., & Kerkez, B. (2017). Open storm: a complete framework for sensing and control of urban watersheds. Environmental Science Water Research & Technology, 4(3), 346–358. https://doi.org/10.1039/c7ew00374a
7. Beretta, I., & Bracchi, C. (2025). Is Climate-Neutral the New Smart and Sustainable City? A Review Towards Urban Climate Neutrality. Urban Planning, 10. https://doi.org/10.17645/up.10033
8. Berro, N. (2025). The Role of Engineers in Implementing Water-Efficient Technologies in Sustainable Building Projects. Open Journal of Civil Engineering, 15(3), 545–562. https://doi.org/10.4236/ojce.2025.153029
9. Bilal, M., Sandi, S. G., Josey, B. M., & Gong, J. (2026). A review of premise plumbing systems: from design and key performance domains to challenges and future research pathways for full-scale integration. Water Research, 293, 125437–125437. https://doi.org/10.1016/j.watres.2026.125437
10. Boongaling, C. G., Sevilla-Nastor, J. B., ESPALDON, M. V. O., Sanchez, P. A., Villanueva, J. D., & Jago-on, K. A. B. (2026). Cost-benefit analysis of decentralized low-impact development (LID) applications in urban areas in the Philippines: a case study of the Canlubang sub-catchment. Water Practice & Technology, 21(2), 444–466. https://doi.org/10.2166/wpt.2026.199
11. Browder, G. J., Ozment, S., Bescos, I. R., Gartner, T., & Lange, G. (2019). Integrating Green and Gray: Creating Next Generation Infrastructure. https://doi.org/10.46830/wrirpt.18.00028
12. Cardoso, B. J., Rodrigues, E., Gaspar, A. R., & Gomes, Á. (2021). Energy performance factors in wastewater treatment plants: A review. Journal of Cleaner Production, 322, 129107–129107. https://doi.org/10.1016/j.jclepro.2021.129107
13. Cascone, S., Coma, J., Gagliano, A., & Pérez, G. (2018). The evapotranspiration process in green roofs: A review. Building and Environment, 147, 337–355. https://doi.org/10.1016/j.buildenv.2018.10.024
14. Castro, A. M. L., Tabliga, C. B., Merecido, P. A. M., Bongo, A. V. P., & Bucao, F. A. (2026). Invisible Infrastructure: A Systematic Review of Wastewater Disposal and Treatment in the Philippines (1982–2026). Asian Journal of Environment & Ecology, 25(3), 16–27. https://doi.org/10.9734/ajee/2026/v25i3898
15. Chen, H., Wang, L., Wang, Y., Ni, Z., Xia, B., & Qiu, R. (2024). New Perspective to Evaluate the Carbon Offsetting by Urban Blue-Green Infrastructure: Direct Carbon Sequestration and Indirect

Carbon Reduction. Environmental Science & Technology, 58(29), 12966–12975. https://doi.org/10.1021/acs.est.3c07337
16. Chen, L., Chen, Z., Liu, Y., Lichtfouse, É., Jiang, Y., Hua, J., Osman, A. I., Farghali, M., Huang, L., Zhang, Y., Rooney, D. W., & Yap, P. (2024). Benefits and limitations of recycled water systems in the building sector: a review. Environmental Chemistry Letters, 22(2), 785–814. https://doi.org/10.1007/s10311-023-01683-2
17. Chiu, Y., Raina, N., & Chen, H. (2021). Evolution of Flood Defense Strategies: Toward Nature-Based Solutions. Environments, 9(1), 2–2. https://doi.org/10.3390/environments9010002
18. Corong, E., Dacuycuy, L., Reyes, R. C., & Taningco, A. (2012). The Growth and Distributive Impacts of Public Infrastructure Investments in the Philippines. SSRN Electronic Journal. https://doi.org/10.2139/ssrn.3168046
19. Corpuz, J. C. G. (2025). Wastewater Management in the Philippines: A Call for Localized Solutions and Policy Integration. PubMed Central, 19. https://doi.org/10.1177/11786302241311529
20. Demegillo, Desamero, Gaco, Maestrado, Pimentel, Salada, Tiangco, Mamitag, & Pudan. (2025). Greening the Flood: Sustainable Urban Solutions for Barangay Lorega, Cebu City. DIT ADS International Multidisciplinary Research Journal. https://doi.org/10.63941/dit.adsimrj.2025.1.3.20
21. Engström, R., Howells, M., Destouni, G., Bhatt, V., Bazilian, M., & Rogner, H. (2017). Connecting the resource nexus to basic urban service provision – with a focus on water-energy interactions in New York City. IIASA PURE (International Institute of Applied Systems Analysis), 31, 83–94. https://doi.org/10.1016/j.scs.2017.02.007
22. Enriquez, Y., Yadav, S., Evangelista, G. K., Villanueva, D., Burac, M. A., & Pede, V. O. (2021). Disentangling Challenges to Scaling Alternate Wetting and Drying Technology for Rice Cultivation: Distilling Lessons From 20 Years of Experience in the Philippines. Frontiers in Sustainable Food Systems, 5. https://doi.org/10.3389/fsufs.2021.675818
23. Green, D. (2010). Creating an army of greegreen plumbers. American Water Works Association, 102(2), 67–69. https://doi.org/10.1002/j.1551-8833.2010.tb10048.x
24. Group, W. B. (2022). World Bank Group - Philippines Country Climate and Development Report. In World Bank, Washington, DC eBooks. https://doi.org/10.1596/38280
25. Haji, M., Namany, S., & Al-Ansari, T. (2024). Strengthening resilience: decentralized decision-making and multi-criteria analysis in the energy-water-food nexus systems. Frontiers in Sustainability, 5. https://doi.org/10.3389/frsus.2024.1367931
26. Hallegatte, S., Rentschler, J., & Rozenberg, J. (2019). More Resilient Infrastructure Assets Are Cost-Effective. In The World Bank eBooks (pp. 95–107). https://doi.org/10.1596/978-1-4648-1430-3_ch6
27. Hamel, P., & Tan, L. Q. (2021). Blue–Green Infrastructure for Flood and Water Quality Management in Southeast Asia: Evidence and Knowledge Gaps. Environmental Management, 69(4), 699–718. https://doi.org/10.1007/s00267-021-01467-w
28. Hamilton, J. A. (2026). Teaching the Design of Sustainable Resilient Plumbing Systems for the Future. 199–205. https://doi.org/10.1061/9780784486610.017
29. Han, J., Chen, W., Zhang, L., & Liu, G. (2018). Uncovering the Spatiotemporal Dynamics of Urban Infrastructure Development: A High Spatial Resolution Material Stock and Flow Analysis. University of Southern Denmark Research Portal (University of Southern Denmark), 52(21), 12122–12132. https://doi.org/10.1021/acs.est.8b03111
30. He, Q., Tapia, F., & Reith, A. (2023). Quantifying the influence of nature-based solutions on building cooling and heating energy demand: A climate specific review. Renewable and Sustainable Energy Reviews, 186, 113660–113660. https://doi.org/10.1016/j.rser.2023.113660
31. He, Z., Wang, R., Wang, J., Chen, H., Zhang, S., Wang, K., Lai, J. Y., Ren, N., & Ho, S. (2025). Water conservation strategies reduce greenhouse gas emission from wastewater treatment plants: A domino effect. Environmental Science and Ecotechnology, 26, 100574–100574. https://doi.org/10.1016/j.ese.2025.100574
32. Howard, G., Calow, R., MacDonald, A., & Bartram, J. (2016). Climate Change and Water and Sanitation: Likely Impacts and Emerging Trends for Action. Annual Review of Environment and Resources, 41(1), 253–276. https://doi.org/10.1146/annurev-environ-110615-085856

33. (IPCC), I. P. on C. C. (2023). Cities, Settlements and Key Infrastructure. In Cambridge University Press eBooks (pp. 907–1040). Cambridge University Press. https://doi.org/10.1017/9781009325844.008
34. Jegatheesan, V., Pachova, N., Velasco, P., Mowjood, M. I. M., Weragoda, S. K., Makehelwala, M., Trang, N. T. D., Dang, B., Tran, C., Vo, T., Trang, N. T. T., Pham, H., Devanadera, Ma. C. E., Torrens, A., Bui, X., Nguyen, P., Lecciones, A., & Jinadasa, K. B. S. N. (2022). Co-development of an integrated assessment framework to evaluate the effectiveness and impact of selected nature-based water treatment technologies in Sri Lanka, The Philippines, and Vietnam. Environmental Quality Management, 32(3), 335–365. https://doi.org/10.1002/tqem.21922
35. Kabisch, N., Stadler, J., & Korn, H. (2017). Nature-Based Solutions to Climate Change Adaptation in Urban Areas. In Theory and practice of urban sustainability transitions. https://doi.org/10.1007/978-3-319-56091-5
36. Kelkar, V., Helm, B., & Krebs, P. (2025). A Semi-Systematic Global Review to Understand the Key Components Essential for Advancing the Actual Design, Planning, and Implementation of Blue–Green Infrastructure in Indian Cities. Land, 14(11), 2287–2287. https://doi.org/10.3390/land14112287
37. Khaffaf, I. A., Al-Tamimi, A. K., & Ahmed, V. (2024). Pathways to Carbon Neutrality: A Review of Strategies and Technologies Across Sectors. Energies, 17(23), 6129–6129. https://doi.org/10.3390/en17236129
38. Khajvand, M., Mostafazadeh, A. K., Drogui, P., & Tyagi, R. D. (2022). Management of greywater: environmental impact, treatment, resource recovery, water recycling, and decentralization. Water Science & Technology, 86(5), 909–937. https://doi.org/10.2166/wst.2022.226
39. Koohestani, S. S., Mukheibir, P., Wakefield-Rann, R., & Santamouris, M. (2025). Adopting a socio-technical perspective on the challenges and barriers in transitioning to Blue-Green Infrastructure (BGI). Blue-Green Systems, 7(1), 79–94. https://doi.org/10.2166/bgs.2025.011
40. Koop, S., & Leeuwen, K. van. (2016). The challenges of water, waste and climate change in cities. Environment Development and Sustainability, 19(2), 385–418. https://doi.org/10.1007/s10668-016-9760-4
41. Kumar, S., Pratap, B., Dubey, D., & Dutta, V. (2022). Integration of Constructed Wetland Technology as Decentralized Wastewater Treatment Facility and Water Reuse in Agriculture (pp. 565–582). https://doi.org/10.1201/9781003220824-39
42. Lantaca, J. R. (2024). Sewage Treatment Facility Maintenance: A Risk-based Approach for High-rise Residential Property. E3S Web of Conferences, 488, 3002–3002. https://doi.org/10.1051/e3sconf/202448803002
43. Larsen, T. A., Hoffmann, S., Lüthi, C., Truffer, B., & Maurer, M. (2016). Emerging solutions to the water challenges of an urbanizing world. Science, 352(6288), 928–933. https://doi.org/10.1126/science.aad8641
44. Li, S., Leitão, J. P., Wang, Z., & Bach, P. M. (2023). A drainage network-based impact matrix to support targeted blue-green-grey stormwater management solutions. The Science of The Total Environment, 912, 168623–168623. https://doi.org/10.1016/j.scitotenv.2023.168623
45. Liu, Y., Hejazi, M., Kyle, P., Kim, S. H., Davies, E., Miralles, D. G., Teuling, A. J., He, Y., & Niyogi, D. (2016). Global and Regional Evaluation of Energy for Water. Environmental Science & Technology, 50(17), 9736–9745. https://doi.org/10.1021/acs.est.6b01065
46. Mason, L. R., Arwood, C., & Shires, M. K. (2017). Seasonal patterns and socio-economic predictors of household rainwater and greywater use. Urban Water Journal, 15(2), 109–115. https://doi.org/10.1080/1573062x.2017.1401098
47. Mihalakakou, G., Souliotis, M., Papadaki, M., Menounou, P., Dimopoulos, P., Kolokotsa, D., Paravantis, J. A., Tsangrassoulis, A., Panaras, G., Giannakopoulos, E., & Papaefthimiou, S. (2023). Green roofs as a nature-based solution for improving urban sustainability: Progress and perspectives. Renewable and Sustainable Energy Reviews, 180, 113306–113306. https://doi.org/10.1016/j.rser.2023.113306
48. Molinos-Senante, M., Poch, M., Rosso, D., & Garrido-Baserba, M. (2024). From wastewater treatment plants to decentralized resource factories. Npj Clean Water, 7(1). https://doi.org/10.1038/s41545-024-00343-4

49. Namratha, B., & Gaonkar, S. L. (2026). Nature-based Solutions for the Management of Urban Wastewater (pp. 70–90). https://doi.org/10.1201/9781003527350-3
50. Nguyen, T. T., Bach, P. M., & Pahlow, M. (2022). Multi-scale stormwater harvesting to enhance urban resilience to climate change impacts and natural disasters. Blue-Green Systems, 4(1), 58–74. https://doi.org/10.2166/bgs.2022.008
51. Nunn, P. D., Smith, T. F., & Elrick-Barr, C. E. (2021). Path Dependency and Future Adaptation of Coastal Cities: Examples From the Asia-Pacific. Frontiers in Environmental Science, 9. https://doi.org/10.3389/fenvs.2021.642385
52. Ogden, M. H. (2013). ATMOSPHERIC CARBON REDUCTION AND CARBON SEQUESTRATION IN SMALL COMMUNITY WASTEWATER TREATMENT SYSTEMS USING CONSTRUCTED WETLANDS. https://doi.org/10.13031/2013.6072
53. Olatunde, T. M., Adelani, F. A., & Sikhakhane, Z. Q. (2024). A REVIEW OF SMART WATER MANAGEMENT SYSTEMS FROM AFRICA AND THE UNITED STATES. Engineering Science & Technology Journal, 5(4), 1231–1242. https://doi.org/10.51594/estj.v5i4.1014
54. Oral, H. V., Carvalho, P. N., Gajewska, M., Ursino, N., Masi, F., Hullebusch, E. D. van, Kazak, J. K., Expósito, A., Cipolletta, G., Andersen, T. R., Finger, D. C., Simperler, L., Regelsberger, M., Rous, V., Radinja, M., Buttiglieri, G., Krzemiński, P., Rizzo, A., Dehghanian, K., … Zimmermann, M. (2020). A review of nature-based solutions for urban water management in European circular cities: a critical assessment based on case studies and literature. Blue-Green Systems, 2(1), 112–136. https://doi.org/10.2166/bgs.2020.932
55. Orale, R. L., Novilla, R. B., & Montecastro, D. (2025). Harmonized Low Impact Development (LID)-based building and urban design policies for the Philippines. IOP Conference Series Earth and Environmental Science, 1511(1), 12007–12007. https://doi.org/10.1088/1755-1315/1511/1/012007
56. Öztürk, Ş., Yılmaz, K., Dinçer, A. E., & Kalpakcı, V. (2024). Effect of urbanization on surface runoff and performance of green roofs and permeable pavement for mitigating urban floods. Natural Hazards, 120(13), 12375–12399. https://doi.org/10.1007/s11069-024-06688-w
57. Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T., Mulrow, C. D., Shamseer, L., Tetzlaff, J., Akl, E. A., Brennan, S., Chou, R., Glanville, J., Grimshaw, J., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E., Mayo-Wilson, E., McDonald, S., … Moher, D. (2021). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ, 372. https://doi.org/10.1136/bmj.n71
58. Palmer, M. A., Liu, J., Matthews, J., Mumba, M., & D'Odorico, P. (2015). Manage water in a green way. Science, 349(6248), 584–585. https://doi.org/10.1126/science.aac7778
59. Persily, A. K., Yashar, D. A., Ferretti, N. M., Ullah, T., & Healy, W. M. (2020). Measurement science research needs for premise plumbing systems. https://doi.org/10.6028/nist.tn.2088
60. Pille, L., & Säumel, I. (2021). The water-sensitive city meets biodiversity: habitat services of rain water management measures in highly urbanized landscapes. Ecology and Society, 26(2). https://doi.org/10.5751/es-12386-260223
61. Pochodyła, E., Glińska-Lewczuk, K., & Jaszczak, A. (2021). Blue-green infrastructure as a new trend and an effective tool for water management in urban areas. Landscape Online, 92, 1–20. https://doi.org/10.3097/lo.202192
62. Pradyumna, G. R., & Hegde, R. B. (2024). Enhancing Blue-Green Infrastructure With Smart Technology. In Advances in public policy and administration (APPA) book series (pp. 183–194). IGI Global. https://doi.org/10.4018/979-8-3693-8069-7.ch009
63. Quon, H., & Jiang, S. C. (2023). Decision making for implementing non-traditional water sources: a review of challenges and potential solutions. Npj Clean Water, 6(1). https://doi.org/10.1038/s41545-023-00273-7
64. Raza, T., Rentoy, F. C., Ahmed, N., Raza, A. V. L. A. T. K. S., Marasigan, K. M. E., & Espinosa, R. I. M. (2019). Water challenges and Urban Sustainable Development in Changing Climate: Economic Growth Agenda for Global South. European Journal of Sustainable Development, 8(4), 421–421. https://doi.org/10.14207/ejsd.2019.v8n4p421
65. Researcher, I., & Thakran, V. (2021). Environmental Sustainability in Piping Systems: Exploring the Impact of Material Selection and Design Optimisation. International Journal of Current Engineering and Technology, 11(5). https://doi.org/10.14741/ijcet/v.11.5.5

66. Retamal, M., Turner, A., & White, S. (2010). The water-energy-climate nexus: systems thinking and virtuous circles. In UTS ePRESS (University of Technology Sydney). University of Technology Sydney. http://hdl.handle.net/10453/14317
67. Roldan, Ma. D. G. Z. (2022). Addressing Climate Change and Disaster Risk Reduction through ICT and EU Assistance: The Case of Philippine Local Governance. European Journal of Sustainable Development, 11(2), 32–32. https://doi.org/10.14207/ejsd.2022.v11n2p32
68. Ruangpan, L., Vojinović, Z., Sabatino, S. D., Leo, L. S., Capobianco, V., Oen, A., McClain, M. E., & López-Gunn, E. (2020). Nature-based solutions for hydro-meteorological risk reduction: a state-of-the-art review of the research area. Natural Hazards and Earth System Sciences, 20(1), 243–270. https://doi.org/10.5194/nhess-20-243-2020
69. Saarinen, A., Leskinen, P., Reini, A., Fagerholm, N., & Kasvi, E. (2025). Policy and regulatory measures supporting the implementation of nature-based solutions in urban stormwater management of private properties: Insights from Finland. AMBIO, 55(4), 903–920. https://doi.org/10.1007/s13280-025-02253-2
70. Seidu, S., Chan, D. W. M., & Taiwo, R. (2025). Integrating green and grey infrastructure systems in dense urban regions: a synthesis of critical barriers and effective implementation guidelines. Clean Technologies and Environmental Policy, 27(12), 7555–7576. https://doi.org/10.1007/s10098-025-03309-3
71. Selerio, E. (2024). Multicriteria Analysis of Decentralized Wastewater Treatment Technologies for the Philippines. In arXiv (Cornell University). Cornell University. https://doi.org/10.48550/arxiv.2410.22484
72. Sharma, R., & Malaviya, P. (2021). Management of stormwater pollution using green infrastructure: The role of rain gardens. Wiley Interdisciplinary Reviews Water, 8(2). https://doi.org/10.1002/wat2.1507
73. Siehr, S. A., Sun, M., & Nucamendi, J. L. A. (2022). Blue-green infrastructure for climate resilience and urban multifunctionality in Chinese cities. Wiley Interdisciplinary Reviews Energy and Environment, 11(5). https://doi.org/10.1002/wene.447
74. Siringan, F. P. (2012). The Country's Water Resources and Issues. Transactions of the National Academy of Science and Technology, 34(2), 1–2. https://doi.org/10.57043/transnastphl.2012.3253
75. Staddon, C., Ward, S., Vito, L. D., Zúñiga-Terán, A. A., Gerlak, A. K., Schoeman, Y., Hart, A., & Booth, G. (2018). Contributions of green infrastructure to enhancing urban resilience. Environment Systems & Decisions, 38(3), 330–338. https://doi.org/10.1007/s10669-018-9702-9
76. Stefanakis, A. (2019). The Role of Constructed Wetlands as Green Infrastructure for Sustainable Urban Water Management. Sustainability, 11(24), 6981–6981. https://doi.org/10.3390/su11246981
77. Steffen, J., Jensen, M. A., Pomeroy, C., & Burian, S. J. (2013). Water Supply and Stormwater Management Benefits of Residential Rainwater Harvesting in U.S. Cities. JAWRA Journal of the American Water Resources Association, 49(4), 810–824. https://doi.org/10.1111/jawr.12038
78. Sun, L., Chen, J., Li, Q., & Huang, D. (2020). Dramatic uneven urbanization of large cities throughout the world in recent decades. Nature Communications, 11(1), 5366–5366. https://doi.org/10.1038/s41467-020-19158-1
79. Tan, F. J. (2021). Flooding and Flood Modeling in a Typhoon Belt Environment: The Case of the Philippines. In IntechOpen eBooks. IntechOpen. https://doi.org/10.5772/intechopen.98738
80. Valerio, A. (2024). INSTITUTIONAL FRAGMENTATION AND SERVICE PERFORMANCE IN DECENTRALIZED URBAN WATER GOVERNANCE: EVIDENCE FROM ZAMBOANGA CITY, PHILIPPINES. Lex Localis - Journal of Local Self-Government, 785–791. https://doi.org/10.52152/nfh8tx97
81. Walle, A. V. de, Kim, M., Alam, M. K., Wang, X., Wu, D., Dash, S. R., Rabaey, K., & Kim, J. (2023). Greywater reuse as a key enabler for improving urban wastewater management. Ghent University Academic Bibliography (Ghent University), 16, 100277–100277. https://doi.org/10.1016/j.ese.2023.100277
82. Wang, X., Daigger, G. T., Lee, D., Liu, J., Ren, N.-Q., Qu, J., Liu, G., & Butler, D. (2018). Evolving wastewater infrastructure paradigm to enhance harmony with nature. Science Advances, 4(8). https://doi.org/10.1126/sciadv.aaq0210

83. Wu, H., Zhang, J., Ngo, H. H., Guo, W., Hu, Z., Liang, S., Fan, J., & Liu, H. (2014). A review on the sustainability of constructed wetlands for wastewater treatment: Design and operation. Bioresource Technology, 175, 594–601. https://doi.org/10.1016/j.biortech.2014.10.068
84. Zevenbergen, C., Fu, D., & Pathirana, A. (2018). Sponge Cities: Emerging Approaches, Challenges and Opportunities. https://doi.org/10.3390/books978-3-03897-273-0
85. Zhou, Y., Zhang, B., Wang, H., & Bi, J. (2013). Drops of Energy: Conserving Urban Water to Reduce Greenhouse Gas Emissions. Environmental Science & Technology, 47(19), 10753–10761. https://doi.org/10.1021/es304816h