Review

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Review of Green Water Systems for Urban Flood Resilience: Literature and Codes

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Review

Review of *Green Water Systems* for Urban Flood Resilience: Literature and Codes

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Abstract: Achieving Urban Flood Resilience (UFR) is essential for modern societies, requiring the implementation of effective practices in different countries to mitigate hydrological events. Green Water Systems (GWS) emerge as a promising alternative to achieve UFR, but they are still poorly explored and present varied definitions. This article aims to define GWS within the framework of sustainable practices and propose a regulation that promotes UFR. Through a systematic review of existing definitions and an analysis of international regulations on Sustainable Urban Drainage Systems (SuDS), the study reveals diverse perceptions and applications of GWS and their role in Blue-Green Infrastructure (BGI). The research proposes a standardized definition of GWS and their role in Blue – Green Infrastructure (BGI). The research proposes a standardized definition of GWS and the implementation of SuDS in Peru, addressing the current knowledge gap and contributing to the development of sustainable urban infrastructure.

Keywords: Green Water Systems; Blue-Green Infrastructure; Sustainable Urban Drainage Systems; Design Code; Urban Drainage System; Green-Gray Infrastructure; Urban Flood Resilience; Nature Based Solutions; Systematic Search

1. Introduction

Urban Drainage Systems (UDS) are essential for stormwater management, as they contribute to urban development by addressing the increasing incidence of floods caused by intense storms, which are often linked to climate change. This leads to an increase in surface runoff and saturation of drainage networks, causing damage to property, infrastructure, and the environment [1]. In particular, urban flooding occurs due to the insufficient capacity of traditional drainage systems based on Gray Infrastructure (GrI), for example van Oorschot, et al. [2] refer to them as urban elements constructed by humans that impact the local environment. This generates growing concern due to urban densification, population growth, and increased impervious surfaces. UDS (Urban Drainage Systems) are generally not designed to handle runoff from extreme storms, which limits their effectiveness as a tool combating urban flooding. This limitation is related to the type of UDS as well as the spatial characteristics and variations within a city [3]. In Europe, these systems are designed for rainfall events with specific return periods. However, there is a significant gap between the expected protection and the actual risk of extreme flooding, as these events can occur anywhere in a city. This highlights the need for a thorough analysis of hazards and risks that includes both natural factors and the built environment [4]. In other parts of the world, such as North America and Latin America, population growth, vulnerability, and a lack of understanding of sustainable urban infrastructure exacerbate urban flood risks. Based on this Arosio, et al. [5] argue that urban flood management is compromised by the lack of accurate data and appropriate models, which impairs the provision of essential services during and after extreme events. Also Rodríguez-Rojas, et al. [6] emphasize the need to close the gap in sustainable drainage systems by integrating SuDS that replicate the natural hydrological cycle, including infiltration, retention and reuse of water. The

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incorporation of these systems into regulations and laws is often developed in a general manner and lacks specific regulatory measures. Consequently, it is crucial to improve urban drainage infrastructure and adopt effective flood management strategies to enhance urban resilience and mitigate adverse impacts, especially in Latin America.

According to the data available in EM-DAT, based on the impact that floods have on the world, Figure 1 shows the number of people affected by floods on each continent, proving the vulnerability they suffer [7].

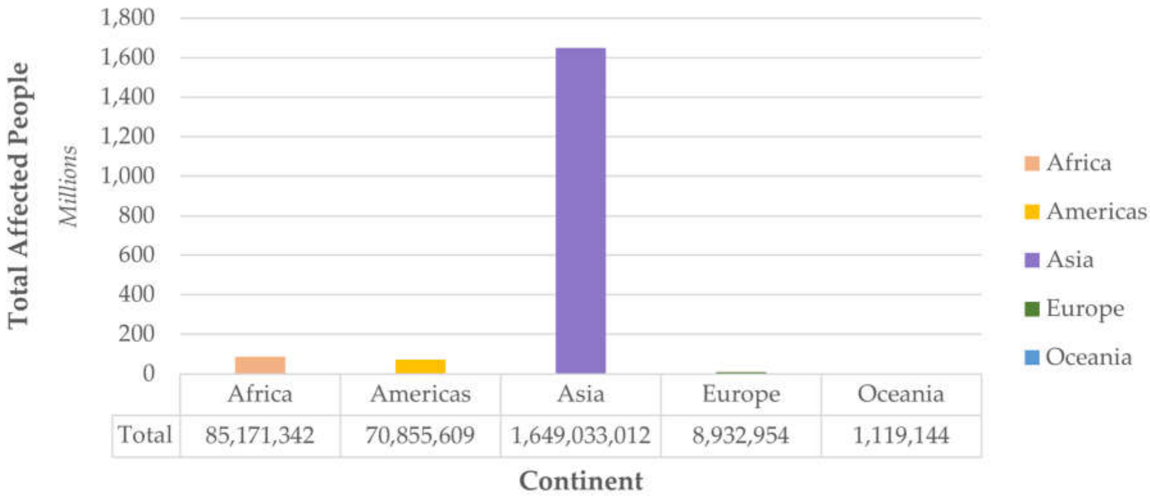

Figure 1. Number of people affected by floods around the world from 2000 to 2024.

On the other hand, **Figure 2** frames the number of deaths due to floods on each continent [7].

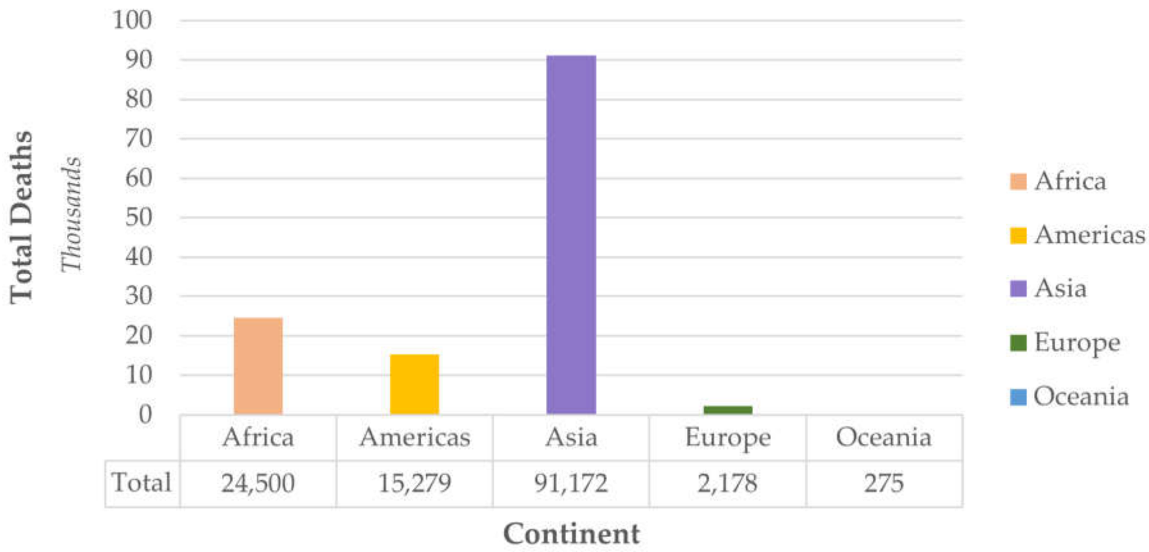

Figure 2. Number of deaths from floods around the world from 2000 to 2024.

Based on the graph, Asia had the highest number of affected people (deaths and victims), which gives an idea of how flood management has not been implemented effectively in several countries on the continent, while continents such as Europe and Oceania have considerably lower figures. This pattern suggests that the impact of natural disasters varies significantly at a global level, influenced by various factors. The main causes of this disparity are the density and distribution of the population, the geographic location (rural or urban areas), the predominant type of meteorological event, the socioeconomic conditions, and the magnitude of the exposed population, among others.

Transferring this data to a national scale, according to EM-DAT, Peru has recently experienced hydrological phenomena that had a serious impact on its citizens. **Figure 3** illustrates the number of victims and **Figure 4** the number of deaths in the recent years.

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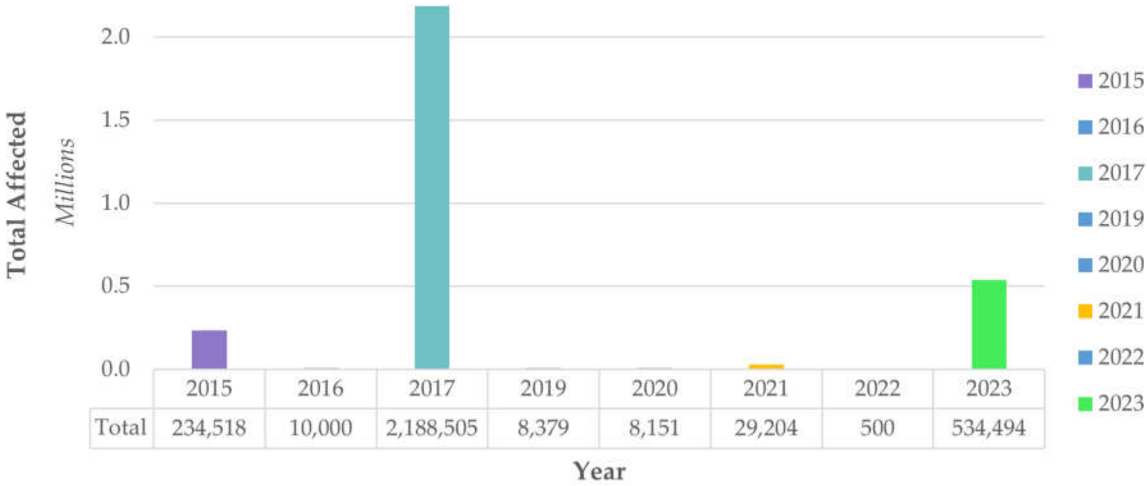

Figure 3. Population affected in Peru from 2015 to 2023 by floods.

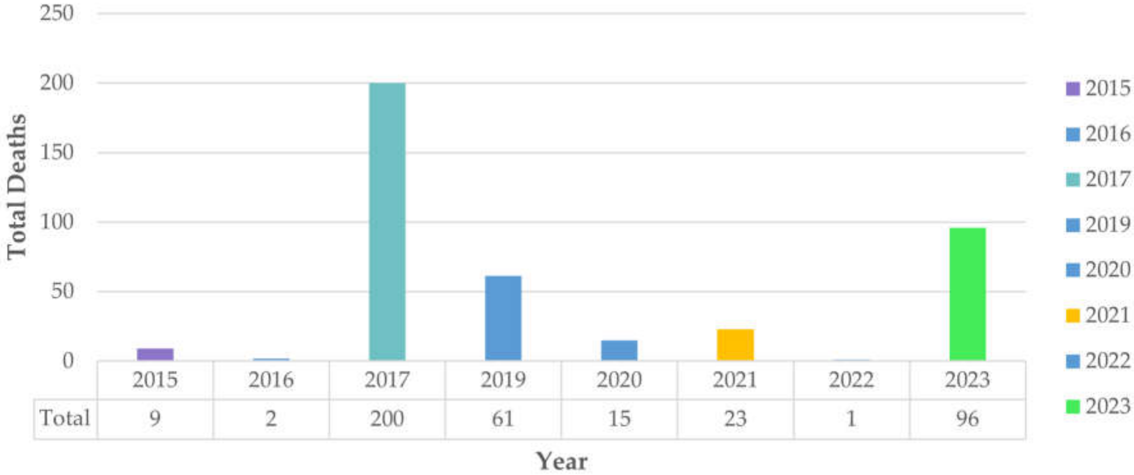

Figure 4. Number of deaths in Peru from 2015 to 2023 due to floods.

According to the data presented, the current context of traditional urban drainage systems in Peru is interpreted, with particular emphasis on extreme weather events associated with El Niño phenomenom (ENSO). The years 2017 and 2023 recorded the highest highest figures for deaths and affected people, coinciding with intense rainfall linked to these phenomena. Following this, Espinoza Vigil and Booker [8] highlight that during the period 2016-2017, ENSO had a devastating impact in Peru, with torrential rains that caused damage to infrastructure and affected about 2 million people. Similarly, Thielen, et al. [9] note that in 2023 there was an intensification of the ENSO, driven by a significant increase in the surface sea temperature, which generated extreme and widespread rainfall in various regions of the country. These events underline the vulnerability of traditional drainage systems, based on grey infrastructure, which have not been able to efficiently manage the volume and intensity of precipitation associated with El Niño. Given this panorama, the need arises for a transition towards more resilient drainage systems supported by green infrastructure or solutions based on nature, which can more effectively reduce the number of deaths and victims in the future impacts of extreme climate phenomena.

According to Barreto, et al. [10], it is suggested that UDS can be optimized in terms of system capacity, pollution reduction and reduction of damage to urban infrastructure, in addition to promoting proper environmental management. However, there is a permanent gap facing extreme rainfall events in Peru. Currently, the comprehensive management of rainwater in urban environments is linked to restoring water cycles, that is, reusing water from rainfall through collection and storage infrastructures. In addition, this comprehensive management aims to make cities more habitable, based on an approach based on water management, use of existing infrastructure and natural alternatives; proposing a real solution to the detiorated infrastructure, urbanization, the need for sustainable tools and the climate crisis [11]. In this regard, the International Water Association (IWA) promotes an intelligent society in water use and a wise behaviour in water use, highlighting the advancement of digital technologies and the integration of hybrid solutions combining natural infrastructure with coventional methods. Furthermore, cross-disciplinary collaboration between stakeholders is crucial to identify and resolve conflicts and to develop adaption strategies that will drive the transition towards sustainable and resilient urban drainage systems [12].

One of the pillars proposed in this GWS research is based on *Green Infrastructure* (GI), for example; [13,14] define this term as a set of natural and sustainable solutions designed to manage rainwater effectively in urban environments. It is also linked to the concept "Nature-based Solutions" (NBS), these integrate the water cycle in built areas, adapting to different denominations such as Sustainable Drainage Systems (SuDS), which replicate natural hydrological responses to reduce flow and store water, mitigate urban flooding and consequently improve local quality of life and promote water security.

Based on this, the integration of GI with traditional grey infrastructure in urban flood management provides effective solutions, social benefits and improved ecosystem services from human well-being and economic development [15]. On the other hand, [16] highlight the integration of *Blue Infrastructure* (BI), which are the components of the natural environment related to water, such as rivers, lakes and wetlands. This approach proposes the use of water resources in a sustainable way. Considering the above [17] mention the importance of achieving a green-grey-blue infrastructure (BGGrI) mix, as they highlight this approach as a comprehensive and sustainable alternative to traditional green-grey infrastructure in urban stormwater management. In accordance with this vision, BGGrI proposes a strategy that combines centralized measures to effectively adapt the impacts or urban development and extreme weather events, and that is because integration with BI elements such as rivers and wetlands, strenghtens the path to more resilient cities by providing natural flood defences and other climate adaptation benefits but they require careful coordination to avoid negative impacts. However, this research focuses on the implementation of green and grey infrastructure (GGrI) in an urban context, as it reduces **Combined Sewer Overflows (CSO),** which are events where urban sewer systems such as designed to carry both waste and stormwater, cannot handle the volume of water during heavy rains. This is why the implementation of GGrI proposes an improvement of urban water quality and offers a real long term solution by optimizing the use of existing infrastructure and integrating real-time control techniques, that maximise the efficiency of the system to manage rain events and reduce **CSO effectively** [18]. In addition, Alves, Vojinovic, Kapelan, Sanchez and Gersonius [18] enhance the integration of GI, as it manages urban flood runoff with Nature-Based Solutions (NBS), reducing pressure on drainage systems during heavy rains, and therefore, improving urban resilience, the combination with traditional grey infrastructure and more robust and efficient water management. **Figure 5** details the idea of continuity integration of terms related to this research in order to control urban flooding. From the figure, urban flooding caused by high rainfall is traditionally managed through GrI, such as sewers and storm drains. However, its limited capacity to manage storm run-off has led to the adoption of hybrid approaches, integrating green and grey infrastructure (gardens, parks, green areas) forming the integrated green-grey infrastructure (GGrI). In addition, the incorporation of blue infrastructure (BI), which leverages natural water resources such as rivers, lakes and wetlands, refines this model into a blue-green and grey infrastructure (BGGrI). Sustainable Urban Drainage Systems (SuDS) complement this strategy in parallel, focusing on resilient groundwater management and run-off infiltration through systems that promote biodiversity, amenity and both water quantity and quality, providing a holistic and sustainable solution for urban flood management.

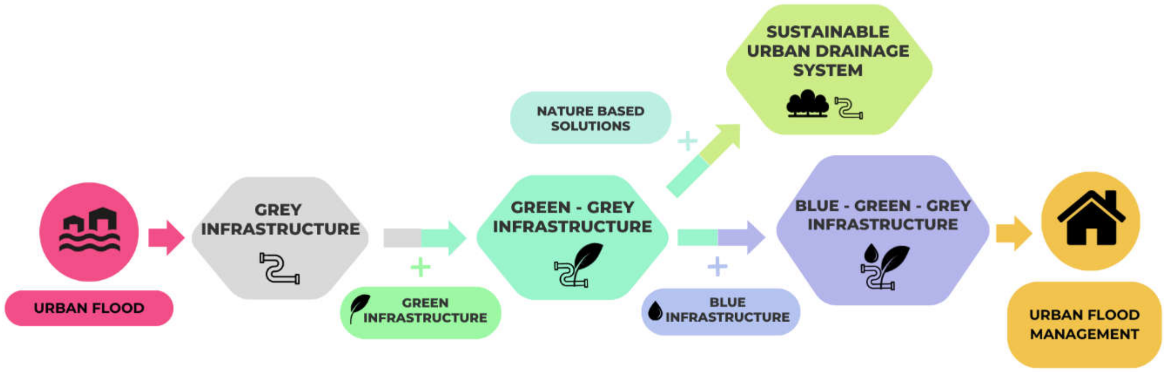

Figure 5. Flow Chart of optimized flood management in relation to existing sustainable tools based on Gray, Green and Blue Infrastructure. Adapted from [13].

Now, with the concepts and definitions developed in Figure 5, where does the term GWS fit? This term is not included in either papers or literature reviews currently, however, its interpretation focuses on the tools implemented by green infrastructure to combat the phenomenon of flooding. According to Ortega Sandoval, et al. [19], they interpret this term as part of an integrated urban stormwater management approach that incorporates green infrastructure techniques, where it is sought to mitigate the adverse effects of rapid urbanization, including increased run-off volume and peak flow, as well as problems of rainfall flooding and waterlogging. Liquete, et al. [20] also understand it as part of the NBS, which seeks to address social, environmental and economic challenges through the use of natural ecosystems or nature-inspired solutions. In the European context, the use of these green infrastructures is promoted as smart strategies to achieve multiple political objectives, including those related to climate change, natural risk management and water policy. It is also important to mention that the countries of the European Union have made various commitments to achieve resilient cities, which are highlighted in the framework of the Smart Mature Resilience project **(2017)**, focusing on the improvement of the capacity of cities to adapt and recover from environmental, social and economic threats, such as natural disasters, climate change and socio-economic crises [21]. This underlines the importance of implementing such measures in Latin American countries such as Peru, adjusting them to the specific vulnerability that each nation faces to natural phenomena.

On the other hand, Rusman, et al. [22] refer to GWS as an aquaculture system that uses dense populations of microalgae present in ponds or other water sources, fed with agricultural and domestic waste, sometimes supplemented with chemical fertilizers. This approach allows for improved management and quality control of water, as well as facilitating the system's rainwater transport. In addition, Zanardo, et al. [23] define it as systems used in aquaculture, especially in shrimp production, that use water from ponds where different species of fish are grown.

Therefore, due to the ambiguity of the term in question, this study will carry out a literature review to understand the various definitions about GWS, that is why this literature exploration aims to answer the following sustainability-based questions **(QBS)**:

- How are GWS developed as a sustainable tool to mitigate urban flooding defined?
- Are GWS a viable alternative to combat pluvial flooding in Peru? Are they the best tool available?

Additionally, and based on the responses of the QBS, a definition of GWS will be reached in this article, from an approach based on NBS resulting in a typology of SuDS. However, it is relevant to consider the definitions of some authors about SuDS, such as [24] who conceptualize it to manage runoff in cities more sustainably and provide other benefits such as mitigation and adaptation to climate change. Also, [19] define it as urban green infrastructure designed for stormwater control, which promotes more sustainable management of runoff in cities and additionally replicates natural drainage conditions prior to urban development and highlights that SuDS research and implementation vary geographically and typologically, depending on local climates and urban conditions.

SuDS undoubtedly play a fundamental role in this research, since it provides a solution to flooding in an urban context. However, for the viability of these, there are "Regulations" or "Design Codes" that provide the criteria, parameters and considerations depending on the type of GWS to be designed. For instance, the SuDS Manual C753 CIRIA [25], is a British guide that provides a comprehensive and detailed framework for the design, implementation and maintenance of SuDS, and offers a variety of SuDS typologies, including bioretention zones, green roofs, permeable pavements, infiltration ditches. This regulation promotes the sustainability and multifunctionality of SuDS, based on a holistic approach, considering both water management and social and environmental benefits. On the other hand, the NS-166 "Criterios para Diseño y Construcción de Sistemas Urbanos de Drenaje Sostenible" EEAB [26] is a Colombian regulation, focused on adapting SuDS to the particular conditions of the city of Bogotá. This regulation considers the climatic, topographic and urban characteristics of the city, providing precise criteria and guidelines for the design and construction of SuDS suitable for these conditions, it also includes the use of local materials and proper construction techniques for the urban environment of the city. Although it also promotes sustainability, its focus is mainly on efficient water management and flood risk reduction, prioritizing hydraulic efficiency and adaptability to local conditions. Now, according to these generalized approaches around the globe, this study will carry out a literature review to understand the various regulations and guidelines that regulate the design, criteria, parameters and considerations for the construction of SuDS in an urban context in Peru, that is why this literary exploration aims to answer the following questions based on design codes (QBC):

- What are the design parameters and characteristics of a GWS with applicability to Peru?
- Is it feasible to develop a "Design Code" proposal for SuDS for an urban context in Peru?

To reach these answers, the "**Materials and Methods**" section outlines the systematic search development in two search engines (Scopus and Web of Science), focused on the definition of GWS. This section analyzes the obtained results accompanied by graphs and tables to aid understanding, and also integrates the concept into the flow chart on urban flood management. Additionally, it addresses the existing regulatory framework on SuDS design worldwide, providing an explanatory and dynamic approach to clarify the concepts developed and related to the article, since it performs a systematic search to obtain results on definitions for GWS and Design Codes for SuDS. The "**Discussion**" section aims to assess the social and economic aspects of applicability regarding the proposed Design Code in Peru, as well as to substantiate the GWS concept. Finally, the "**Results**" section encompasses the entire development of this article, based on hypotheses.

2. Materials and Methods

The methodological development is presented below in the Figure 6.

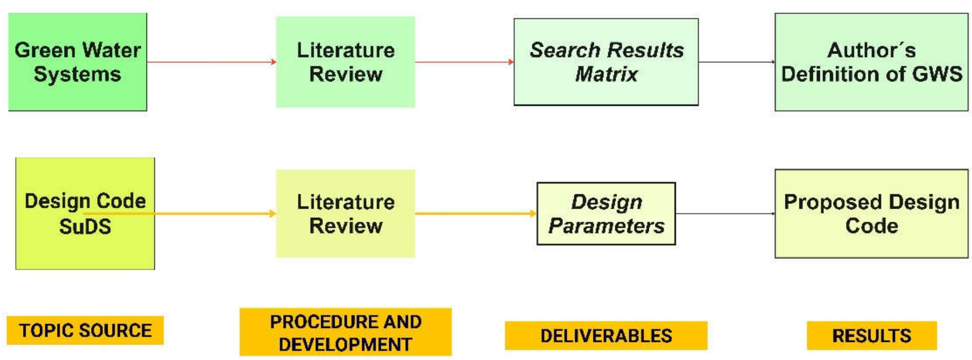

Figure 6. Methodology diagram.

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2.1. Literature Review: Green Water Systems

Scopus and Web of Science (WoS) are considered two of the most rigorous databases in the world, as stated by Zhu and Liu [27], this is due to the attractiveness of different countries, disciplines and researchers to publish their research. Also, according to Martín-Martín, et al. [28], Scopus and WoS are notable because of the correct coverage of indexing and reliable information search. In this article, both search engines were selected since they offer different results to be analysed. Although the information retrieved from Scopus is relevant and varied, the aim is to understand how multiple authors describe GWS, this allows for a wider perspective and a more complete approach to the subject. On the other hand, WoS offers search results aligned with the goal of achieving UFR, by including papers adressing topics such as sustainable urban water management, green and blue infrastructure, sustainable development, green space construction, green technology, water security and green water infrastructure systems. However, there is no precise definition of what GWS are, which requires a detailed analysis of how the authors interpret and define these systems.

2.1.1. Literature Review

The literature review was carried out using specific search operators offered by search engines, with the aim of finding papers related to "Green Water Systems" (GWS). The following consultation was used in the first place: "Green Water Systems" OR "Green Water System", retrieving 38 papers for analysis. Subsequently, an expanded search was conducted using the combination: Green AND Water AND Systems OR System, which yielded 32,431 results.

These results were filtered by topics of interest or keywords such as: (urban, flood, drainage), the area of study (environmental science, engineering), and the type of document, selecting only scientific papers. As a result of this filtering process, 99 papers were obtained and considered for analysis. It should be noted that both search chains cover a period of results from **1999** to 2024. This process is illustrated in **Figure 7**.

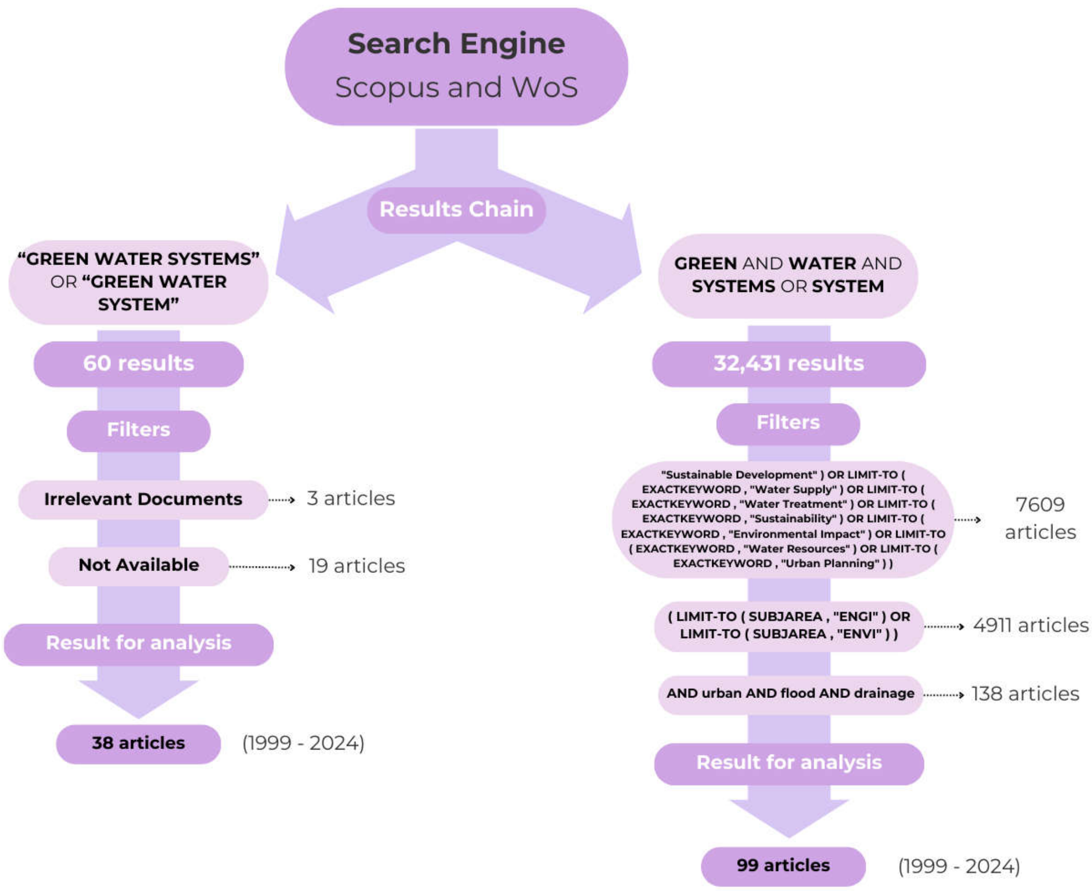

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Figure 7. Flowchart for literature review based on [29].

From the 38 papers selected for analysis, which focus exclusively on the main topic of "Green Water Systems" (GWS), the majority relate to sustainable tools for combating urban flooding. A significant percentage of these studies address topics in aquaculture and marine sciences, while a smaller number focus on areas such as agriculture and chemical ecology. This distribution reflects the various applications and approaches within the field of GWS, highlighting the importance of this concept across different scientific and geographical contexts.

Table 1 shows the distribution of the analyzed papers according to their country of origin, which allows to identify the regions of the world where research on GWS is most active and how it is oriented towards different areas of study. This will be reflected in **Table 3**.

Table 1. Distribution of papers in countries that have at least one GWS-related article.

Country	Documents
Australia	2
Brasil	5
Egypt	1
Spain	1
E.E.U.U.	6
Philippines	2
Greece	1
India	9
Iran	3
Malaysia	3
Peru	2
Sweden	1
Thailand	1
Vietnam	1
Total	**38**

Table 2 shows the journals in which GWS-related papers were published, giving results regarding the line of research on aquaculture, marine sciences, chemical ecology, agrotechnology, pharmacy and environmental sustainability, in addition to adding an indicator for the development of **Table 3**.

Table 2. Journals consulted and their categorization by indicators.

Scientific Journal	ID	Quartile
Aquaculture International	**R1**	**Q2**
Algal Research	**R2**	**Q1**
Applied Biochemistry and Biotechnology	**R3**	**Q2**
Aquaculture	**R4**	**Q1**
Aquaculture International	**R5**	**Q2**
Aquaculture Nutrition	**R6**	**Q1**
Aquaculture Reports	**R7**	**Q1**
Aquaculture Research	**R8**	**Q2**
Comparative Biochemistry and Physiology - Part A: Molecular and Integrative Physiology	**R9**	**Q1**
Developmental and Comparative Immunology	**R10**	**Q3**
Environmental Science: Water Research and Technology	**R11**	**Q1**
Fisheries Science	**R12**	**Q3**
Food Security	**R13**	**Q1**
Indian Journal of Fisheries	**R14**	**Q4**
International Journal of Agriculture and Biology	**R15**	**Q3**
Israeli Journal of Aquaculture - Bamidgeh	**R16**	**Q3**

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Journal of Green Building	**R17**	**Q2**
Journal of Sustainability Science and Management	**R18**	**Q3**
Journal of the World Aquaculture Society	**R19**	**Q3**
Scientific Reports	**R20**	**Q1**
Journal of Fish Diseases	**R21**	**Q1**

Table 3. The distribution of the 38 analyzed papers according to their study areas reveals a significant percentage in the fields of aquaculture and marine sciences. This predominance highlights the relevance of these disciplines in research on Green Water Systems (GWS), demonstrating their application and importance in these sectors.

ID	**Aquaculture**	**Agriculture**	**Agrotechnology**	**Marine Science**	**Chemical Ecology**	**Pharmacy**	**Environmental Sustainability**	**Total**
R1	2							2
R2					1			1
R3	1							1
R4	**3**			3	1			6
R5	1			2				3
R6	1	1						2
R7		1						1
R8	3		1	1				5
R9				1				1
R10				1				1
R11							1	1
R12				1				1
R13							1	1
R14	1			1				2
R15				1				1
R16	1							1
R17	**1**						1	1
R18				1				1
R19	1			1				2
R20						1		1
R21	1							1
Total	**16**	**2**	**1**	**13**	**2**	**1**	**3**	**38**

It is important to highlight that each of the analyzed journals are within the relative importance indicators related to the research line (aquaculture, marine sciences, agrotechnology, chemical ecology, pharmacy, and environmental sustainability), with 43% of journals in Q1, 23% in Q2, 28% in Q3, and 5% in Q4. Thus, **Table 3** presents, based on the analyzed journals, the research line that develops the concept of GWS.

From **Table 3**, it is evident that the aquaculture and marine science lines predominate with 76,3% in relation to the others and that is because the closest definition of what a GWS is within these study areas. From the point of view of aquaculture in relation to larval farming: GWS are an aquaculture method using green water, which consists of microalgae or phytoplankton in order to improve the environment and nutrition of larvae of different marine families, such as various species of fish [30–37], octopus [38], crabs [39,40] and lobsters [41–43]. Also, different authors pay attention to the breeding of shrimps from natural feeding strategies produced endogenously [44–58]. The breeding of sea horses with microalgae paste replacing a clear water system [59]. [60] argue that GWS use microalgae such as "Chlorella" to improve water quality and aquatic animal health, increasing their

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growth and survival, this system is activated to provide an abundant source of natural food. [61] refers to it as an ecological method for synthesizing an adsorbent nanocompound used in the removal of heavy metals from water. Finally, from the science of environmental sustainability, [62] emphasize GWS based on green water management, which covers evaporation and precipitation used mainly in agriculture. Rhoads, et al. [63] frame green water systems in sustainable buildings, because they can have unexpected consequences for public health and aesthetics. Also, Brazeau and Edwards [64] refer to GWS, as instantaneous hot water systems that promise energy and water savings.

On the other hand, when placing GWS with boolean operators, that is: *Green AND Water AND Systems OR System* the search engine offers 106 relevant results, **Figure 8** shows the number of documents per country assigned to this search.

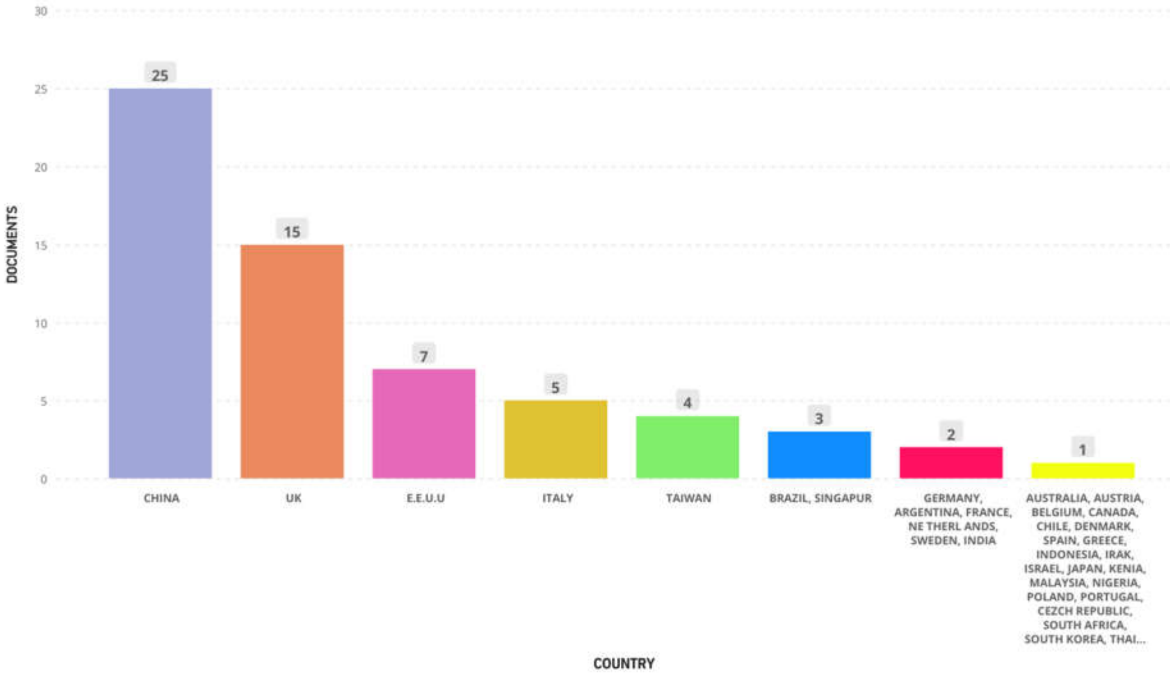

Figure 8. Number of documents per country assigned to this search.

The figure shows that China has a significant impact on GWS-related studies, accounting for 25.3% of published papers. However, the UK with 15.2% and the US with 7.1% also maintain a strong presence in this field of research. Upon reviewing the papers from China, it is observed that they focus on sustainable water management in urban environments. The titles highlight concepts such as "sponge cities," green and gray infrastructure, stormwater management, and resilience strategies. These studies address key challenges such as climate change adaptation, optimizing water use, and integrating sustainable technologies into urban planning.

Figure 9 presents an analysis of the field of research based on the number of papers retrieved through the search: "Green AND Water AND Systems OR System". The results obtained show a significantly different picture compared to a specific search for "Green Water Systems". Based on this, disciplines such as aquaculture and marine sciences are virtually excluded from the agenda, suggesting that these areas have less relevance or impact in the context of green systems and water management in urban or sustainable environments. This contrast underlines the importance of a proper selecton of search terms to obtain a more accurate view of the field of study.

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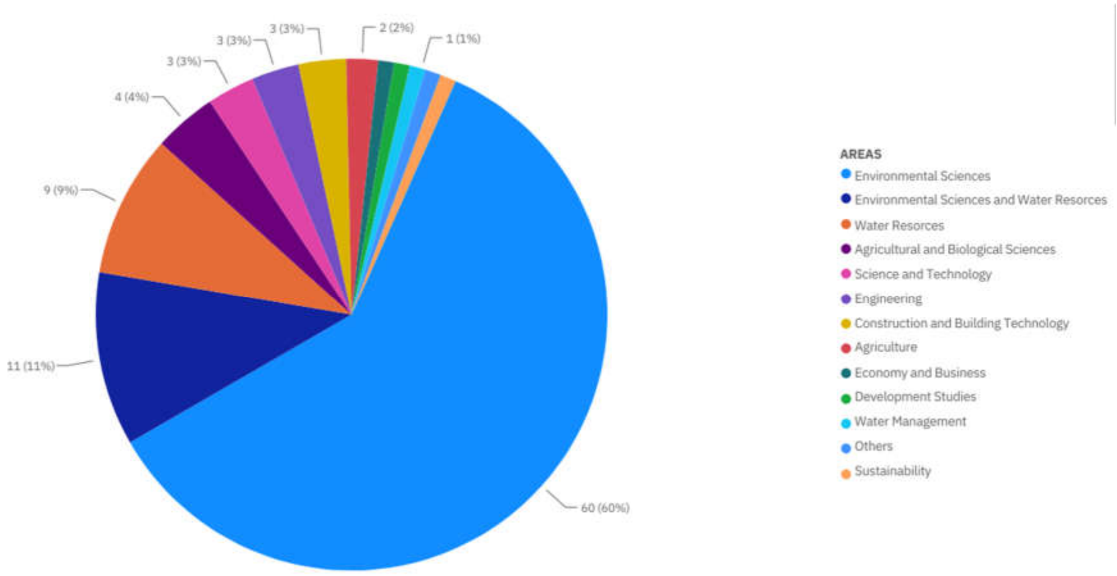

Figure 9. Distribution of papers in the different research areas of the second search model.

Environmental Sciences and Water Resources are highlighted as the predominant areas in the analysis, together representing 71% of the evaluated fields of study. This strong presence reflects the interconnection and relevance of both disciplines in the current research, emphasizing their crucial role in developing sustainable solutions for water management and environmental preservation. Undoubtedly, the review has revealed high-quality information related to urban flood mitigation. However, it is important to highlight that the specific concept or definition of GWS is not explicitly mentioned in any of the analyzed papers. Instead, this concept can be inferred or interpreted implicitly through the content of the studies. This suggests that, although the topic is addressed, the lack of a clear and direct definition might limit the uniform understanding and consistent application of the term in research on sustainability and water management in urban environments.

This hypothesis is demonstrated, based on studies [65–68], which indicate that the tools and systems needed to mitigate urban challenges related to flooding, water scarcity and climate change are the "Sponge Cities" through the incorporation of green systems. They focus on rainwater collection and reuse, offering a sustainable and efficient solution to manage water resources in vulnerable environments. Centralized stormwater management, proposed by a large body of literature [69–78], through the implementation of systems that control runoff, minimize erosion, pollution and promote water reuse. Adapting existing infrastructures to improve resilience to climate change, plus [79–83] implementing models and assessments, such as the Storm Water Management (SWMM) and Real Time Control (RTC) allow the design and improvement of drainage infrastructure, adapting it to future needs and local characteristics even through these models have not reached the expected range, [84,85] denote systems wich include vegetation, not only improve the urban aesthetic but also increase resilience to flooding by naturally absorbing water (NBS); these proposal of various strategies such as integration of BGI, GIS tools and SuDS seek to maximize environmental, social and economic benefits while minimizing environmental impact [18,78,86–100]; additionally the need for policy and strategic frameworks to emphasize effective water resource management, including green water valuation and technologies adapting to new concepts for water monitoring and conservation in vulnerable areas [68,101–117]; a concept that highlights among papers [118–137], is urban resilience wich is achieved through the integration of green, blue and grey infrastructures, this implies a proactive and innovative approach; added to this [138,139] support the sustainability criterion in urban ecosystem management not only control floods but also provide vital ecosystem services such as habitat provision and water quality regulation. In parallel to these ideas SuDS take a main pillar because their effectiveness lies in their multifunctional approach wich includes systems such as green roofs, vegetated ditches, permeable pavements, among others, strengthen and encourage a reduction

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in the load of traditional drainage infrastructure and the improvement of water efficiency [140–155]. Finally, [156,157] plays a crucial role in urban flood mitigation by providing advanced tools to model and assess water behavior in urban environments through the use of hybrid frameworks that combine hydrological and hydraulic modeling.

Based on the approach outlined in the definitions of the first search model, *"Green Water Systems"* is understood as a sustainable aquaculture approach that uses phytoplankton or microalgae to improve water quality and the health of aquatic organisms. This system aims to optimize the aquatic Environment to enhance the growth and survival of various species, either in recirculating green water systems or in microalgae-enriched tanks. Although definitions related to UFR in the environmental sustainability field are limited, these are not closely linked to urban flood mitigation. On the other hand, the second search model which combines the terms *"Green AND Water AND Systems OR System"*, focuses on sustainable tool approaches based on the integration of traditional infrastructure with green elements and the need to implement them in a real context such as SuDS, highlighting an important role in water management, hydrological technology, innovate concepts, all in order to mitigate urban flooding and promote sustainable practices in water management.

2.1.2. Design Codes SuDS

Since various countries already have guidelines or standards for SuDS design in their territories, these will serve as a basis for developing a GWS proposal using SuDS. In this study, the countries considered in the comparison were selected because they represent a wide range of climates and economies. **Table 4** displays the comparison of climate and economic classification for each country shown for the review of parameters.

Table 4. Distribution of SuDS types designed in the guides or regulations of each studied country.

Country	Climate [158]	Economy [159]
United Kingdom	Maritime	Developed
Canada	Continental	Developed
Colombia	Tropical	Developing
El Salvador	Tropical	Developing
France	Temperate	Developed
Malaysia	Tropical	Developing
Spain	Mediterranean	Developed

Within these climate and economic classification criteria, Peru would be categorized as a tropical climate country with a developing economy.

Below are the regulations and guidelines used in this article:

- United Kingdom: The SuDS Manual (C753) [25]
- Canada: Stormwater Management Planning and Design Manual [160]
- Colombia: EAAB – Norma Técnica de criterios para diseño y construcción de sistemas urbanos de drenaje sostenible (NS-166) [26]
- El Salvador: Guía Técnica para el diseño de SuDS [161]
- France: Guide de Gestion des eaux pluviales [162]
- Malaysia: Urban Stormwater Management Manual [163]
- Spain: Guía Básica para el Diseño de Sistemas Urbanos de Drenaje Sostenible [164]

3. Results

3.1. Proposed GWS Definition

Based on the systematic approach developed in the Materials and Methods section, it is concluded that there is no clear and concise definition of GWS in the fields related to urban flooding, resilience, sustainability, environmental sciences, and water resources. However, a more established

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definition does exist in the context of aquaculture and marine sciences, which diverges from the focus on urban flood resilience. Taking this into account, formulating a definition for GWS requires a definition of "Green Water,"; and since [104,165] define it as water derived from precipitation that is stored in the soil and subsequently absorbed by plants through processes such as evapotranspiration. This type of water is part of a natural cycle and differs from blue water (surface or groundwater) or gray water (contaminated water). However, based on the systematic search analysis, important variables emerge that researchers highlight in their studies. **Figure 10** brings together those key terms that are fundamental for a concrete and clear definition of what GWS is.

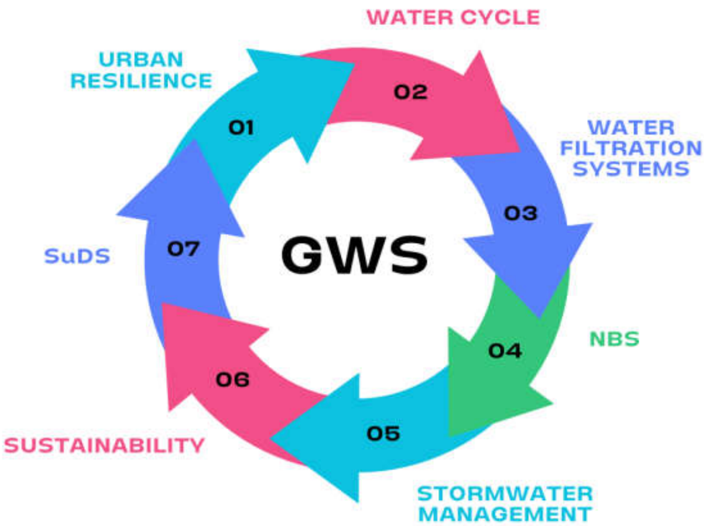

Figure 10. Variables considered for proposing a definition of GWS.

Based on this, a Green Water System can be defined as follows: A Green Water System is an approach to sustainable water management in urban environments that considers the natural water cycle and combines nature-based solutions, such as integrated green water collection and filtration systems, with sustainable urban drainage systems. These elements work together to improve stormwater management, promote sustainable tools, and enhance urban resilience to flooding, ensuring a balance between gray, green, and blue infrastructure. This method considers specific parameters of green water to ultimately reuse the captured water for specific purposes.

This definition helps clarify a key term in urban flood management. By integrating concepts of sustainable urban drainage systems (SuDS), water collection, and transport systems, it provides a clearer, more direct, and comprehensive approach to developing resilient infrastructure in an urban context. This helps to bridge the knowledge gap in the study of sustainable tools, promoting a robust and applicable conceptual framework for water management and the water cycle.

3.2. International Review of SuDS Regulations

Table 5 analysed the various types of SuDS in the mentioned countries in the Materials and Methods section.

Table 5. The distribution of SuDS types designed in the guides and/or regulations of each studied country.

Types of SuDS	Country						
	United Kingdom	Canada	Colombia	El Salvador	France	Malaysia	Spain
Green roofs	X			X	X		
Soakaways	X	X					
Water butts	X						

Rainwater tank	X		X	X		X	
Filter strips	X	X		X			
Trenches	X	X	X	X	X		X
Swales	X	X	X	X		X	X
Bioretention	X			X	X	X	X
Pervious pavement	X		X	X	X	X	X
Geocellular/modular systems	X						
Sand filters	X	X			X		
Infiltration basins	X	X	X		X		
Detention basins	X				X		
Ponds	X	X		X		X	X
Stormwater wetlands	X	X		X	X	X	X
Reduced lot grading		X					
Rear year ponding		X					
Pervious pipes		X			X	X	
Oil/grit separators		X			X		
Filter drains	X				X		X
Trees	X		X				X

However, it is worth noting that despite having a variety of SuDS, the focus will be on one particular type: bioretention areas. According to CIRIA [25], these areas are vegetated zones that help filter runoff, and they consist of layers of materials such as gravel and sand that assist in filtering and treating the water. They offer benefits such as reduced runoff, improved water quality, and decreased drainage infrastructure. And based on the research conducted by [165], these areas can store captured water in an underground reservoir for future reuse. In summary, these bioretention areas are also a type of Green Water System due to their ability to treat and manage rainwater for reuse. Therefore, this type of SuDS meets the definition proposed in section 3.1 on GWS. As a result, they will be considered in the review of parameters shown in **Table 6**.

Table 6. Review of the design parameters for bioretention areas in countries that include them.

Design parameters	Units	Country				
		United Kingdom	El Salvador	France	Malaysia	Spain
Area	ha			1 or less	1 or less	-
Impervious Surface Area	%	5 to 10	5 to 10	5 to 10	-	-
Slope	%	-	< 10	< 5	< 5	
Distance to the water table	m	1	3	1.2	> 0.6	1
Composted organic material	%	-	5 a 10	-	-	-
Time for adequate capacity	hrs	24	-	-	-	-
Water Depth	m	< 0.15	-	-	-	-
System Depth	m	-	-	-	-	< 0.3
Width	m	-	-	-	-	> 0.6
Conductivity	mm/hr	-	-	25 or more	> 13	100 - 300
Planting density	plants/m2	-	-	-		6 a 10
Velocity	m/s	-	-	-	< 0.5	-

The variation in values in the previous table is evident, which is due to the different hydraulic characteristics of the area being addressed.

3.3. Aplication in Peruvian Context

Currently, Peru has a stormwater drainage regulation, CE.040 Saneamiento [166], still, this document does not consider sustainable systems, and it mentions traditional drainage systems as the only alternative. Among these systems are infiltration galleries, which aim to filter water similarly to

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bioretention areas. Unfortunately, it only provides the maximum flow velocity within this system as the sole parameter.

Based on the above, once the design parameters for bioretention areas were compared in section 3.2, the following values were recommended as part of the proposed regulations in **Table 7**.

Table 7. Proposed design parameters.

Design parameters	Units	Proposal
Area	ha	1 or less
Impervious Surface Area	%	5 a 10
Slope	%	< 5
Distance to the water table	m	> 0.6
Composted organic material	%	5 to 10
Time for adequate capacity	hrs	24
Water Depth	m	< 0.15
System Depth	m	< 0.3
Width	m	> 0.6
Conductivity	mm/hr	> 13
Planting density	plants/m2	6 to 10
Velocity	m/s	< 0.5

All the recommended parameters from each regulation and guide were considered. However, when overlapping values were encountered, the climate and economic classifications presented in section 2.1.2 were considered. Notably, countries with climates and economies like Peru's are Colombia and Malaysia, with the latter being the only one with regulations for bioretention areas. Therefore, the proposal favors Malaysia's values in case of discrepancies with other standards.

Additionally, since it involves a GWS and aims to reuse Green Water, it will be used a storage tank sized using the Daily Water Balance method. The following expressions developed by García-Colin, Díaz-Delgado, Salinas Tapia, Fonseca Ortiz, Esteller Alberich, Bâ and García Pulido [165] can be used to design the tank, taking into account precipitation and evapotranspiration in the system.

The efficiency of supply over a period j (EF_j) is represented by a split between daily accumulated deficit and demand as shown in the **Equation 1**.

$$EF_j = 1 - \frac{\sum Def_i}{\sum R_i} \tag{1}$$

Where $\sum Def_i$ is the cumulative deficit and $\sum R_i$ is the sum of the irrigation depth, which may be considered with or without leaching as appropriate. In turn, the amount of water in the tank is calculated using **Equations 2** and **3**.

$$Def_i = \begin{cases} 0, & SG_i + SG_{i-1} \geq R_i \\ R_i - SG_i - SG_{i-1}, & SG_i + SG_{i-1} < R_i \end{cases} \tag{2}$$

$$SG_i = \begin{cases} 0, & Gp_i + SG_{i-1} \leq R_i \\ SG_i + SG_{i-1} - R_i, & SG_i + SG_{i-1} > R_i \\ S, & SG_i + SG_{i-1} - R_i \geq S \end{cases} \tag{3}$$

Where SG_i is the percolation (offer), R_i is the daily irrigation depth (demand), both being in mm units, SG_{i-1} is the daily amount of water and S is the proposed height, both measured in mm. With this procedure, it can be determined the efficiency of each proposed reservoir height, allowing to verify that the system will be capable of storing water and releasing it at the desired time.

4. Discussion

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The discussion in this article is relies on the research questions (QBS and QBC), and based on the methods used and the results obtained, it is possible to address each of the formulated questions.

- **How are GWS developed as a sustainable tool to mitigate urban flooding defined?**

Green Water Systems (GWS) encompass a comprehensive approach to the collection and management of green water in urban environments. These systems employ nature-based solutions and sustainable urban drainage practices. This method considers green water parameters to optimize water capture and reuse. The primary goal of GWS is to mitigate urban flooding. To achieve this, they efficiently integrate existing infrastructure (gray infrastructure) with green and blue infrastructure elements. This integration not only improves stormwater management and reduces flood risk, but also contributes to overall environmental sustainability by promoting a more balanced and resilient urban envinroment (UFR).

- **Are GWS a viable alternative to combat pluvial flooding in Peru? Are they the best tool available?**

Peru presents a great climatic and geographic diversity. Coastal and urban areas, such as Lima, Arequipa, Cusco, and other regions of Peru, can benefit from GWS due to their capacity to manage rainwater/precipitation and reduce flood risk in areas with limited gray infrastructure. However, in regions with intense rainfall or mountainous terrain, implementing or integrating GWS may require technical adjustments to adapt to local conditions. Additionally, GWS promote environmental sustainability by integrating vegetation (green areas) with existing urban infrastructure, improving water quality and fostering biodiversity. They highlight their connection to SuDS as fundamental design pillars, encouraging the creation of green spaces that enhance quality of life in urban areas without the need to completely replace existing systems, such as stormwater drainage and sewer systems. Nature-Based Solutions (NBS) align with GWS principles by offering a more integrated approach that combines green, gray, and blue infrastructure with water management systems. **Figure 11** highlights how GWS fit into the proposed continuity line for urban flood management.

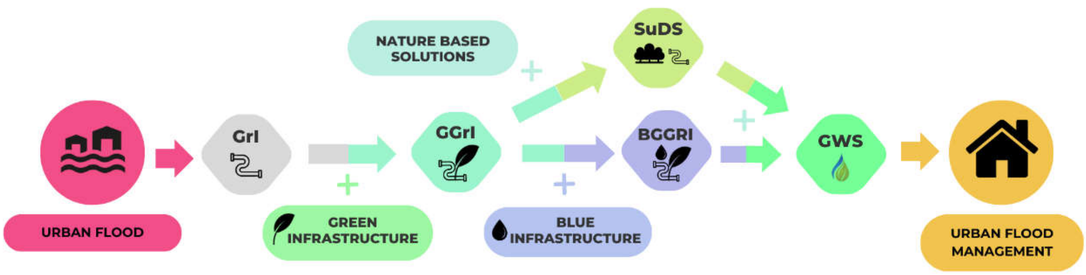

Figure 11. The continuity line frames GWS as a current sustainable tool that combines fundamental pillars of green infrastructure, nature-based solutions, and sustainable urban drainage systems, integrated with water capture and infiltration systems (BI) to manage and handle urban flooding.

It can be concluded that GWS can be a valuable tool for combating urban flooding in Peru, especially when adapted to local conditions and integrated with existing infrastructure. According to Espinoza Vigil and Carhart [167] the need and the challenge of implementing sustainable and resilient infrastructure in a Peruvian context will depend on a holistic management and approach to prevent them from operating in isolation and adapting to the changing needs of the population in Peru. Added to this, the effectiveness of GWS will depend on proper planning and design, as well as their integration with other water management strategies.

- **What are the design parameters and characteristics of a GWS type with applicability to Peru?**

As seen in section 3.2 of the Results, the most important parameters to consider are: area, impervious surface area, slope, distance to the water table, composted organic material, time for adequate capacity, water depth, system depth, width, conductivity, planting density, and velocity. Each of these design criteria has been developed using the International System of Units (SI) in each of the countries studied, so the proposal for Peru will also follow these units. However, if another region wishes to use this research to develop its own regulations and uses a different system of units, the values are easily convertible. It is also noted that the proposal is pending field validation for future implementation.

- **Is it feasible to develop a "Design Code" proposal for SuDS in an urban context in Peru?**

Although this research standardizes GWS through the use of bioretention areas, which is a type of SuDS, it does not overlook the opportunity to utilize the design parameters of this system to develop SuDS regulations in Peru. It is important to note that Peru already has stormwater drainage regulations; however, they lack parameters regulating SuDS or GWS. Therefore, this article can be used to expand the current regulatory framework.

Regarding the SuDS design regulations, it should be noted that there are more documents worldwide that regulate their design. In some of the countries mentioned in the Materials and Methods section, there are various guides for each region within the country. For example, in Spain, this study used the document from Valencia. However, there is another guide from Madrid, which was not included in this study because the parameters examined are similar regardless of the city.

Peru currently does not have regulations governing SuDS or GWS, on the other land in its OS.010 [168] of its National Building Regulation have "Filter Gallaries" that have a similiar use to the bioretention zones. However, they do not have defined the parameters seen in this investigation.

5. Conclussions

Flood resilience in urban areas can be significantly improved with the proposed definition of Green Water Systems (GWS), as they offer a comprehensive approach to managing green water in urban environments. GWS utilize nature-based solutions and sustainable drainage practices, optimizing water capture and reuse by considering important parameters such as evapotranspiration. In Peru, GWS are a viable option for mitigating floods in urban areas, adapting to specific local conditions and enhancing stormwater management. Additionally, they promote sustainability by integrating vegetation with existing urban infrastructure, improving water quality and fostering biodiversity. However, the effectiveness of GWS will depend on proper planning and their integration with other water management strategies. Although they do not completely replace traditional drainage systems, their combination with gray infrastructure and alignment with Nature-Based Solutions (NBS) offers a sustainable solution to urban flooding. Therefore, GWS can be a valuable tool within a comprehensive strategy to enhance flood resilience.

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