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Review

Integrating Biophysical and Economic Assessment: Review of Nature-Based Adaptation to Urban Flood Extremes

Carlotta Quagliolo [1,*], Peter Roebeling [2,3], Rita Mendonça [2], Alessandro Pezzoli [1] and Elena Comino [4]

[1] DIST—Interuniversity Department of Regional and Urban Studies and Planning, Politecnico di Torino and Università degli Studi di Torino, 10125 Torino, Italy
[2] Centre for Environmental and Marine Studies (CESAM), Department of Environment and Planning (DAO), University of Aveiro, 3810-193 Aveiro, Portugal
[3] Wageningen Economic Research, Wageningen University and Research (WUR), 6708PB Wageningen, The Netherlands
[4] DIATI—Department of Environment, Land and Infrastructure Engineering, Politecnico di Torino, 10129 Torino, Italy
* Correspondence: carlotta.quagliolo@polito.it; Tel.: +39-3333103770

Abstract: Over the last decade, the potential of nature-based solutions (NBS) has been recognized to support climate change adaptation, by promoting sustainable urban planning. Nevertheless, a wider uptake of such solutions in urban areas faces different challenges and barriers. A comprehensive mapping of available NBS impact assessment methods could help to accelerate this process. There is, however, a lack of comprehensive systematization of economic analysis. This research aims to provide an overview of NBS impact evaluations by assessing how the scientific literature integrates such economic analysis into urban planning adaptation. A systematic review approach has been used to discuss the role of NBS in climate change adaptation. This review presents two main stages. Firstly, it identifies the biophysical–economic assessment of NBS adaptation measures to reduce urban flood extremes in coastal cities. Secondly, the NBS approaches were categorized based on the biophysical benefits (in terms of flood-risk reduction) related to each specific solution and the subsequent economic evaluation of such implementations. This research review revealed a low-level gap of integration between climate change issues and NBS analysis (i.e., it is commonly used as background condition). Most publications provide NBS biophysical impacts assessment, without combining these results with economic evaluation of the flood damages to finally achieve the avoided cost due to the implementation of such solutions. This work shows the growing interest on further research to develop spatially integrated environmental–economic assessment of NBS implementation, by highlighting the needs and opportunities of a trans-disciplinary approach to support policy-making in the framework of urban climate change adaptation.

Keywords: climate change adaptation; nature-based solutions (NBS); coastal cities; spatial assessment methods

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1. Introduction

Climate change has been widely acknowledged as a global issue that results in even larger impacts on the city level [1]. Although climate change effects are directly related to temperature and sea-level rise, the increasing frequency and severity of urban floods are also strictly associated with climate change processes [2]. An urban (or pluvial) flood refers to the runoff exceedance in respect to the drainage capacity, during high-intensity and short-duration precipitation events [3,4]. Consequently, the sensitivity of urban areas to runoff is increasing because of the high level of impervious surfaces and the changes in precipitation patterns [5,6]. Indeed, these impacts are directly related to microclimate and land-use differences within each city, instead of differing only in their geographical locations and climate conditions [7]. Land-use dominated by built-up areas strongly reduces water infiltration and causes excessive runoff [8]. This situation is likely to become more relevant in the future, particularly in coastal cities where the simultaneous occurrence of pluvial floods and storm surges, combined with high tides, exacerbates the level of risk [2,9,10].

Climate and flood-risk adaptation should be flexible and multifunctional because of the uncertainty of climate impacts, especially considering local spatial variability within the urban environment [7]. Consequently, urban design principles should be driven by ecological ideas of non-linearity and heterogeneity [11]. Moreover, harmonizing the increasingly urban development and the ecological balance of urban spaces is becoming one of the biggest challenges for urban planning [12]. The European Commission (EC) is addressing these challenges by emphasizing the potential of nature-based solutions (NBS) as an urban climate change adaptation strategy, being multifunctional, as well as by providing connectivity and multiple co-benefits [13,14]. NBS emerged as a new concept built on older concepts, such as the "ecosystem-based approach", and has been promoted by the EC through financial support embedded in the Horizon 2020 agenda [15]. Following the EC, NBS are intended to be "solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience. Such solutions bring diverse natural features and processes into cities through locally adapted, and systemic interventions" [16].

To be effective, NBS require trans-sectoral and integrated planning into urban climate change adaptation for their mainstreaming at the local level. Despite the potential of NBS being increasingly recognized, comprehensive knowledge and consistent data about their benefits are still missing [17]. In this view, specific assessments of NBS biophysical and economic performance could give a significant contribution to overcoming some barriers that are limiting wider implementation of NBS in cities. Such analysis can aid the urban-planning practice by selecting, simulating, and evaluating NBS application, thus assessing the related costs and benefits of flood adaptation [18]. Employing such an approach helps to adopt site-specific performance-based solutions suitable for future urban strategies given the climate change trend [19].

In literature NBS for flood-risk mitigation range from the building scale, such as green roofs and facades, to the street and park scale, such as rain gardens and permeable paving. Given their high ability for retrofitting to existing structures, the effectiveness of NBS to reduce flood risk. in terms of peak flow, runoff, flood volume and flooded area. has been addressed by a range of prior studies [3,20–23]. However, more quantitative results, by integrating biophysical and economic (co-)benefits regarding the impacts of NBS, are needed [18,24,25].

The aim of this study is, hence, to analyze how NBS biophysical performance and economic impact evaluations are developed and integrated into urban planning adaptation. By systematically reviewing the biophysical and economic assessment of such measures to address flood extremes in coastal cities, this article discusses the role of NBS in climate change adaptation planning.

The paper consists of five sections. Section 1 includes the introduction, while Section 2 presents the applied methodology to conduct the rapid systematic literature review. Section 3 shows the results by describing the different phases of the review process, until the in-depth analysis on the focus areas of this article. Finally, a discussion on overlaps and gaps identified by assessing focus themes has been conducted in Section 4, followed by the conclusions in Section 5.

2. Systematic Literature Review: Methodology

A rapid literature review carried out systematically, to examine the recent literature with consistency, which has been subjected to the peer-review process [26,27]. The conduction of rapid reviews, instead of full systematic ones, allows a literature review to be undertaken in a shorter time and with limited financial funding, while being considered robust [28,29]. The competences of the authors are strictly related to those needed to cover the three focus areas (see Section 2.2) considered in this review. This literature review was conducted based on a research methodology consisting of two subsequent macrosections (see Figure 1). The first stage (Section 2.1) includes the search phase and three-step procedure to create the inventory of the studies, by using a standardized data-extraction sheet (Excel). Subsequently, the selected database has been reviewed, deepening the focus areas. Section 2.2 describes the method employed to collect the relevant concepts, answering this review objective.

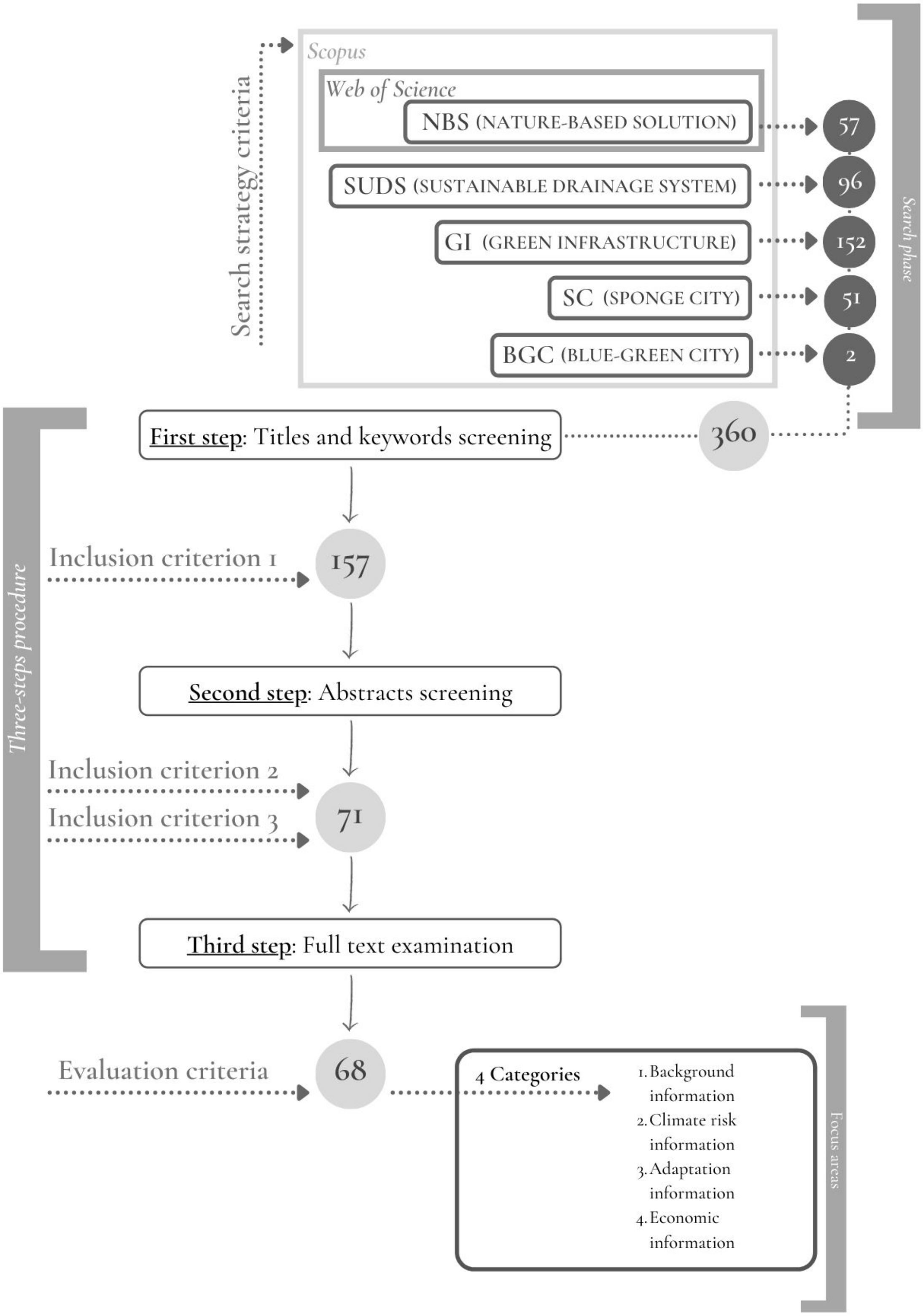

Figure 1. Systematic literature review flowchart.

2.1. Search Strategy and Inclusion Criteria

The initial phase of the review consisted of a literature search for relevant studies published in English, up to December 2020. The literature search was finalized in July 2021. In this case, the rapid systematic review has been limited to two electronic search databases. Firstly, the search was carried out by using the online database in Scopus (www.scopus.com (accessed on 16 March 2020)) through a combination of different search strings. The search strategy includes the following combination of terms and their synonyms: "nature-based solution*" together with "flood*", "cit*", and "adaptation*". In order to conduct a wider review on nature-based adaptation approaches to mitigate urban-flood issues, other terminologies meeting the NBS concept have been identified. The definitions related to urban stormwater management became more complex and diverse [30]. Therefore, four additional terms overlapping the broad principles of NBS were selected for this search step: sustainable urban drainage system (SuDS), green infrastructure (GI), sponge city (SC), and blue-green city (BGC). The search strings and strategy are available on request to the authors. Given the main focus on exploring NBS, which is a quite recent term, an additional search by adopting the scientific database Web of Science (www.webofknowledge.com (accessed on 16 March 2020)) has been conducted [12,15]. This last search includes the same combination of terms with NBS. After the exclusion of duplicates, 360 publications remained.

The first step procedure consists of scanning the titles and keywords. Studies focused on the following aspects were excluded from further analysis because they were out of scope (criterion 1—Figure 1):

- Governance and institutional aspects;
- Hydrological and engineering aspects;
- Different hazards from urban and coastal flood;
- Inland cities or rural areas.

This screening resulted in 157 studies for inclusion in the second step of the review process. Abstracts were scanned using indicator analysis. Four indicator groups with a set of related keywords were selected in order to have an overview of this review topic. The second screening limited the publications to peer-reviewed articles and book chapters (criterion 2—see Figure 1) and studies that contained at least one economic-related keyword from the abstracts (criterion 3—Figure 1). After this step, 71 studies fulfilling all the inclusion criteria remained, and full-text documents were downloaded to conduct the in-depth evaluation. The final number of publications included for the third step of the procedure is 68, because of the exclusion of studies that could not be accessed. Refer to Appendix A for the full list of selected studies.

2.2. Review Focus Areas

To ensure consistency and controlled extracting data across all selected studies, the publications were analysed using a standardized data-extraction sheet (Excel) inspired by previous review articles [7,31]. The Excel sheet used to obtain the data is available on request to the authors. The use of predefined evaluation criteria has been refined in an iterative process, by considering four sections (Table 1): (i) background information, (ii) climate risk information, (iii) economic information, and (iv) adaptation information. For each publication, the whole content was considered in the review.

Table 1. Evaluation criteria used for the in-depth analysis.

Category	Description	Indicator
Background information		
Temporal scale	Time of analysis	Reference year(s), NA
Spatial scale	Scale of analysis	Global, national, regional, local/city, district, neighborhood
Geographical area	Setting of conducted analysis	Country—Region—City, NA
Study type	Kind of methodology used	Conceptual/empirical framework, spatial assessment, modelling
Data used	Type of information and data employed for the analysis	(Short explanation)
Data provided	Kind of data provided by the study	Qualitative, quantitative, spatial, and mixed data (quantitative and qualitative)
Climate risk information		
Climate hazard	Climate and natural hazards addressed by the studies	Single, compound, and multiple hazards
Climate Change perspective	How climate change issue has been addressed by the studies	Background, analytical, scenarios, NA
Economic information		
Economic assessment	Kind of approach employed in the analysis	Cost–benefit analysis, Life-cycle cost analysis (LCCA), flood depth damage analysis, unit cost value analysis, cost effectiveness analysis, NA
Currency	Currency used for the analysis	
Unit	Unit used for the analysis	
Adaptation information		
Adaptation planning perspective	How adaptation through NBS implementation is integrated into urban planning	(Short explanation)
NBS type	Specific NBS to reduce flood-related effects	(Most common measures to flood reduction)
NBS approach	Kind of information provided on NBS	Qualitative, quantitative, NA
Biophysical assessment	Numeric value of biophysical flood reduction	Runoff reduction values

The final database consists of a first part aimed at framing the studies in relation to a contextualization in temporal and spatial terms. Information considered relevant to grasp the background of this analysis of the study type, as well as the data used and provided by the peer-reviewed publications, have been included. The information on the applied methodology is useful to identify if and how the researchers implement NBS impacts assessment. The collected information on the data used serves to provide knowledge of in which ways the analysis has been conducted. Therefore, based on the information provided, the studies were classified in qualitative, quantitative, mixed (both qualitative and quantitative), or spatial analysis.

The second part of the database includes three focus areas to be addressed by this review. The first focus area concerns the climate risk category, to understand the level of integration in the literature in relation to the compound flood hazards in coastal cities. Within this area, data on the climate change perspective have been extracted to identify how this issue has been addressed by the researchers. This information was classified in 'background', where climate change has been just mentioned as a context, 'analytical', where climate change data were used in the analysis, and 'scenarios', where climate change projections were included in the assessment analysis. The second focus area concerns the economic category, by exploring how economic evaluation related to NBS implementation has been addressed by the literature. This aspect includes economic assessments and the currency and unit used by the studies. Finally, the third focus is related to the climate adaptation challenge, namely, by comprehending how NBS implementation is integrated into urban planning in practice. This category aims to identify the kind of biophysical assessment employed by the studies, through the collection of information related to the specific natural solutions implemented. This knowledge helps to classify the most-used NBS, linked to their biophysical flood-mitigation values.

3. Results and Analysis

Data extraction from the three-step procedure covered both quantitative and some qualitative aspects. Section 3.1 presents a quantitative discussion about the results, as comparative descriptive analysis. Section 3.2 shows an in-depth analysis of the results in relation to the focus areas, by presenting, firstly, a background that frames the NBS studies. The following sections represent an in-depth evaluation about the three emergent themes this review analysis deals with: climate risk, the economic perspective, and the economic perspective.

3.1. Statistical Overview

Given the relatively large number of publications, when combining different searches from the online databases, a first general overview as a statistical descriptive analysis has been conducted. This summary starts by showing the evolution over time of publications on ecosystem-based adaptation concepts related to flood issues that resulted from the first review step (N = 360). The bars show the number of publications per year, and the dotted line represents the cumulative values of the studies until 2020. The number of studies published on that topic have been rapidly increasing over the last couple of decades (Figure 2)—especially as of 2016. About 90% of publications are from the period of 2013 to 2020.

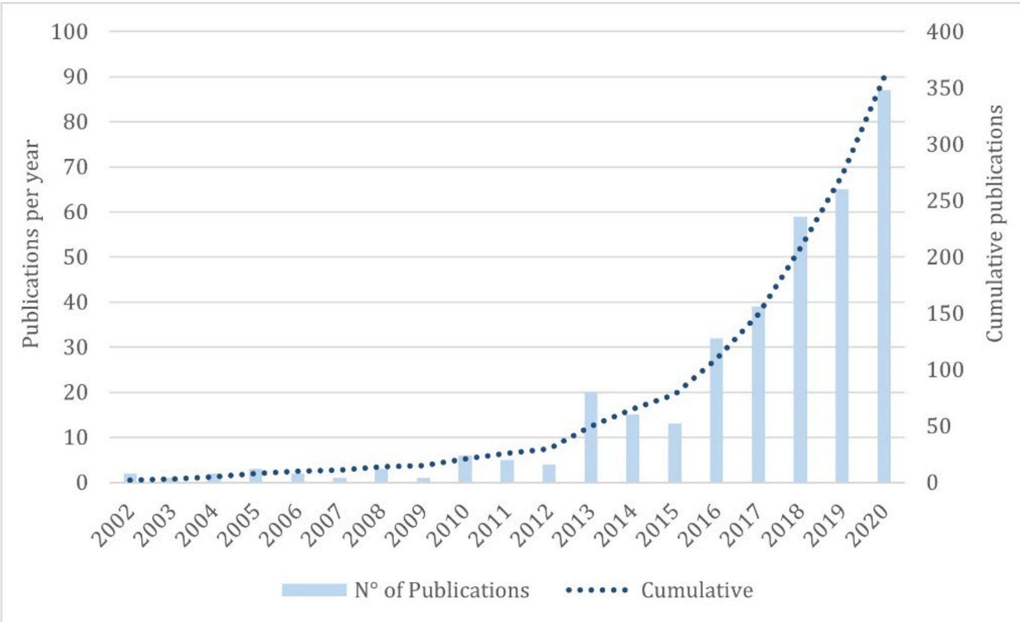

Figure 2. Publications per year with cumulative studies over time (N = 360).

Looking at the distribution of publications over time, by nature-based adaptation terminologies (Figure 3), SuDS is the first term used in the literature (since 2002). The first two publications in 2002 concern more qualitative descriptions of SuDS, particularly on the application of permeable pavements. NBS and SC resulted in quite new concepts from 2015 and 2016, respectively. Publications on GI resulted in the largest number of studies, with a significant rise from 2012 to 2020. The publications are from 138 journals and 71 conference proceedings. Most of the studies (65%) are from three journals: *Water* (24%), which started to publish on this topic from 2014, and *Sustainability* (21%) and *Science of the Total Environment* (20%), which show first publications in 2016.

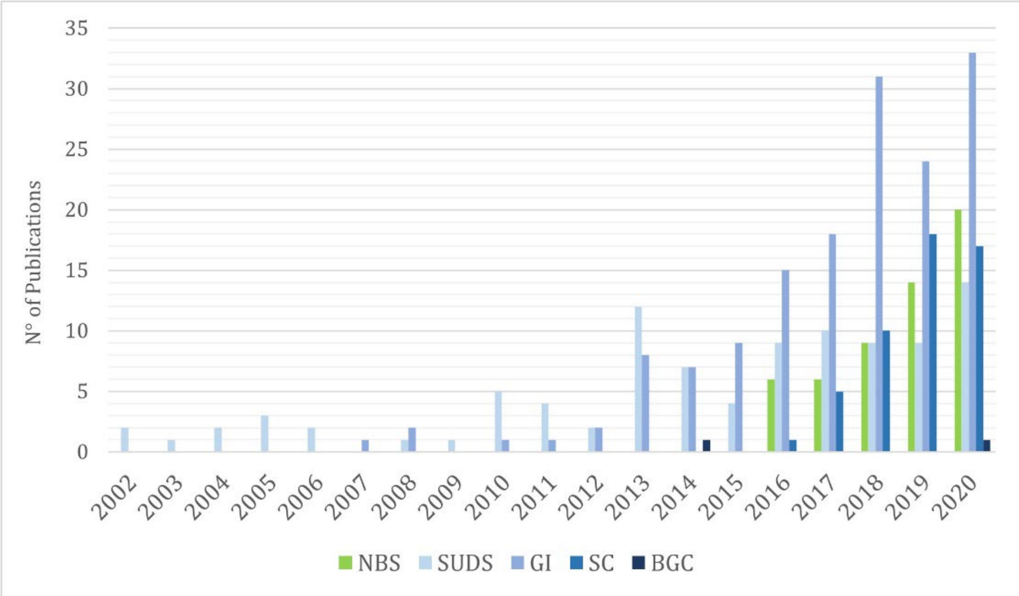

Figure 3. Number of studies over time per generic nature-based adaptation (N = 360).

The second review step highlighted that the GI concept has been extensively applied to urban flood adaptation in peer-reviewed studies, as compared to the other generic nature-based adaptation approaches (see Figure 4). The NBS concept is rapidly gaining interest over time, especially by framing the studies as research articles (64%), followed by the highest number of review articles (29%) among all the other generic nature-based concepts.

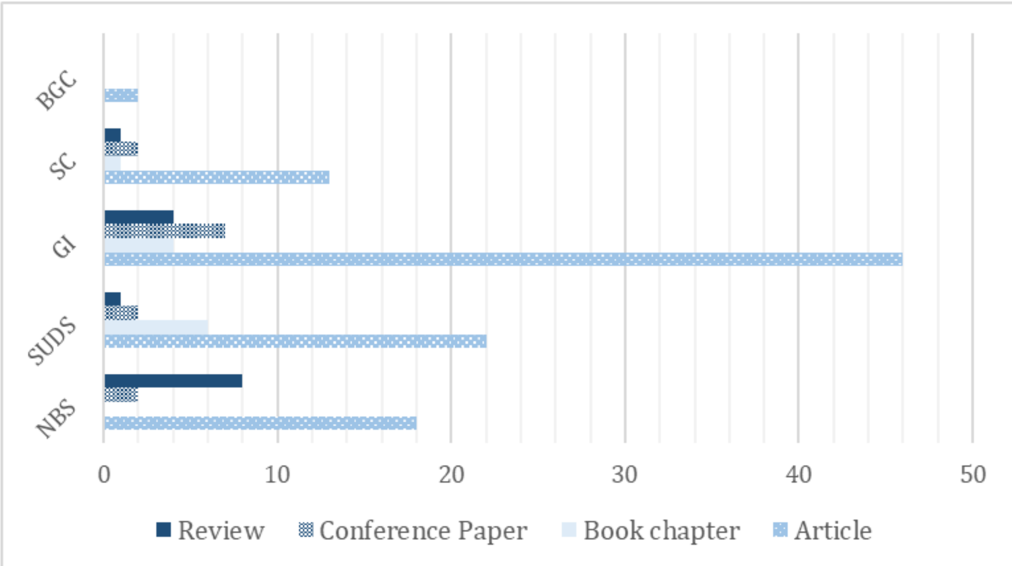

Figure 4. Number of publications per generic nature-based adaptation by study type (N = 157).

However, the use of specific kinds of measures is not yet widely studied. By looking at Figure 5, "Pond" is the most popular solution (16 studies), followed by "Wetland" (15 studies) and "Green roof" (13 studies), even if relatively few studies examine the application of such measures.

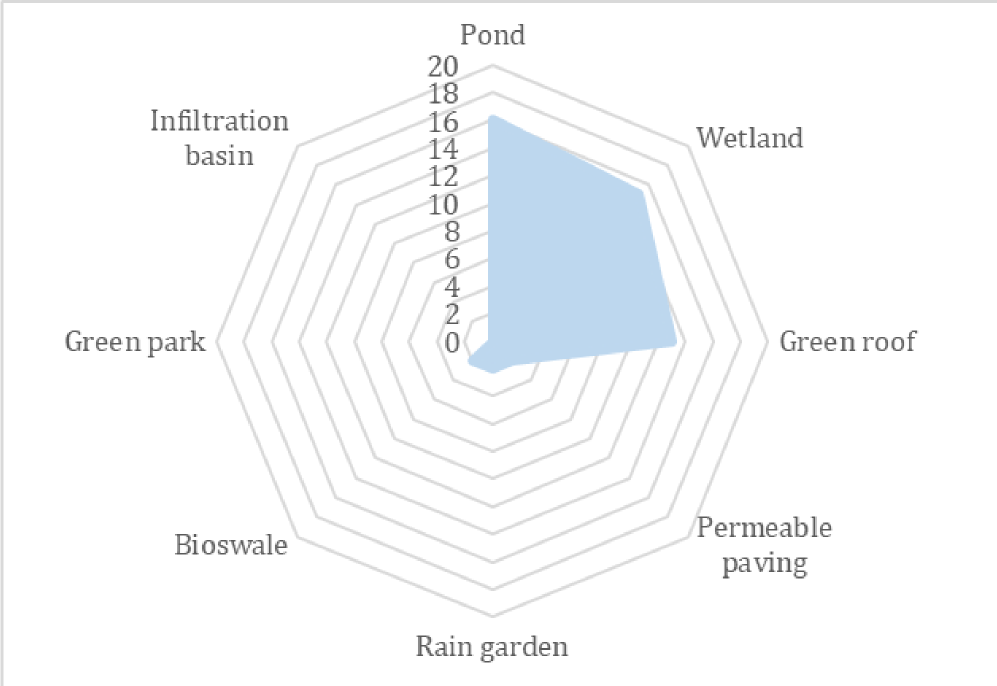

Figure 5. The radar chart on keywords frequency (NBS type) in the documents (N = 157).

3.2. Background: Framimg the Application of NBS

From a geographical perspective, about 8% concerns publications with a global scope. Only one publication concerning a conceptual framework is independent of geographical context. The other studies, which are all reviews, employ data from different geographic areas. Most publications have applied case studies, as shown in Figure 6. The map illustrates the distribution of the NBS applications by showing the number of cases in relation to the spatial scale for each continent. The local level in Figure 6 includes different larger scales of analysis, such as city level, neighbourhood level, district level, and catchment level. Around 40% of case studies cover European contexts, where only 3 applications are at the national level, and 22 are at the local level. Among the applications at the local level in Europe, only seven cases are at the city level. Moreover, most of those cases are focused on flooding-related issues. The United Kingdom is the European country that started earlier in the case-study application of natural-based approaches, in respect to other countries. Indeed, the first application dates from 2013. For NBS applications in Asian and American countries, the percentage of coverage is almost the same (26% and 25%, respectively), while it is only 6% and 3%, respectively, in Oceanian and African countries. In relation to applications at the local scale in American countries, only five cases deepen the flooding-related issues, while the majority is focused on multiple hazards. There are even less for Asian countries, specifically China, where only three case studies work on a single hazard (flood).

For the study types, most of the publications cover two different kinds of methodologies (44%): review (15) and spatial assessment (15) (Figure 7). Among the review studies, 53% provide qualitative data and can be divided into two subgroups. The first group gives information based on surveys [32,33], while the second group builds on the current evidence of NBS applications for flooding challenges [14,34–36]. Around 27% of reviews provide qualitative and quantitative data (mixed data) [37–39], while only 7% of reviews present quantitative information about the unit cost estimates for flood adaptation [40], and 14% do not give any details (NA). The spatial assessment studies are quantitative (27%), quantitative and spatial (47%), mixed (13%), or mixed and spatial (13%).

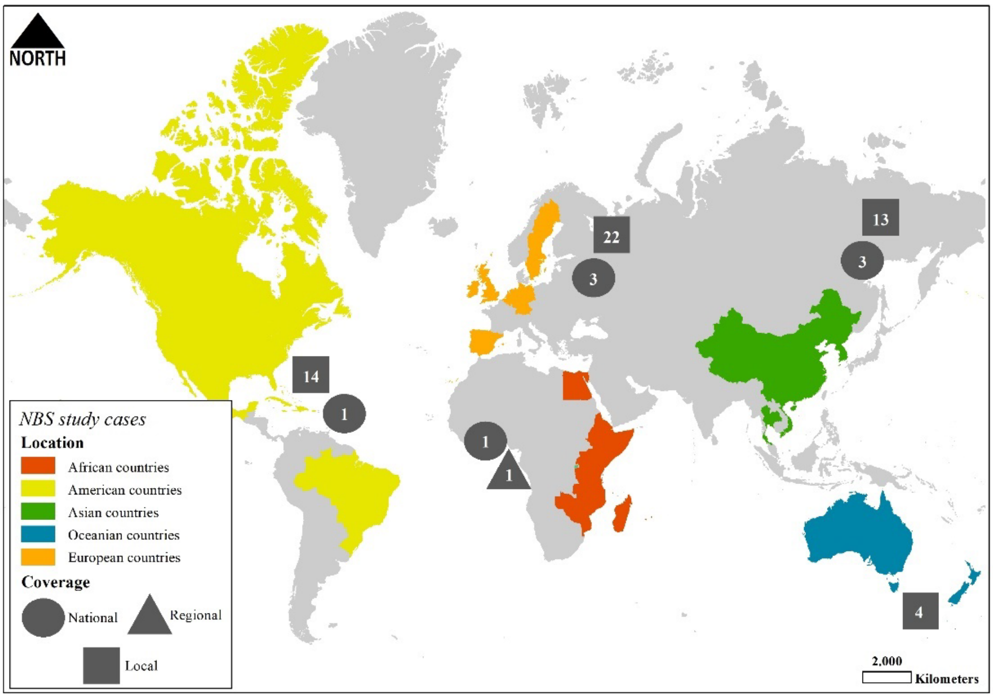

Figure 6. Geographical distribution and scale of the NBS case studies identified in the rapid systematic review.

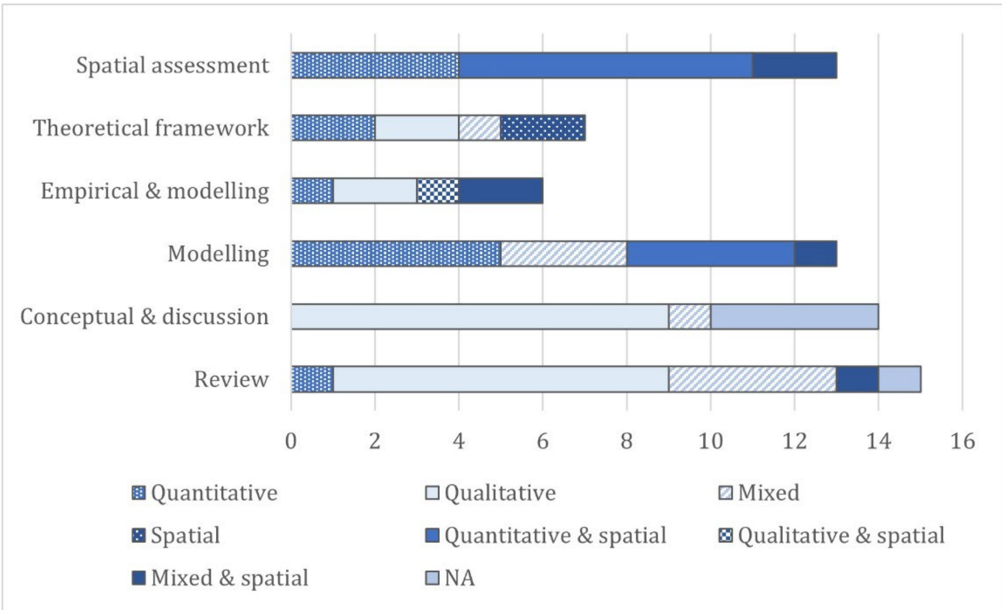

Figure 7. Kind of data provided by each study across different study type.

A large portion of publications (40%) covers two other study types, namely conceptual/discussion (14) and modelling (13) studies (Figure 7). Most of the data and information provided by conceptual/discussion typology are qualitative (64%). One paper presents a comparative analysis between SUDS and SCP in the UK and China, respectively, to identify the barriers and enablers for the adoption of GI, through 12 in-depth semi structured interviews with stakeholders [41]. Four publications describe case studies to test conceptual frameworks or demonstrate how research project collaborations addressed many biophysical and socio-political barriers for the NBS applications [42–45]. Data from modelling studies are mostly quantitative (38%) and quantitative and spatial (30%), with a few that are mixed (23%) and mixed and spatial (8%). Most modelling studies apply hydraulic models by estimating the NBS impacts without developing any economic assessment [46–49]. Porse [50] uses risk-based modelling to assess cost-effective (cost–benefit analysis) urban-floodplain-development decisions by providing qualitative and quantitative data [50]. Schubert et al. [51] apply stormwater flow and quality modelling to assess the GI impacts, by assuming fixed construction costs, which ignore the potential savings resulting from the benefits of the measures' implementation [51]. Alves et al. [52] develop a monetary analysis of different co-benefits related to the implementation of green-blue-grey infrastructure. This study provides spatial data from the 2D hydrodynamic models, to assess the expected annual damage (EAD) for buildings, to finally obtain quantitative data derived from the cost–benefit analysis of flood-risk mitigation measures, by comparing the expected annual benefits and costs converted to the net present value [52].

Few papers (9%) develop empirical studies. Of the remaining five theoretical framework papers (7%), different subjects have been covered. One study tests a conceptual model to assess the groundwater table variation by providing both qualitative and quantitative data on groundwater infiltration and storage capacity [53]. Two studies provide qualitative data through the application of the analytical framework that conceptualizes ecosystem-based adaptation in urban environments and the employment of a HAMIED framework (Hydrological Assessment and Management of green Infrastructure to Enhance Decision-making) to systematically identify and manage the aspects that stakeholders would like to be assessed using specific models within the SuDS system [54,55]. The other two studies provide quantitative data. One focuses on a new formula of resilience based on three parts of system severity: social severity affected by urban flooding, environmental severity caused by sewer overflow, and technological severity considering the safe operation of downstream facilities [56]. The other article presents an evaluation framework that aims to quantify the co-benefits of implemented NBS [57].

3.2.1. Emergent Theme: Climate Change Perspective into NBS Analysis

The first challenge identified concerns how climate change and which climatic risks were addressed by NBS analysis. The level of integration of the climate change issue varies across publications (Figure 8). Most of the studies (51%) show a low level of integration related to the climate change concept into NBS analysis ('background' indicator). Of those publications that only mentioned climate change as a background condition, 21 are focused on a single hazard (flooding) (e.g., [58–61]), while the rest (14 studies) are focused on multiple hazards (flooding, drought, coastal erosion, heat island effect, air quality, etc.) (e.g., [14,34,55,62]). Those studies use the term climate change in at least one section of the publication (e.g., the title, abstract, keywords, introduction, methods, results or discussion/conclusion).

Among the publications that do not mention climate change (34%), most (17 studies) analyse the flooding hazard (e.g., [63–65]), while the other six publications broadly mention and focus on multiple hazards, by considering, especially, sea-level rise, air temperature, and drought (e.g., [44,45]).

Only three studies show a medium level of integration of climate change issues ('analytical' indicator; 4%). A review paper focuses on flooding as a single hazard, by discussing internal and external aspects that are influencing flash flood events. Climate change is included as an external factor that induces heavy precipitation [66]. One paper focuses on multiple hazards (flood and drought), while another study focuses on a compound hazard, by considering river–fluvial flooding, high tides, and sea-level rise [67,68].

The seven studies that integrate climate change issues to a large extent consider climate data to build different scenarios ('scenario' indicator; 10%). The major part of these studies (five) tackle a single hazard (flooding), while one article analyses flooding and sea-level rise as a compound hazard and one concerns multiple hazards (flood, drought, temperature, and sea-level rise) [47,56,69–73].

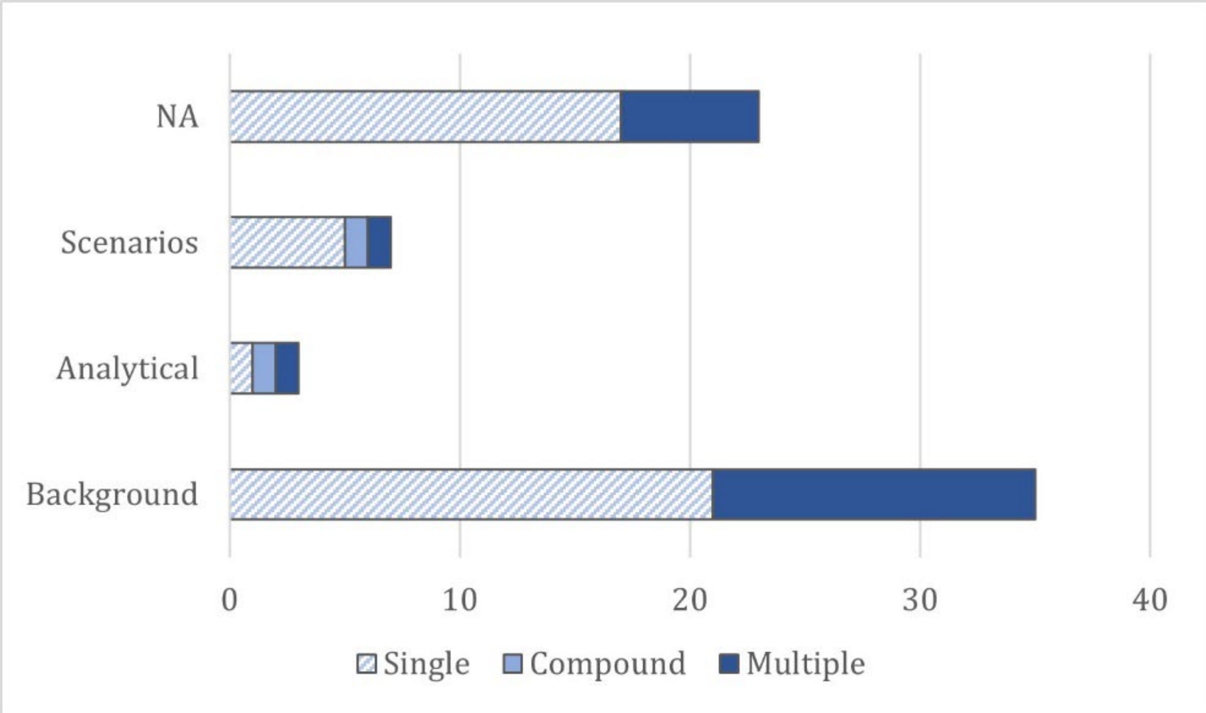

Figure 8. Level of integration of climate change issue into NBS studies.

3.2.2. Emergent Theme: Economic Perspective into NBS Analysis

For the second challenge, only 19 publications (28%) report on economic research approaches. Figure 9 shows the number of studies per each specific economic approach, by showing the currency employed. About 10% of the studies develop a flood-damage analysis. These studies use a flood-depth damage function to estimate the economic damages—two studies use buildings and the other one works with income classes for flood-costs calculation [59,64,73]. The currency is mentioned in just one of these studies, which is GBP. Most of the publications (37%) develop cost analysis on NBS implementation to reduce flood risk. Three studies include construction and maintenance costs of NBS in the analysis by using USD [74,75] and GBP as currencies [76]. The other part of the studies include only the construction costs of the measures by using the currencies USD [56,69], RMB [77], or AUD [51], respectively. About 26% employ cost–benefit analysis (CBA) to conduct the economic calculation of NBS. One study is a review on the unit-cost information of adaptation measures, by including the currency GBP and USD [40]. Two publications use EUR as the currency [52,70], while one economic assessment conducted in China is expressed in RMB [78]. Only one of those studies does not explicitly state the currency [71]. Among the remaining 20% of studies, one focuses on life-cycle cost analysis (LCCA), by including USD [79] m and one conducts a value-transfer methodology to monetize the natural capital (NC) benefits by using GBP [80]. The other two studies, which do not explicitly state the currency, show a historical comparison and a least-cost path analysis [61,66].

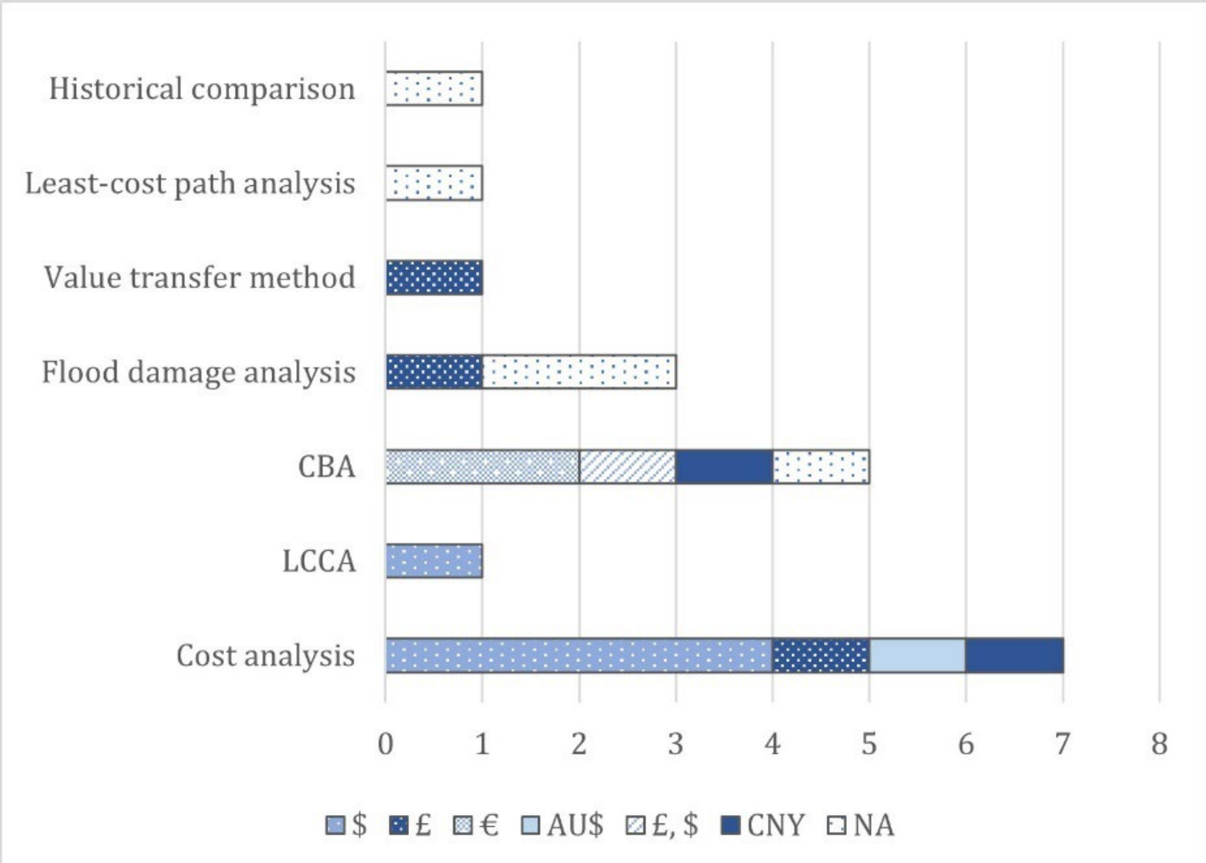

Figure 9. Economic approaches and currency employed for each NBS study.

3.2.3. Emergent Theme: Adaptation Perspective into NBS Analysis

Finally, the third theme addressed in this research is related to the adaptation challenge, essentially by highlighting the biophysical assessment employed by the studies through the collection of the information related to the specific natural solutions implemented. Only 31 publications address this theme, which helps to classify the most used NBS types linked to their biophysical flood-mitigation values. Table 2 shows the number of times that each of the most common NBS are employed in the literature, addressing the different types of information (quantitative and/or qualitative) provided. Green roof and permeable paving are the mostly studied solutions, for which quantitative evidence is available. For example, most of the studies provide the numeric runoff-reduction values of flooding, as water infiltration or retention capacity in terms of percentage, mm, or m^3 [59,78,81,82]. One study expresses the numeric flood-risk values related to the climate change mitigation in terms of kg of CO_2 reduction [83]. Green roof and permeable paving studies are also the ones for which most qualitative evidence is available, followed by rain garden. The kind of evidence presented refers to qualitative ranking expressed in terms of reduction capacity (i.e., low–medium–good or including fixed values as 0–1), as developed by the authors [63,76,84]. Green facade, green park, and green street are the less-studied solutions. In general, only a few studies provide both qualitative and quantitative information [65,85].

Table 2. Number of times that specific NBS address different types of information. Colours vary from red (none or a few times) to green (several to most of the time).

		Type of Information on NBS			
	No. of Times NBS is Studied	**Quantitative**	**Qualitative**	**Quantitative and Qualitative**	**NA**
Green facade	2	1	0	1	0
Green park	3	0	2	1	0
Green street	3	0	1	2	0
Green roof	20	10	7	2	1
Infiltration basin	10	6	2	2	0
Permeable paving	19	10	7	2	0
Pond	10	3	5	1	1
Rain garden	11	4	6	1	0
Swale	11	4	5	1	1
Wetland	9	3	4	2	0

Note: -Dark red is associated to a low level of times in which NBS address different type pf information. Moving to even more lighter red, orange, yellow and finally light green and dark green where NBS address several or most of the time these different kind of information.

4. Discussion

What emerges from this literature review are research gaps for each of the deepened focus areas and an overall lack of studies integrating the three themes together. The first theme about climate hazard and the level of integration of climate change issues into NBS analysis, essentially highlights the gaps in the two fields. One is related to gaps on vulnerability and risk assessment, due to the compound effects of urban flooding and storm surges. Generally, compound climate events are an integral part of almost all climate-related risks and pose significant challenges to many risk-reduction measures [86]. Better comprehension of compound events is crucial for improving risk assessment and defining site-specific NBS to reduce the associated impacts [86,87]. Moreover, a small portion of the literature works with climate change scenarios. The level of integration of climate change data into analyses is weak, even though defining scenarios is a useful tool to visualize potential futures and to address the related trade-offs [88].

For the second theme, the first issue that can be pointed out is related to the kind of economic assessment employed. Some studies are unclear as to which currency has been employed to address the economic evaluation. In addition, the reference year associated to the analysis is specified only a few times. This shows the important role in economic analysis of clarifying this information, thus helping to build useful and consistent data for further implementation. Another issue is linked to the cost components or cost–benefit analysis, which should be addressed. Uncertainties are associated with the NBS cost of operation and maintenance, while NBS benefits are often not clarified and partial. Future research should address these issues and expand the research by estimating both the cost and benefits of flood adaptation measures.

Finally, some gaps should be addressed on the third focus area concerning the adaptation theme. Urban planning is the process of developing and designing urban areas to meet the needs of a community. Among the different disciplines—architecture, engineering, economics, sociology, public health, finance, etc.—involved in planning, few of them have been prioritized in the process of NBS promotion. Some studies highlighted the social dimension by fostering stakeholder involvement and participatory planning to identify co-benefits and barriers in the process of NBS integration into urban adaptation, e.g., [32,39,54]. However, most of them underlined the need to cover the economic and finance area of planning. These focused on broadly proving multiple co-benefits versus different barriers in NBS implementation, as compared to traditional solutions such as [45,56,72]. Few studies highlighted the relevant role of evaluative tools (such as cost–benefit analysis) to support the decision-making process in planning, as in [70,83]. The lack of studies in this field is probably related to the scarcity of biophysical studies that assess the multiple impacts of NBS, which underpin such analyses. What emerges as one of the most important barriers to increased implementation of NBS is related to finance, both in upfront and maintenance costs, as in [41,89]. Thus, filling these gaps through long-term monitoring and demonstration of impacts and benefits of NBS helps to overcome such barriers and promote implementation of NBS. Additionally, specific vegetation information has not been mentioned, even though it plays a crucial role when considering climate change. The choice of specific NBS should be strictly related to the vegetation type to be effective. A repository concerning the technical aspects (as dimensions) of each specific NBS is also still missing.

Through this review, it is possible to infer that a large number of studies only partly assess the biophysical and economic impacts of NBS scenarios' implementation. Moreover, most of the studies do not mention specific practices or procedures to systematically conduct biophysical–economic assessment on NBS scenarios' implementation. Many attempts at ecosystem services (ES) quantification and NBS biophysical benefit evaluation, for their inclusion into the decision-making process, have been carried out [90]. Moreover, a great number of NBS studies on flood vulnerability concerns engineering aspects (hydraulic modelling assessment). However, it is argued that developing this kind of analysis as standalone is not enough for mainstreaming wider implementation of NBS. Especially, under changing climate conditions, it is urgent to focus on spatially integrated environmental–economic assessments of NBS, by simulating climate change and adaptation scenarios.

Given the relevance of NBS in the execution of the United Nations (UN) Sustainable Development Goals (SDGs; https://sdgs.un.org/goals (accessed on 14 July 2022)), in particular SDG 11 (sustainable cities and communities) and SDG 13 (climate action), it becomes even more important to contribute to overcome barriers that hamper a wider NBS implementation. An essential aspect derived by this review is related to how climate adaptation through nature-based implementation is integrated into traditional urban planning. This is related to the disciplines involved in the planning and implementation of such adaptation measures. Some studies focus on presenting and evaluating perceived barriers to NBS implementation, which are compared a few times to the potential benefits, mainly related to increasing urban ES, as in [29,42,60,61,81]. Another part of the publications shows methodological frameworks and evaluative tools, by working with adaptation scenarios to help local governments, as in [49,59,74,85]. One study highlighted the crucial role of CBA as a relevant tool for decision-making for urban planning, by comparing different scenarios of adaptation and future climate [70]. These aspects are essential strategies towards more structural incorporation of NBS in urban planning. However, a widespread implementation of NBS still remains limited by the lack of knowledge about how to embed urban ecological science within urban-planning practices and policies [91]. For instance, the uncertainty and lack of information on NBS' long-term behaviour and effects, together with the difficulty of quantitatively assessing their multidimensional impacts.

This rapid systematic review is not lacking shortcomings. Firstly, the number of publications included come from two electronic databases (Scopus and Web of Science) and may exclude some other important publications that are not stored in those databases. Secondly, the data extracted are also limited by the areas that this study focuses on. Rather, a reflection of the emergent themes has been carried out, even though the lack of climate, biophysical, and economic data for some cases undermined the comparison between the different studies.

5. Conclusions

Research interest and efforts to evaluate NBS impacts has been growing rapidly over the last decade. So far, current approaches for NBS impacts assessment are diverse and often vague, especially in relation to the idea of integrating NBS into the planning process. This review, therefore, aims to systematically analyse how NBS biophysical performance and economic impact evaluations are developed and integrated into urban planning adaptation.

The four focus themes identified by the review process provide a basis for the discussion around the role of NBS in climate change adaptation for flood issues in coastal cities.

This study contributes to the existing body of knowledge, especially by highlighting the emergent importance of NBS in flooding-related urban planning and the lack of spatially explicit simulation and economic assessment. Indeed, the NBS approach helps with urban-flood management and, especially, dealing with the more extreme flooding events due to climate change. For this reason, the information extracted by this review can be useful for future studies that focus on comparative discussion of NBS application and economic assessment employed for urban-flood management.

Looking at the results from an integrated perspective, which combines climate and economic analysis by overcoming the boundaries of adaptation planning, it seems to become even more important to conduct studies on integrated assessment methods for policy support. This would help delineate future research aimed at assessing the significant role of NBS to reduce the biophysical and economic impacts of flood events. Such research reflects the growing interest in further research to develop spatially integrated environmental–economic assessments on NBS implementation, by underlining the need for trans-disciplinary approaches to provide science-based evaluations supporting policy-making in the framework of urban climate change adaptation. By further performing in-depth analyses to demonstrate the multiple costs and (co-)benefits of NBS, as compared to traditional approaches, will help to better integrate such solutions into traditional urban planning. Once sufficient studies are available, meta-analyses can be performed to derive conclusions about the factors and conditions that determine the effectiveness of NBS. Based on this consideration, further research on the role of specific vegetation and on the interaction between plants and substrate, should be developed to optimize the NBS' efficacy.

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Appendix A

Reference	Authors	Title	Year	Journal
[45]	Connop S., Vandergert P., Eisenberg B., Collier M.J., Nash C., Clough J., Newport D.	Renaturing cities using a regionally-focused biodiversity-led multifunctional benefits approach to urban green infrastructure	2016	*Environmental Science and Policy*
[83]	Senosiain J.L.	Urban regreeneration: Green urban infrastructure as a response to climate change mitigation and adaptation	2020	*International Journal of Design and Nature and Ecodynamics*

Reference	Authors	Title	Year	Journal
[75]	Karamouz M., Heydari Z.	Conceptual Design Framework for Coastal Flood Best Management Practices	2020	*Journal of Water Resources Planning and Management*
[84]	Chan F.K.S., Griffiths J.A., Higgitt D., Xu S., Zhu F., Tang Y.-T., Xu Y., Thorne C.R.	"Sponge City" in China—A breakthrough of planning and flood risk management in the urban context	2018	*Land Use Policy*
[47]	Boelee E., Janse J., Le Gal A., Kok M., Alkemade R., Ligtvoet W.	Overcoming water challenges through nature-based solutions	2017	*Water Policy*
[63]	Alves A., Gómez J.P., Vojinovic Z., Sánchez A., Weesakul S.	Combining co-benefits and stakeholders perceptions into green infrastructure selection for flood risk reduction	2018	*Environments*
[68]	Duy P.N., Chapman L., Tight M., Linh P.N., Thuong L.V.	Increasing vulnerability to floods in new development areas: evidence from Ho Chi Minh City	2018	*International Journal of Climate Change Strategies and Management*
[64]	Bertilsson L., Wiklund K., de Moura Tebaldi I., Rezende O.M., Veról A.P., Miguez M.G.	Urban flood resilience—A multi-criteria index to integrate flood resilience into urban planning	2019	*Journal of Hydrology*
[58]	Sörensen J., Emilsson T.	Evaluating flood risk reduction by urban blue-green infrastructure using insurance data	2019	*Journal of Water Resources Planning and Management*
[32]	O'Donnell E.C., Lamond J.E., Thorne C.R.	Recognising barriers to implementation of Blue-Green Infrastructure: a Newcastle case study	2017	*Urban Water Journal*
[54]	El Hattab M.H., Theodoropoulos G., Rong X., Mijic A.	Applying the systems approach to decompose the SuDS decision-making process for appropriate hydrologic model selection	2020	*Water*
[39]	O'Sullivan J.J., Bruen M., Purcell P.J., Gebre F.	Urban drainage in Ireland—embracing sustainable systems	2012	*Water and Environment Journal*
[49]	Ramírez J.I., Qi K., Xiaobo L.	Sustainable stormwater management in Yinchuan New Town	2016	*Water Practice and Technology*
[56]	Dong X., Guo H., Zeng S.	Enhancing future resilience in urban drainage system: Green versus grey infrastructure	2017	*Water Research*
[92]	Hasala D., Supak S., Rivers L.	Green infrastructure site selection in the Walnut Creek wetland community: A case study from southeast Raleigh, North Carolina	2020	*Landscape and Urban Planning*
[72]	Kunapo J., Fletcher T.D., Ladson A.R., Cunningham L., Burns M.J.	A spatially explicit framework for climate adaptation	2018	*Urban Water Journal*
[38]	Butt N., Shanahan D.F., Shumway N., Bekessy S.A., Fuller R.A., Watson J.E.M., Maggini R., Hole D.G.	Opportunities for biodiversity conservation as cities adapt to climate change	2018	*Geo: Geography and Environment*
[67]	Pimentel-Rodrigues C., Silva-Afonso A.	Adaptation measures to climate change. Integration of green roofs with rainwater harvesting systems	2018	*WSEAS Transactions on Environment and Development*
[51]	Schubert J.E., Burns M.J., Fletcher T.D., Sanders B.F.	A framework for the case-specific assessment of Green Infrastructure in mitigating urban flood hazards	2017	*Advances in Water Resources*
[74]	Zidar K., Belliveau-Nance M., Cucchi A., Denk D., Kricun A., O'Rourke S., Rahman S., Rangarajan S., Rothstein E., Shih J., Montalto F.	A framework for multifunctional green infrastructure investment in Camden, NJ	2017	*Urban Planning*

Reference	Authors	Title	Year	Journal
[79]	Xie J., Chen H., Liao Z., Gu X., Zhu D., Zhang J.	An integrated assessment of urban flooding mitigation strategies for robust decision making	2017	*Environmental Modelling and Software*
[85]	Voskamp I.M., Van de Ven F.H.M.	Planning support system for climate adaptation: Composing effective sets of blue-green measures to reduce urban vulnerability to extreme weather events	2015	*Building and Environment*
[93]	Farrugia S., Hudson M.D., McCulloch L.	An evaluation of flood control and urban cooling ecosystem services delivered by urban green infrastructure	2013	*International Journal of Biodiversity Science, Ecosystem Services and Management*
[48]	Rozos E., Makropoulos C., Maksimović Č.	Rethinking urban areas: An example of an integrated blue-green approach	2013	*Water Science and Technology: Water Supply*
[33]	Xie X., Qin S., Gou Z., Yi M.	Engaging professionals in urban stormwater management: the case of China's Sponge City	2020	*Building Research and Information*
[77]	Bu J., Peng C., Li C., Wang X., Zhang Y., Yang Z., Cai Y.	A method for determining reasonable water area ratio based on flood risk and cost-effectiveness in Rainy City	2020	*Environmental Earth Sciences*
[66]	Wu H.-L., Cheng W.-C., Shen S.-L., Lin M.-Y., Arulrajah A.	Variation of hydro-environment during past four decades with underground sponge city planning to control flash floods in Wuhan, China: An overview	2020	*Underground Space (China)*
[53]	Lancia M., Zheng C., He X., Lerner D.N., Andrews C., Tian Y.	Hydrogeological constraints and opportunities for "Sponge City" development: Shenzhen, southern China	2020	*Journal of Hydrology: Regional Studies*
[36]	Rubinato M., Nichols A., Peng Y., Zhang J.-M., Lashford C., Cai Y.-P., Lin P.-Z., Tait S.	Urban and river flooding: Comparison of flood risk management approaches in the UK and China and an assessment of future knowledge needs	2019	*Water Science and Engineering*
[42]	O'Donnell E.C., Thorne C.R., Yeakley J.A., Chan F.K.S.	Sustainable Flood Risk and Stormwater Management in Blue-Green Cities; an Interdisciplinary Case Study in Portland, Oregon	2020	*Journal of the American Water Resources Association*
[43]	Lawson E., Thorne C., Ahilan S., Allen D., Arthur S., Everett G., Fenner R., Glenis V., Guan D., Hoang L., Kilsby C., Lamond J., Mant J., Maskrey S., Mount N., Sleigh A., Smith L., Wright N.	Delivering and evaluating the multiple flood risk benefits in Blue-Green cities: An interdisciplinary approach	2014	*WIT Transactions on Ecology and the Environment*
[71]	Kirshen P., Borrelli M., Byrnes J., Chen R., Lockwood L., Watson C., Starbuck K., Wiggin J., Novelly A., Uiterwyk K., Thurson K., McMann B., Foster C., Sprague H., Roberts H.J., Bosma K., Jin D., Herst R.	Integrated assessment of storm surge barrier systems under present and future climates and comparison to alternatives: a case study of Boston, USA	2020	*Climatic Change*
[94]	Lafortezza R., Sanesi G.	Nature-based solutions: Settling the issue of sustainable urbanization	2019	*Environmental Research*
[57]	Watkin L.J., Ruangpan L., Vojinovic Z., Weesakul S., Torres A.S.	A framework for assessing benefits of implemented nature-based solutions	2019	*Sustainability*
[95]	Sutton-Grier A.E., Sandifer P.A.	Conservation of Wetlands and Other Coastal Ecosystems: a Commentary on their Value to Protect Biodiversity, Reduce Disaster Impacts, and Promote Human Health and Well-Being	2019	*Wetlands*

Reference	Authors	Title	Year	Journal
[89]	Huang, YJ; Tian, Z; Ke, Q; Liu, JG; Irannezhad, M; Fan, DL; Hou, MF; Sun, LX	Nature-based solutions for urban pluvial flood risk management	2020	*Water*
[80]	Gunasekara R., Pecnik G., Girvan M., De La Rosa T.	Delivering integrated water management benefits: The North West Bicester development, UK	2018	*Proceedings of the Institution of Civil Engineers: Water Management*
[61]	Diaz-Nieto J., Lerner D.N., Saul A.J.	Least-cost path analysis to identify retrofit surface-water conveyance solutions	2016	*Journal of Hydrologic Engineering*
[73]	Jenkins K., Surminski S., Hall J., Crick F.	Assessing surface water flood risk and management strategies under future climate change: Insights from an Agent-Based Model	2017	*Science of the Total Environment*
[96]	Li L., Uyttenhove P., Van Eetvelde V.	Planning green infrastructure to mitigate urban surface water flooding risk—A methodology to identify priority areas applied in the city of Ghent	2020	*Landscape and Urban Planning*
[52]	Alves A., Gersonius B., Kapelan Z., Vojinovic Z., Sanchez A.	Assessing the Co-Benefits of green-blue-grey infrastructure for sustainable urban flood risk management	2019	*Journal of Environmental Management*
[46]	Fenner R., O'Donnell E., Ahilan S., Dawson D., Kapetas L., Krivtsov V., Ncube S., Vercruysse K.	Achieving urban flood resilience in an uncertain future	2019	*Water*
[59]	Webber J.L., Fu G., Butler D.	Rapid surface water intervention performance comparison for urban planning	2018	*Water Science and Technology*
[69]	Moore T.L., Gulliver J.S., Stack L., Simpson M.H.	Stormwater management and climate change: vulnerability and capacity for adaptation in urban and suburban contexts	2016	*Climatic Change*
[81]	Zellner M., Massey D., Minor E., Gonzalez-Meler M.	Exploring the effects of green infrastructure placement on neighborhood-level flooding via spatially explicit simulations	2016	*Computers, Environment and Urban Systems*
[65]	Cook E.A.	Green site design: Strategies for storm water management	2007	*Journal of Green Building*
[41]	Li L., Collins A.M., Cheshmehzangi A., Chan F.K.S.	Identifying enablers and barriers to the implementation of the Green Infrastructure for urban flood management: A comparative analysis of the UK and China	2020	*Urban Forestry and Urban Greening*
[97]	Li Y., Li H.X., Huang J., Liu C.	An approximation method for evaluating flash flooding mitigation of sponge city strategies—A case study of Central Geelong	2020	*Journal of Cleaner Production*
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[98]	Ellis J.B., Lundy L.	Implementing sustainable drainage systems for urban surface water management within the regulatory framework in England and Wales	2016	*Journal of Environmental Management*

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[62]	Im J.	Green streets to serve urban sustainability: Benefits and typology	2019	*Sustainability*
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[50]	Porse E.	Risk-based zoning for urbanizing floodplains	2014	*Water Science and Technology*
[82]	Yu C.	Sustainable urban drainable systems for management of surface water	2013	*Design and Management of Sustainable Built Environments*
[99]	Sharma D., Kansal A.	Sustainable city: A case study of stormwater management in economically developed urban catchments	2013	*Mechanism Design for Sustainability: Techniques and Cases*
[100]	Watkins S., Charlesworth S.M.	Sustainable Drainage Systems—Features and Designs	2014	*Water Resources in the Built Environment: Management Issues and Solutions*
[101]	Coupe S.J., Faraj A.S., Nnadi E.O., Charlesworth S.M.	Integrated Sustainable Urban Drainage Systems	2013	*Water Efficiency in Buildings: Theory and Practice*
[102]	Nasr M., Shmroukh A.N.	Gray-to-Green Infrastructure for Stormwater Management: An Applicable Approach in Alexandria City, Egypt	2020	*Advances in Science, Technology and Innovation*
[103]	Kalantari Z., Ferreira C.S.S., Keesstra S., Destouni G.	Nature-based solutions for flood-drought risk mitigation in vulnerable urbanizing parts of East-Africa	2018	*Current Opinion in Environmental Science and Health*
[37]	Saleh F., Weinstein M.P.	The role of nature-based infrastructure (NBI) in coastal resiliency planning: A literature review	2016	*Journal of Environmental Management*
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[14]	Hobbie S.E., Grimm N.B.	Nature-based approaches to managing climate change impacts in cities	2020	*Philosophical Transactions of the Royal Society B: Biological Sciences*
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