Reponses to editor's comments on "Nature-Based Solutions for hydro-meteorological risk reduction: A state-of-the-art review of the research area" by Laddaporn Ruangpan et al.

As you know, two reviewers have now provided detailed reviews, which you have replied in detail to. Both reviewers recommended major revisions and highlighted serval major issues regarding the design of your research, the chosen methods and evaluation criteria as well as the added-value for the scientific community.

In particular, in addition to mentioned issues by the reviewers, I kindly ask you to include in your manuscript more explicit also the terms of hazards and risks because the different communities addressing NBS also define differently the following terms related their research field

Authors' response: Thank you for your encouragement and comments. Your concerns are addressed in this response letter and the manuscript revised accordingly. Please find our point-by-point response below.

1. <u>Comments from the editor:</u> hydro-meteorological hazard vs hydro-meteorological risk vs hydro-meteorological disaster: It seems throughout the manuscript that you use hazard and risk synonymously (e.g. p5 l10). Furthermore, which hazards types did you include/select in your review considering the brought spectrum of hydro-meteorological hazards (e.g. storms, hail, snow avalanches, flash floods, …). Please provide here further explanations.

<u>Authors' response</u>: The authors have explained both terms hydro-meteorological hazard and hydro-meteorological risk more explicitly in abstract and introduction (page 1, line 13-15 and line 27-31). The hazards that have been included in this review are floods, droughts, storm surges, and landslides (page 2, line 24-25 and page 5, line 6).

2. <u>Comments from the editor:</u> vulnerability

<u>Authors' response</u>: Key references are now provided further explanation of vulnerability since it is not the main part of this work and only briefly mentioned in relation to hydro-meteorolgical risk.

3. **<u>Comments from the editor:</u>** climate change adaptation and disaster risk reduction

<u>Authors' response</u>: In the revised version**,** climate change adaptation and disaster risk reduction have been explained on page 2, line 2-4.

3. **<u>Comments from the editor:</u>** Moreover, I wonder why you did not include the term 'risk' in your second order concept for the literature research even 'risk reduction' is mentioned in the title of your manuscript.

<u>Authors' response</u>: Thank you very much for your comment. In the revised version, we have revised the methods, thus now the term 'risk' have been included.

Reponses to first referee's comments on "Nature-Based Solutions for hydro-meteorological risk reduction: A state-of-the-art review of the research area" by Laddaporn Ruangpan et al.

The premise of this article is extremely interesting and some of the conclusions of the article, in particular the "Overview of knowledge gaps / potential future research" is a very useful contribution to advancing this topic. The article helps to give an overview of the many concepts and terms associated with Nature based solutions for disaster risk reduction and it attempts to provide a mixed quantitative /qualitative assessment of a number of pre-determined questions that the authors have outlined as the objectives of the review. It therefore merits to be published if some fundamental methodological issues can be resolved.

Authors' response: Thank you for your encouragement and comments. Your concerns are addressed in this response letter and the manuscript revised accordingly. Please find our point-by point response below.

1. Concepts

Comments from Referee: The article provides an interesting historical overview of the different related concepts but there is still a confusion of terms. The abstract in particular is confusing, i.e. Nature based Solutions (NbS) is generally considered to be an umbrella term under which other types of approaches, Eba, Eco-DRR and GI / GBI provide more specific solutions to more specific issues (see various definitions given by IUCN and EU-related). This does not come out clearly in the article.

For example: p. 4/ line 30 NbS is not just about storm water

Authors' response: Thank you for pointing out this issue. We agree that terminology was confusing in the Abstract and other instances. This has been clarified in the revised manuscript. Furthermore, Section 3 "Overview of definitions and theoretical backgrounds", has been modified and expanded to better highlight the definition of NBS as an umbrella concept, as the reviewer suggested. This section also has been relocated to section 2 before "Materials and methodology" section as it discusses more on the background of NBS.

P.4 line 30: revised. Now, we specifically refer to SuDs, LIDs and WSUD terms in the sentence.

Authors' change in the revised manuscript:

There are several terms and concepts which have been used interchangeably in the literature to date. In terms of NBS, the two most prominent definitions are from International Union for Conservation of Nature (IUCN) and the European Commission. The European Commission defines Nature-Based Solutions as "Solutions that aim to help societies address a variety of environmental, social and economic challenges in sustainable ways. They are actions inspired by, supported by or copied from nature; both using and enhancing existing solutions to challenges, as well as exploring more novel solutions. Nature-based solutions use the features and complex system processes of nature, such as its ability to store carbon and regulate water flows, in order to achieve desired outcomes, such as reduced disaster risk and an environment that improves human well-being and socially inclusive green growth" (European Commission, 2015). The IUCN has proposed a definition of NBS as "actions to protect, sustainably manage and restore natural and modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits” (Cohen-Shacham et al., 2016). Eggermont et al. (2015) proposed a typology characterising NBS into three types: i) NBS that address a better use of natural/protected ecosystems (no or minimal intervention), which fits with how IUCN frames NBS; ii) NBS for sustainability and multi-functionality of managed ecosystems and iii) NBSs for the design and the management of new ecosystems, which is more representative of the definition given by the European Commission.

NBS is a collective term for innovative solutions to solve different types of societal and environmental challenges, based on natural processes and ecosystems. Therefore, it is considered as an “umbrella concept” covering a range of different ecosystem-related approaches and linked concepts (Cohen-Shacham et al., 2016; Nesshöver et al., 2017), that provides an integrated way to look at different issues simultaneously.

Due to the diverse policy origins, NBS terminology has evolved in the literature to emphasize different aspects of natural processes or functions. In this regard, nine different terms are commonly used in the scientific literature in the context of hydro-meteorological risk reduction: Low Impact Developments (LIDs), Best Management Practices (BMPs), Water Sensitive Urban Design (WSUD), Sustainable Urban Drainage Systems (SUDs), Green Infrastructure (GI), Blue-Green Infrastructure (BGI), Ecosystem-based Adaptation (EbA) and Ecosystem-based Disaster Risk Reduction (Eco-DRR). The timeline of each term, based on their appearance in literature is shown in Figure 1 and their definitions are given in Table 1.

The commonalities between NBS and its sister concepts (i.e., GI, BGI, EbA, Eco-DRR) are that they take participatory, holistic, integrated approaches, using nature to enhance adaptive capacity, reduce hydro-meteorological risk, increase resilience, improve water quality, increase the opportunities for recreation, improve human well-being and health, enhance vegetation growth and connect habitat and biodiversity. More information on the history, scope, application and underlying principle of terms of SUDs, LIDs, BMPs, WSUD and GI can be found in Fletcher et al. (2015) while the relationship between NBS, GI/BGI, and EbA is described in detail by Nesshöver et al. (2017).

Although all terms are based on a common idea, which is embedded in the umbrella concept of NBS, differences in definition reflect their historical perspectives and knowledge base that were relevant at the time of the research (Fletcher et al., 2015). The distinguishing characteristic between NBS and its sister concepts is how they address social, economic and environmental challenges (Faivre et al., 2018). Some terms such as SUDs, LIDs, and WSUD refer to NBS that specifically address stormwater management. They use landscape feature to transform the linear approach of conventional stormwater management into a more cyclic approach where drainage, water supply, and ecosystems are treated as part of the same system, mimicking more natural water flows (Liu and Jensen, 2018). GI/BGI focus more on technology-based infrastructures by applying natural alternatives (Nesshöver et al., 2017) for solving a specific activity (i.e., urban planning or stormwater). EbA looks at long-term changes within the conservation of biodiversity, ecosystem services and climate change, while Eco-DRR is more focused on immediate and medium-term impacts from the risk of weather, climate and non-climate-related hazards. EbA is often seen as a subset of NBS that is explicitly concerned with climate change adaptation through the use of nature (Kabisch et al., 2016). From the above discussion, it can be concluded that EbA, Eco-DRR and GI/BGI provide more specific solutions to more specific issues. One key distinction is that unlike the sister concepts, the concept of NBS is more open to different interpretations, which can be useful to encourage stakeholders to take part in the discussion.

Moreover, features of NBS provide an alternative to work with existing measures or grey infrastructures. Therefore, it is important to note that very often a combination between natural and traditional engineering solutions (a.k.a. "hybrid" solutions) is likely to produce more effective results than any of these measures alone, especially when their co-benefits are taken into consideration.

An important advance in the science and practice of NBS is given by the EKLIPSE Expert Working Group, which developed the first version of a multi-dimensional impact evaluation framework to support planning and evaluation of NBS projects. The document includes a list of impacts, indicators and methods for assessing the performance of NBS in dealing with some major societal challenges (EKLIPSE, 2017; Raymond et al., 2017). Lafortezza et al., (2018) reviewed different case studies around the world where NBS have been applied from micro-scale to macro-scale. Furthermore, an overview of how different NBS measures can regulate ecosystem services (i.e., soil protection, water quality, flood regulation, and water provision) has been carried out by Keesstra et al., (2018).

2. Methodology of the review; This is where this reviewer has the greatest number of questions:

Comments from Referees 2.1 Good that multiple data bases were used but why assume that just because Scopus has the greatest number of articles, that it is the most comprehensive? You could have merged all three searches and then removed duplicates.

Authors' response 2.1 Thank you very much for your comment. The authors have revised the methodology (see also next comment) by including both Web of Science and Scopus databases and merged the two searches together as recommended by the reviewer, and removed duplicates. Note that Google Scholar has been completely excluded from the revised methodology because it has limited metadata and filters which, at present, do not allow to limit results to articles published in peer-reviewed, scientific journals written in English (one of the three selection criteria adopted in our search process).

Comments from Referees 2.2 Adding missing articles adds a huge bias to your search. Which articles were selected and based on what criteria? That the keywords were there? - Which criteria were used for deleted certain articles - perhaps I missed this?

Authors' response 2.2 We agree that the methodology of this review was not clearly explained and had some flaws. Thanks to Reviewer's comments, our methodological approach has been carefully revised and improved. Specifically:

1) Bias introduced by missing articles has been removed, namely those articles are no longer evaluated neither included/added in the analysis. Note that few comments drawn upon this subset of articles have been retained because considered of relevance to our discussion, but they are now included in the new Section 2, which is not part of the "Findings" section.
2) An analysis of why other papers in the extended list did not appear in the search shows that they were missed because they use the terms 'green and grey infrastructure' as opposed to 'green infrastructure'

directly. As this is merely a language issue, the term ‘green and grey infrastructure’ was added to the search terms.

3) As this Reviewer pointed out, the selection process was not clearly explained in the original manuscript. We have now substantially expanded the methodological section, by explicitly stating the objectives of the review and by explaining the criteria used for selecting the literature of relevance with respect to these objectives. This is summarized in the diagram below (included in the new version of the manuscript) which shows that the method consists of two phases. For the search process (phase I) the only selection criteria adopted were that (a) articles are published in peer-reviewed and scientific journals written in English; (b) articles reported on NBS in terms of hydro-meteorological risk reduction (construction of the search query based on the keywords in Table 1); (c) articles were published in the period 2007 to 1 December 2018. The search process resulted in a total of 1204 articles which were then subjected to selection process (Phase II). The selection process involved a set of progressive steps as schematized in Fig.3 and detailed in the following: << *Initially, all articles were analysed on the basis of reading titles and keywords and their relation to the search terms. For example, if titles and keywords of articles were not considered relevant because of their complete titles, or because the keywords did not match closely enough to the topics, they were omitted. This step served to reduce the number of articles from 1395 to 30. Secondly, a more in-depth analysis was conducted, based on reading the abstract of each article selected in the previous step. The criteria at this step was that the abstract should discuss hydro-meteorological risk reduction. For example, if the abstract of the articles focused more on water quality than risk, then that paper was excluded. This step served to reduce the number of articles from 380 to 185. Finally, articles were read in full to identify those that were relevant to the review objectives. Any studies appearing to meet the key objectives (dealing with subjects such as effectiveness of NBS, techniques, method and tools for planning, and others subjects relevant to the key objectives) would then be included in the review. As a result, the entire selection process resulted in a total of 137 articles relevant to the objectives of the present review.*>> (text extrapolated from the revised Section 2.2 (now Section 3.2)). For the sake of completeness and clarity, the new version of the entire methodological section is provided below.

<u>Authors' change in the revised manuscript:</u>

3. Materials and methodology

The methodology consisted of two phases as schematized in Figure 2. The first phase consisted of the identification of articles satisfying the search criteria discussed in Section 3.1. Next, all articles were screened and filtered based on the selection criteria discussed in section 3.2.

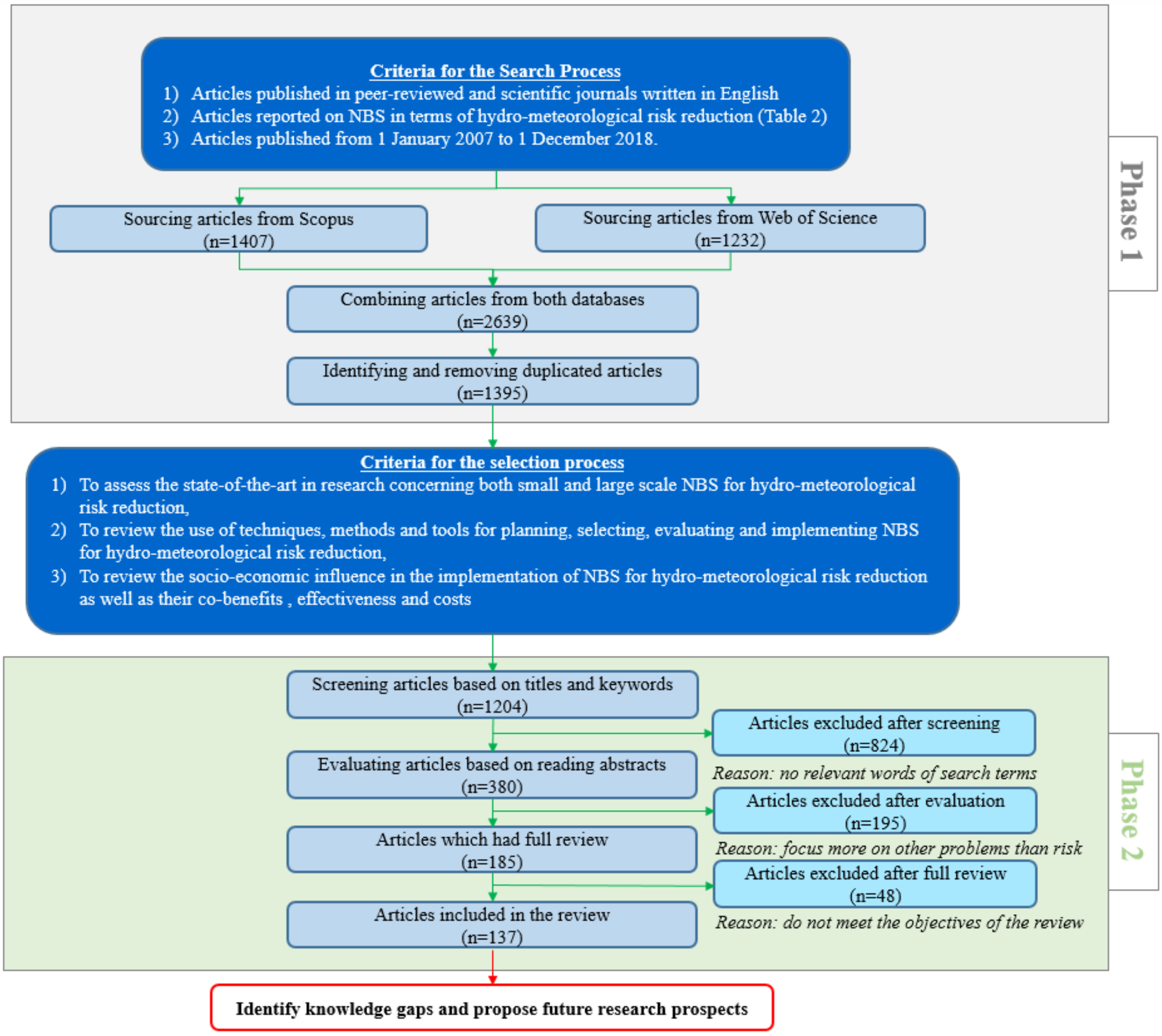


Figure 3: Process of article selection on Nature Based Solutions for hydro-meteorological risk reduction. The final number of fully reviewed articles is 137.

3.1 Search strategy

The review analysis concerned articles from scientific journals written in English. Two main concepts were used in the search: Nature-Based Solutions and hydro-meteorological risk reduction. As the concept of ‘Nature-Based Solutions’ appears under different names (which more or less relate to the same field of research), articles related to LIDs, BMPs, WSUD, SUDs, GI, BGI, EbA and Eco-DRR were included in the identification of relevant articles (see Table 2). The review of hydro-meteorological risk included literature on relevant terms (i.e. disasters, risks, hydrology etc.) and different types of hazards (floods, droughts, storm surges and landslides) (Table 2).

During the construction of the queries, the strings were searched only within index terms and metadata “titles, abstract, and keywords” in the Scopus database. The search terms for the two concepts were linked with the Boolean operator “AND” while the Boolean operator “OR” was used to link between possible terms (Table 2). An example of a protocol is shown below:

“TITLE-ABS-KEY ("Nature-based solutions" OR "Nature based solutions" OR "Nature Based Solutions" OR "Nature-Based Solutions" OR "Low impact development" OR "Sustainable Urban Drainage Systems" OR "Water Sensitive Urban Design" OR "Best Management Practices" OR "Green infrastructure" OR "Green blue infrastructure" AND "flood") AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "ch") OR LIMIT-TO (DOCTYPE , "re") OR LIMIT-TO (DOCTYPE , "bk")) AND (LIMIT-TO (LANGUAGE , "English"))”

The time window selected for the review process was from 1 January 2007 to 1 December 2018. 1407 articles published in scientific journals were found in the Scopus database and 1232 were found in the Web of Science database. The articles from both databases were combined to 2639 articles. Duplicate articles were removed, resulting in a total of 1204 articles to be considered for further evaluation.

3.2 Selection process

As stated in the introduction, this study aims at reviewing the state-of the-art of the research on NBS that specifically address hydro-meteorological risk reduction. In this regard, the key objectives of the present review work were carefully formulated as follows:

1) To assess the state-of-the-art in research concerning both small and large scale NBS for hydro-meteorological risk reduction;
2) To review the use of techniques, methods and tools for planning, selecting, evaluating and implementing NBS for hydro-meteorological risk reduction;
3) To review the socio-economic influence in the implementation of NBS for hydro-meteorological risk reduction as well as their multiple benefits, co-benefits, effectiveness and costs;
4) To identify trends, knowledge gaps and proposed future research prospects with respect to the above three objectives.

These key objectives were defined for the review with the intention that the results could be both quantitative and qualitative.

The 1204 articles resulting from the search query were thus evaluated with respect to these objectives, and those found of little or no relevance with the topic removed. This selection process involved a set of progressive steps as schematized in Figure 2.

Initially, all articles were analysed on the basis of reading titles and keywords and evaluating their relation to the search terms. Articles were discarded if their title and keywords were considered of little or no relevance to the key objectives. This step served to reduce the number of articles from 1204 to 380.

Secondly, a more in-depth analysis was conducted, based on reading the abstract of each article selected in the previous step. The criteria at this step was that the abstract should discuss hydro-meteorological risk reduction.

For example, if the abstract focused more on water quality than risk, that paper was excluded. This step served to reduce the number of articles from 380 to 185.

Finally, articles were read in full to identify those that were relevant to the review objectives. Any studies appearing to meet the key objectives (dealing with subjects such as effectiveness of NBS, techniques, method and tools for planning, and others subjects relevant to the key objectives) were included in the review. As a result, the entire selection process resulted in a total of 137 articles relevant to the objectives of the present review.

Comments from Referee 2.3 Search terms you had several search terms from your first column with "urban", this may have included a bias toward urban

Authors' response 2.3: We understand the Reviewer's concern, but we would like to point out that as mentioned on page 3 line 10, the concept of Nature-Based Solution was historically linke to different names in different countries [e.g. Low Impact Developments (LIDs), Best Management Practices (BMPs), Water Sensitive Urban Design (WSUD), Sustainable Urban Drainage Systems (SuDS), Green Infrastructure (GI), Blue-Green Infrastructure (BGI), Ecosystem-based Adaptation (EbA) and Ecosystem-based Disaster Risk Reduction (Eco-DRR)]. In this cases, there are only 2 search terms that include "Urban" out of the 10 search terms. Therefore, if we do not include search terms like 'Water Sensitive Urban Design' (WSUD) and 'Sustainable Urban Drainage Systems' (SuDS), we may miss some important articles related to the topic. Furthermore, only 130 of the 1387 papers from Scopus appear due to these terms and only 4 articles out of 137 were included in the review. This means that the word "urban" contributed to only 2.9% of the total 88% urban cases shown in Figure 5.a Therefore, we concluded that including these 2 terms does not have a significant impact in terms of bias. For sake of clarity, this has been now clarified also in the manuscript (section "Trends, knowledge gaps and future research prospects").

Authors' change in the revised manuscript:

The review of the 137 articles indicates that most of the research to date has been carried out in an urban context, whereas the contexts concerning river and coastal floods, droughts and landslides are the least addressed. More specifically, 88% of all articles deal with runoff reduction or flood risk reduction in urban areas (Fig. 5b). It is worthwhile to notice that two out of the ten search terms in Table 2 contain the word "urban". This was in order to include two popular concepts linked to NBS for hydro-meteorological risk, which are WSUD and SUDs (cf. the overview of terminology given in Section 2). Nevertheless, the literature sourced using these two search terms only accounts for 2.9% of the total 88% urban cases shown in Figure 5b. Therefore, no significant bias was introduced in our findings by the inclusion of the word "urban" through these two search terms.

Comments from Referee 2.4 One of the main objectives of this review was to find trends and patterns, so only section 4.1 Trends, knowledge gaps and future research prospects provides quantitative results, the remaining sections onward are mainly qualitative descriptions to answer your pre-defined research questions: e.g. (2) Effectiveness of multiple NBS sites, etc. It should be clarified that you the review is quantitative but also qualitative based on pre-defined questions. However you do not justify why you selected these topics - again, they did not emerge as trends in the literature, you selected them and then found literature to analyse them. In other words, you combine deductive with inductive research. This should be made more explicit, or you should choose one or the other.

<u>Authors' response 2.4:</u> We thank you the reviewer for this comment which really helped us to re-shape the manuscript in a much more coherent form. As discussed earlier (comment 2.2), we have now explicitly stated that the literature material was selected to answer our pre-defined research questions. Trends, knowledge gaps and proposed future research prospects were mainly evaluated with respect to these pre-defined objectives - something that should have been evident from Table 3 but that we had negelcted to comment on in text, thus leading to confusion. For each given topic embedded in our key research questions, this Table specifies the number of articles found that deal with it and it summarizes the knowledge gaps and future research prospects drawn upon them. Trends and path - as emerging from those articles – are therefore discussed not in general, but with respect to each of these topics, which was the criterion based on which Section 4 was divided into subsections. The different sub-sections are meant to reflect the key objectives defined for the review with the intention that the results could be both quantitative and qualitative

In the revised manuscripts, we also slightly modify the titles and contents of some subsections of Section 4 to better highlight the correspondence between them and the research questions of this review. Furthermore, we have moved Section 4.1 "Trends, knowledge gaps and future research prospects" to end of Section 4, as we feel this is better clarify the logic of the paper. Here we also plan to include a paragraph to explicitly comment on Table 3 and to better highlight the quantitative results emerging from our analysis. Finally, we have expanded the "Introduction" Section to better motivate our research questions' choice.

3. Other

<u>Comments from Referees</u> 3.1 Some paragraphs appeared to be more a promotion of author's projects rather than related to the literature review ?? They might belong in the conclusions but not as part of the analysis.

<u>Authors' response 3.1</u> We apologize if some paragraphs appeared to be more a promotion of author's projects. Paragraph on page 10, line 12 has been relocated to conclusion.

<u>Comments from Referees</u> 3.2 The manuscript needs to be redrafted by a native English speaker. e.g. p8, line 27 "desiderative" ;)

<u>Authors' response 3.2</u> Thank you for suggestion. The revised manuscript has been reviewed by a native English speaker.

<u>Comments from Referees</u> 3.3 The table on websites related to the topic is good but excludes a few important sites, namely IUCN's data base on EbA projects and the Partnership for Environment and Disaster Risk Reduction (PEDRR) website.

<u>Authors' response 3.3</u> We apologize for the missing site lists. IUCN's database on EbA projects and the Partnership for Environment and Disaster Risk Reduction (PEDRR) website have been included in Table 4.

Reponses to second referee's comments on "Nature-Based Solutions for hydro-meteorological risk reduction: A state-of-the-art review of the research area" by Laddaporn Ruangpan et al.

Comments from Referee: Summary of the manuscript This manuscript (ms) reviews scientific publication on Nature-based solutions (NBS) for hydro-meteorological risk reduction and related terms. The authors proceeded in a systematic way by using search terms in various scientific literature databases and analyzed over 1000 references. The ms concludes by summarizing the main findings and suggesting further research in some of the reviewed areas. Evaluation I think the topic of this manuscript is highly relevant and important in order to review NBS to tackle the ecological crisis the world is facing. Accordingly, I do think that this ms should be considered for publication. However, I have major doubts if the presented ms really helps to summarize the vast amount of literature on NBS and if it really identifies the knowledge gap in order to be able to recommend the area of focus for future research. My main concerns are the following:

Authors' response: Thank you for your encouragement and comments. Your concerns are addressed in this response letter. Please find our point-by point response below.

i) Methodology

Comments from Referee: a simple search for "Nature-based solutions" in the WoS shows that three of the four most relevant and most cited papers have not been considered in this ms (Keesstra et al. 2018, Nesshover et al. 2017, and Eggermont et al. 2015). Accordingly, I would recommend revising the method of selecting research articles that are being taken into account in the review.

Authors' response: Thank you for your suggestion to make this review more complete. Yes indeed, a simple search for "Nature-based solutions" in the WoS shows that these three papers that the review is referring to did come up in the search and they are indeed among the most cited ones and -without doubt- of relevance for the general subject of NBS. However,we would like to clarify that the goal of our study is to not review the state of the art on all NBS terms (i.e. SuDs, WSUD, BMP, GI etc.) in general, rather to specifically investigate how Nature-based solutions have been used or studied to reduce hydro-meteorological risk. Therefore, the search terms were required to simultaneously include one term for "Nature-based solutions" and one term for hydro-meteorological risk as risk was one of the critieria used to filter the total number of articles (over 6,300). For that reason, Nesshöver et al., (2017) and Eggermont et al., (2015) are not shown in this case and were not taken forward for a more detailed analysis in the 'Finding' section. On the other hand, having recognized the relevance of those articles with respect to the general topic of NBS, and therefore are included in "Overview of definitions and theoretical backgrounds" in the revised version. This section is not part of the Findings section. On the contrary, Keesstra et al., (2018) has now been included as it fulfils the search criteria mentioned above. Note that following Reviewer 1's suggestion, we have expanded the literature search beyond Scopus, by including Web of Science database. This has made more articles, including Keesstra et al., (2018)", discoverable.

ii) Structure

Comments from Referee: I recommend limiting the structure to three levels of subsection: especially section 4 could be better structured, avoiding sections with titles that do not clearly adhere to a three-level subsection structure.

Authors' response: Thank you very much for pointing out the structural issues. The authors have limited the structure to three levels of the subsection. The different sub-sections in Section 4 are meant to reflect the 5 key objectives defined for the review with the intention that the results could be both quantitative and qualitative.

Author's changes in manuscript: We also changed the heading of section 4.2 from "small and large scale NBS for hydro-meteorological risk reduction" to "Lessons from research on small and large scale NBS for hydro-meteorological risk reduction", section 4.2.1 from "Small scale NBS" to "Research on Small scale NBS for hydro-meteorological risk reduction" and section 4.2.2 from "Large scale NBS" to "Research on Large-scale NBS for hydro-meteorological risk reduction."

iii) Content

Comments from Referee: Content is more valuable than academic metrics: while I do see a value in using academic metrics and search engines to select relevant literature, it would be helpful to review the actual characteristics, benefits, and scales of various NBS. Specifically, it would be helpful to have a table that summarizes area, volume of water retention, costs, and effectiveness (and other characteristics) of different NBS. The number of articles does not indicate anything about the effectiveness of a NBS, accordingly, I would encourage the authors to focus more on the characteristics of NBS rather than the number of articles found. In short, more quantitative assessments of the benefits of NBS rather than generic statements would be highly appreciated.

Authors' response: In the revised version, we have investigated further those aspects and carried out a a more quantitative assessment of NBS for hydro-meteorological risk reduction. A new table has been included, which summarizes effectiveness, benefits and costs of different NBS based on the case studies found in the reviewed literature. The table is given below.
We agree that such quantitative information are indeed very valuable and thank the Reviewer for this input. Neverthless, we also see value in using academic metrics: although the number of articles does not indicate anything about the effectiveness of NBS, it provides indications on the direction and the degree of advancement of the research done on this specific topic, which is one of the review objectives.

Author's changes in manuscript: A summary of effectiveness, co-benefits and cost of NBS measures at small scale is shown in Table 4 and at large scale is shown in Table 5

Table 4: Summary of effectiveness, co-benefits and costs of small scale NBS measures

Measures	References	Case studies	Area/ volume covered by NBS	Effectiveness		Co-benefits	Cost/ m^2*	Remark
				Runoff volume reduction	Peak flow reduction			
Porous pavement	Shafique et al., (2018)	Seoul, Korea	1050 m^2	~30–65%	-	• Removing diffuse pollution	~$252	• More effective in heavier and shorter rainfall events.
	Damodaram et al., 2010	Texas, USA	2.99 km^2	-	~10% - 30%			

Measures	References	Case studies	Area/ volume covered by NBS	Effectiveness		Co-benefits	Cost/ m^2*	Remark
				Runoff volume reduction	Peak flow reduction			
						• Enhancing recharge to groundwater		
Green roofs	(Burszta-Adamiak and Mrowiec, 2013)	Wroclaw, Poland	2.88 m^2	-	54%-96%	• Reducing nutrient loadings. • Saving energy • Reducing air pollution • Increasing amenity value	~$564	• More efficient in smaller storm events than larger storm events
	(Ercolani et al., 2018)	Milan, Italy	0.39 km^2	~15%-70%	~10-80%			
	(Carpenter and Kaluvakolanu, 2011)	Michigan, USA	325. 2 m^2	~68.25%	~88.86%			
Rain gardens	(Ishimatsu et al., 2017)	Japan	1.862 m^2	~36-100%	-	• Providing a scenic amenity. • Increasing the median property value • Increasing biodiversity	~$501	• More effective in dealing with small discharges or rainwater
	(Goncalves et al., 2018)	Joinville, Brazil	34,139 m^2	50%	48.5%			
Vegetated swales	(Luan et al., 2017)	Beijing, China	157 m^3	~0.3–3.0%.	2.2%	• Reducing concentrations of pollutants • Increasing biodiversity	~$371	• More effective in heavier and shorter rainfall events. • Not suitable in mountains areas
	(Huang et al., 2014)	Haihe River basin, China	1,500 m^3	9.60%	23.56%			
Rainwater harvesting	(Khastagir and Jayasuriya, 2010)	Melbourne, Australia	1 m^3 -5 m^3	~57.8%-78.7%	-	• Improving water quality (TN was reduced around 72%-80%)	~$865 /$m^3$	
	(Damodaram et al., 2010)	Texas, USA	1.5 km^2	-	~8%-10%			
Dry detention pond	(Liew et al., 2012)	Selangor, Malaysia	65,000 m^2	-	33-46%	• Providing recreational benefits.		• Delaying the time to peak by 40-45 min
Detention pond	(Damodaram et al., 2010)	Texas, USA	73,372 m^3	-	~20%	• Providing biodiversity benefits • Providing recreational benefits.	~$60	
	(Goncalves et al., 2018)	Joinville, Brazil	9,700 m^3	55.7%	43.3%			
Bio-retention	(Luan et al., 2017)	Beijing, China	945.93 m^3	~10.2–12.1%.	-	• Reducing TSS pollution • Reducing TP pollution	~$534	• Measure has a better reduction effectiveness in various rainfall intensities.
	(Huang et al., 2014)	Haihe River basin, China	1,708.6 m^3	9.10%	41.65%			
	Khan et al., 2013;	Calgary	48 m^3	~90%	-			
Infiltration trench	(Huang et al., 2014)	Haihe River, China	3,576 m^3	30.80%	19.44%	• Reducing water pollutant • Improving surface water quality.	~$74	
	(Goncalves et al., 2018)	Joinville, Brazil	34,139 m^2	55.9%	53.4%			
Street trees	(Soares et al., 2011)	Lisbon, Portugal	41,247 street trees			• Net benefit €6.55 million per annual of benefits	€45.6 per annual	
Green roof and Porous pavement	(Damodaram et al., 2010)	Texas, USA	4.49 km^2	-	~10%-35%	• Saving energy • Increasing amenity value		• More effective in smaller events

Measures	References	Case studies	Area/ volume covered by NBS	Effectiveness		Co-benefits	Cost/ m^2*	Remark
				Runoff volume reduction	Peak flow reduction			
Swale and Porous pavement	(Behroozi et al., 2018)	Tehran, Iran	-	5%-32%	~10%-21%	• Decreasing TSS pollution 50-60%		More effective in smaller events
Rainwater harvesting and Porous pavement	(Damodaram et al., 2010)	Texas, USA	4.49 km^2	-	20%-40%	• Removing diffuse pollution		• More effective in smaller events
Detention pond and Raingarden	(Goncalves et al., 2018)	Joinville, Brazil	18,327 m^2	70.8%	60.0%	• Providing a scenic amenity.		
Detention pond and Infiltration trench	(Goncalves et al., 2018)	Joinville, Brazil	18,327 m^2	75.1%	67.8%	Improving surface water quality.		

***Remark** Cost of each measure is based on (CNT, 2009; Nordman et al., 2018; De Risi et al., 2018)

Table 5: Summary of effectiveness, co-benefits and costs of large scale NBS measures

Measures	References	Case studies	Area/ volume covered by NBS	Effectiveness	Co-benefits	Cost
De-culverting (river restoration)	(Chou, 2016)	Laojie River, Taiwan	3 km	• It can reduce flood risk up to 100 year return period	• Increasing landscape value • Increasing recreational value	~$18.6 million
Floodplain lowering	(Klijn et al., 2013).	Deventer Netherlands	5.01 km^2	• It can reduce water level 19 cm	• Increasing nature area • Increasing agriculture value	~€136.7 million e
Dike relocation/ floodplain lowering	(Klijn et al., 2013).	Nijmegen/ Lent, Netherlands	2.42 km^2	• It can reduce water level 34 cm	• Increasing floodplain area • Increasing recreational value	~€342.6 0 million
Floodwater storage	(Klijn et al., 2013).	Volkenrak-Zoommeer	200 million m^3	• It can reduce water level 50 cm	• Increasing habitat and biodiversity in the area • Increasing recreational value	~€386.2 0 million
Green floodway	(Klijn et al., 2013).	Veessen-Wapenveld	14.10 km^2	• It can reduce water level 71 cm	• Increasing floodplain area • Increasing recreational value	
Wetlands (Mangroves and salt Marshes)	(Coppenolle, 2018; Gedan et al., 2011)			• It can mitigate storm surge 80% • It can protect against tsunami impacts	• Providing shoreline protection services	
Forest rapirian buffer, basins and ponds and coarse woody debris	(McVittie et al., 2018)	Pickering, North Yorkshire, UK	68,6 km^2	• Increased water storage 90,000-138,000 m^3 • Peak flow rate reduction 6.7–14.7%	• Increase habitat creation value • Education and knowledge • Community development • A benefit/cost ratio of 4.98	~€1.58 million

Measures	References	Case studies	Area/ volume covered by NBS	Effectiveness	Co-benefits	Cost
				• Flood peak delay by 20 min		
Renaturation	(McVittie et al., 2018; NWRM, 2019)	Seymaz river, Switzerland	0.4 km^2	• Water storage 800,000 m^3		~€61 million (€76.3/ m^3)

iv) Definitions

<u>Comments from Referee</u>: in my opinion, it would be helpful to provide a table with definitions and examples of the various academic terms used in the review: The study provides generic definitions for GI, EbA, and NBS, but it is left upon the reader to interpret the definitions. I would recommend to complement Table 2 with some quantitative figures on water retention, area, costs, advantages, disadvantages etc.... (see also the previous comment).

<u>Authors' response:</u> Thank you for the comment and suggestion. Referee 1 also raised similar comments on the definitions. We have included more explanation on the definition in section 3 (now section 2) "Overview of definitions and theoretical backgrounds on the terminology of NBS" Here we also recommend the reader to refer to Nesshöver et al., (2017). and others works for a more exhaustive analysis on terminology, which is beyond the goal of our study. We feel that this additions, together with the newly provided Tables 4 and 5, should provide the reader enough guidance in the interpretation of our results.

<u>Author's changes in manuscript</u> <u>(revised and added texts have yellow highlights)</u>**:**

There are several terms and concepts which have been used interchangeably in the literature to date. In terms of NBS, the two most prominent definitions are from International Union for Conservation of Nature (IUCN) and the European Commission. The European Commission defines Nature-Based Solutions as "Solutions that aim to help societies address a variety of environmental, social and economic challenges in sustainable ways. They are actions inspired by, supported by or copied from nature; both using and enhancing existing solutions to challenges, as well as exploring more novel solutions. Nature-based solutions use the features and complex system processes of nature, such as its ability to store carbon and regulate water flows, in order to achieve desired outcomes, such as reduced disaster risk and an environment that improves human well-being and socially inclusive green growth" (European Commission, 2015). The IUCN has proposed a definition of NBS as "actions to protect, sustainably manage and restore natural and modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits" (Cohen-Shacham et al., 2016). Eggermont et al. (2015) proposed a typology characterising NBS into three types: i) NBS that address a better use of natural/protected ecosystems (no or minimal intervention), which fits with how IUCN frames NBS; ii) NBS for sustainability and multi-functionality of managed ecosystems and iii) NBSs for the design and the management of new ecosystems, which is more representative of the definition given by the European Commission.

NBS is a collective term for innovative solutions to solve different types of societal and environmental challenges, based on natural processes and ecosystems. Therefore, it is considered as an “umbrella concept” covering a range of different ecosystem-related approaches and linked concepts (Cohen-Shacham et al., 2016; Nesshöver et al., 2017), that provides an integrated way to look at different issues simultaneously.

Due to the diverse policy origins, NBS terminology has evolved in the literature to emphasize different aspects of natural processes or functions. In this regard, nine different terms are commonly used in the scientific literature in the context of hydro-meteorological risk reduction: Low Impact Developments (LIDs), Best Management Practices (BMPs), Water Sensitive Urban Design (WSUD), Sustainable Urban Drainage Systems (SUDs), Green Infrastructure (GI), Blue-Green Infrastructure (BGI), Ecosystem-based Adaptation (EbA) and Ecosystem-based Disaster Risk Reduction (Eco-DRR). The timeline of each term, based on their appearance in literature is shown in Figure 1 and their definitions are given in Table 1.

The commonalities between NBS and its sister concepts (i.e., GI, BGI, EbA, Eco-DRR) are that they take participatory, holistic, integrated approaches, using nature to enhance adaptive capacity, reduce hydro-meteorological risk, increase resilience, improve water quality, increase the opportunities for recreation, improve human well-being and health, enhance vegetation growth and connect habitat and biodiversity. More information on the history, scope, application and underlying principle of terms of SUDs, LIDs, BMPs, WSUD and GI can be found in Fletcher et al. (2015) while the relationship between NBS, GI/BGI, and EbA is described in detail by Nesshöver et al. (2017).

Although all terms are based on a common idea, which is embedded in the umbrella concept of NBS, differences in definition reflect their historical perspectives and knowledge base that were relevant at the time of the research (Fletcher et al., 2015). The distinguishing characteristic between NBS and its sister concepts is how they address social, economic and environmental challenges (Faivre et al., 2018). Some terms such as SUDs, LIDs, and WSUD refer to NBS that specifically address stormwater management. They use landscape feature to transform the linear approach of conventional stormwater management into a more cyclic approach where drainage, water supply, and ecosystems are treated as part of the same system, mimicking more natural water flows (Liu and Jensen, 2018). GI/BGI focus more on technology-based infrastructures by applying natural alternatives (Nesshöver et al., 2017) for solving a specific activity (i.e., urban planning or stormwater). EbA looks at long-term changes within the conservation of biodiversity, ecosystem services and climate change, while Eco-DRR is more focused on immediate and medium-term impacts from the risk of weather, climate and non-climate-related hazards. EbA is often seen as a subset of NBS that is explicitly concerned with climate change adaptation through the use of nature (Kabisch et al., 2016). From the above discussion, it can be concluded that EbA, Eco-DRR and GI/BGI provide more specific solutions to more specific issues. One key distinction is that unlike the sister concepts, the concept of NBS is more open to different interpretations, which can be useful to encourage stakeholders to take part in the discussion.

Moreover, features of NBS provide an alternative to work with existing measures or grey infrastructures. Therefore, it is important to note that very often a combination between natural and traditional engineering solutions (a.k.a. “hybrid” solutions) is likely to produce more effective results than any of these measures alone, especially when their co-benefits are taken into consideration.

An important advance in the science and practice of NBS is given by the EKLIPSE Expert Working Group, which developed the first version of a multi-dimensional impact evaluation framework to support planning and evaluation of NBS projects. The document includes a list of impacts, indicators and methods for assessing the performance of NBS in dealing with some major societal challenges (EKLIPSE, 2017; Raymond et al., 2017). Lafortezza et al., (2018) reviewed different case studies around the world where NBS have been applied from micro-scale to macro-scale. Furthermore, an overview of how different NBS measures can regulate ecosystem services (i.e., soil protection, water quality, flood regulation, and water provision) has been carried out by Keesstra et al., (2018).

v) Drought

Comments from Referee it is well know that land reclamation and restoration reduces evaporation and mitigates the drought risk. However, the authors found only one single study referring to the drought risk. This might be due to a methodology based on "key words" rather than content.

Authors' response:

Thank you very much for your suggestion. While the methodology helps limit the scope of the paper, the authors understand that it may also cause some gaps in the study. However, the authors have attempted to review papers as comprehensively as possible to mitigate this issue.

Since the aim of the study is to review Nature Based Solutions and those terms used in conjunction with NBS, additional terminology like reclamation and restoration were not specifically used. This search term could introduce a bias, as the authors then assume the solutions before the review. To be transparent, we have included a sentence to acknowledge that the selection of key search words can limit the hydro-meterological risk measures that appear in returned papers.

Nevertheless, the authors believe that the method still provides useful direction for a state of the art review and defining research gaps on Nature-Based Solutions for Hydro-meteorological risk reduction.

vi) Scale and examples

Comments from Referee one example that struck me is the NBS "Room for the River Programme" in the Netherlands at the Rhine and Meuse. It is general knowledge that flood protection has to start upstream in the headwaters, where most of the precipitation occurs, to be efficient. Nevertheless, the ms only mentions NBS in the Netherlands (a third of the Netherlands are below sea level and sea levels are rising), ignoring the far more relevant NBS in upstream countries. This might be linked to the somewhat limited methodology of the literature review (see comment i).

Authors' response: Thank you very much for your comment. The requirements of this articles that is to focus on peer-reviewed articles in English and we agree with the reviewer that upstream cases exist, which the authors had conducted additional research based on the comment of the reviewer.

It can be summarized that the EU Flood directive specifies that countries upstream or downstream should avoid taking measures that will increase the flood risk to other countries in the same river catchment. In case this is not feasible, the countries should consult with the other member states to agree to the proposed measures (EU, 2019). As far as the authors are aware, there is a project in the Rhine basin called Adaptive Land use for Flood Alleviation

(ALFA). “Room for the River Programme” by the Ducth is also part of this project. However, all of the project’s documents from upstream in Germany that the authors have found are only in the grey literatures and in the German language, which are out of the scope of this article.

On the other hand, there are many documents and publications on the “Room for the River Programme” that are available in English. Moreover, “Room for the river programme” is one of the big projects on a large scale NBS which has been successfully studied and implemented it can be used as an example to other countries.

vii) Tools

Comments from Referee: in my opinion, the review of tools could be shortened, as it is slightly off the topic. Instead, more attention could be given to the quantification of the various benefits of NBS could be provided (see comment iii).

Authors’ response: Authors have shortened the review of tools. However, the leading message should still be included since the tools are important for selection, evaluation and operation of NBS. One of the purposes of this review is to review the use of techniques, methods and tools for planning, selecting, evaluating and implementing NBS. The benefit of this section is to provide information to the reader as to what the available tools are that can be used for a specific purpose.

The authors have also included some quantification of NBS measures as suggested by the reviewer in Table 4 and 5 as shown in comment iii and benefits of NBS also discuss in section 4.5 in manuscripts. However, discussing the quantitative co-benefits of NBS is still very challenging as there is a lack of information on assessment quantitative value of the ecosystem. Such challenges and limitations will be explictely commented on in the revised version.

viii) Conclusion

Comments from Referee: the current conclusion provides general and generic statements and any reader somewhat familiar with the topic does not really learn anything new. It would be helpful to generate more conclusive and quantitative statement based on the review: which NBS are most effective, which provide most multi-benefits, which require least areas, which are most accepted?

Authors’ response: Thank you for the suggestion. The authors have revised the conclusion to summarize the quantitative statement of NBS on; “which NBS are most effective, which provide most multi-benefits, which require the least area, which are the most accepted” as the authors suggested.

However, this has proven to be very difficult because the effectiveness, benefits and acceptance of NBS are dependent on the implementation purposeslocal context and cultural setting. For example, small NBS are more suitable for urban flooding while large scale NBS are more suitable for river floods, coastal floods, droughts and landslides. Large scale NBS can provide more benefits compared to small scale NBS because it has a bigger space, thus more function can be included in the design process. For example, Laojie river project in Taoyuan City in Taiwan changed the channel into an accessible green corridor. This project helps in reducing flood risk, improving riverside landscapes, increasing recreation area, increasing the aesthetic value in the area, and improving river water quality. On the other hand, small scale NBS need less area because most of the measures can be implemented in the free space. For example, green roofs can be implemented on the roofs of buildings, and permeable pavements can be implemented in car parks. Investments in NBS will benefit society by providing cost-effective measures and adaptive strategies that protect their communities and achieve a range of co-benefits. Therefore, bridging the gaps between researchers, engineers and stakeholders will help to improve the capacity of NBS in reducing hydro-meteorological risk as well as increasing thier benefits. Strengthening these aspects may be beneficial for improving acceptance of NBS at the local level.

In the revised version, all of the above information has been included in the conclusion section, and a summary of quantitative information on effectiveness, co-benefits and cost for different NBS measures can be found in Table 4 and 5 in the revision.

Track changes document

Nature-Based Solutions for hydro-meteorological risk reduction: A state-of-the-art review of the research area

Laddaporn Ruangpan[1,2,], Zoran Vojinovic[1,3], Silvana Di Sabatino[4], Laura Sandra Leo[4], Vittoria Capobianco[5], Amy M. P. Oen[5], Michael McClain[1,2] , Elena Lopez-Gunn[6]

[1] IHE Delft Institute for Water Education, Delft, the Netherlands
[2] Department of Water Management, Faculty of Civil Engineering and Geosciences, Delft University of Technology, the Netherlands
[3] College for Engineering, Mathematics and Physical Sciences, University of Exeter, UK
[4] Department of Physics and Astronomy, University of Bologna, Italy
[5] Norwegian Geotechnical Institute, Norway
[6] ICATALIS, Spain

Correspondence to: Laddaporn Ruangpan (L.Ruangpan@tudelft.nl)

Abstract. Hydro-meteorological risks due to ~~N~~natural hazards such as severe floods, storm surges, landslides, ~~avalanches, hail, windstorms, droughts, heat waves~~ and droughts are causing impacts on different sectors of society.~~forest fires occur almost daily~~. Such risks are expected ~~This situation is likely~~ to become worse given the projected changes in climate, degradation of ecosystems, population growth and urbanisation. In this respect, Nature-Based Solutions (NBS) have emerged as effective means to respond to such challenges. NBS is a term used for innovative solutions that are based on natural processes and ecosystems to solve different types of societal and environmental challenges. ~~The new concepts such as Ecosystem-based Adaptation, Green Infrastructure and/or Nature-Based Solutions have emerged as effective means to respond to such challenges.~~ The present paper provides a critical review of the literature and identifies current knowledge gaps and future research prospects. There has been an explosion of scientific publications on this topic with a more significant rise taking place from 2007 onwards Hence, the review process presented in this paper starts by sourcing 1407 articles from Scopus and 1232 articles from Web of Science. The full analysis was performed on 137 articles. The analysis confirmed that numerous advancements in the area of NBS have been achieved to date. ~~. Hence, the review process started by sourcing 1381 articles from Scopus which were also cross-referenced with the articles sourced from Web of Science and Google Scholar. The full analysis was performed on 159 closely related articles.~~ The analysis confirmed that numerous advancements have been achieved to date. These solutions have already proven to be valuable in providing sustainable, cost-effective, multi-purpose and flexible means for hydro-meteorological risk reduction. However, there are still many areas where further research and demonstration is needed in order to promote their upscaling and replication and to make them become mainstream solutions.

1 Introduction

There is an increasing evidence that climate change and associated hydro-meteorological riskdisasters are already causing wide-ranging impacts on different sectors of society. Natural hazards such as severe Ffloods, storm surges, landslides, avalanches, hail, windstorms, droughts, heat waves and forest fires are a few examples of hydro-meteorological hazards that pose a significant risk. Hydro-meteorological risk is the probability of damage due to hydro-meteorological hazards and its interplay with exposure and vulnerability of the affected humans and environments (Merz et al., 2010). have already made unprecedented impacts on the global economy, human well-being, and the environment. Some of the main reasons for this situation are climate change, land use change, water use change and other pressures linked to population growth (Thorslund et al., 2017a) and the situation is likely to become worse given the projected changes in climate (see for example, EEA, 2017). Therefore, climate change adaptation (CCA) and disaster risk reduction (DRR) strategies are needed to mitigate risks of the extreme events and to increase resilience to disasters, particularly among vulnerable populations. (Maragno et al., 2018; McVittie et al., 2018) effective adaptation strategies are needed to mitigate risks related to the increased frequency of extreme events (Maragno et al., 2018).

Since biodiversity and ecosystem services can play important role in responding to climate-related challenges, both mitigation and adaptation strategies should take into consideration a variety of Green Infrastructure (GI) and Ecosystem-based Adaptation (EbA) as effective means to respond to present and future disaster risk (see also EEA, 2015). Such approaches are already well accepted within multilateral frameworks such as the international United Nations (UN) Framework Convention on Climate Change (UNFCCC), the Convention on Biological Diversity (CBD) and the Sendai Framework for Disaster Risk reduction (SFDRR). As such, they are recognized as effective means for climate change adaptation (CCA) and disaster risk reduction (DRR), and for the implementation of the Sustainable Development Goals (SDGs).

In view of the above, many countries are nowadays developing adaptation and mitigation strategies based on GI and EbA to reduce their vulnerability to hydro-meteorological hazards (Rangarajan et al., 2015). Nature-Based Solutions (NBS) have been introduced relatively recently. The reason behind is that NBS offer the possibility to work closely with nature to adapt with the future changes and to reduce the impact of climate change as well as to improve human well-being (Cohen-Shacham et al., 2016). NBS have been in the focus for reseach in several EU Horizon2020 funded projects. The Horizon2020 offers new opportunities in the focus area of 'Smart and Sustainable Cities with Nature based solutions' (Faivre et al., 2017). Some of these important projects are: Nature4Cites, Naturvation, NAIAD, BiodiverEsA, Inspiration, URBAN GreenUP, UNaLaB, URBINAT, CLEVER Cities, proGIreg, EdiCINET, RECONECT, OPERANDUM, ThinkNature, EKLIPSE and PHUSICOS (nature4cities, 2019).

NBS are typically implemented through both structural (green-blue infrastructure, e.g. wetlands, green roofs) and non-structural measures (e.g. improving the local knowledge of NBS) (Lottering et al., 2015; Raymond et al., 2017). They are associated with multiple benefits such as improving water quality, increasing the opportunities for recreation, improving

~~human well-being and health, enhancing vegetation growth and connecting habitat and biodiversity (Donnell et al., 2018; Raymond et al., 2017; Song et al., 2018; Thorslund et al., 2017b).~~

The number of scientific studies focused on GI, EbA and/or NBS to reduce disaster risk are continuously increasing all over the world. The aim of this article is to provide a state-of-the-art review of publications on hydro-meteorological risk reduction with NBS to indicate some directions for future research based on the current knowledge gaps. The analysis focuses on the following hydro-meteorological hazards: floods, droughts, storm surges, and landslides. The review addresses both small and large scale interventions and explores available techniques, methods and tools for NBS assessment, while also providing a snapshot of the major socio-economic factors at play in the implementation process. The key objectives and methods of this study are discussed in Section 3, while Section 2 provides a brief overview of concepts and definitions related to NBS either in general or specifically linked to hydro-meteorological risk reduction. Results and conclusions are discussed in Sections 4 and 5 respectively. ~~to explore the patterns and trends of current research activities as well as to indicate some directions for future research based on the knowledge gaps. The systematic review process presented in this article concerns only scientific journal articles although there is a considerable body of knowledge available in various project reports and other kind of literature. However, since they do not necessarily follow scientific publication standards most of them were excluded from the scope of the present work. Only in those cases where with a more significant contribution has been achieved (and in the absence of scientific articles) such literature was included into the analysis. The key objectives of the present review work are as follows:~~

~~To identify patterns and trends of NBS publications in scientific journals,~~

~~To assess the state-of-the-art in research concerning both small and large scale NBS,~~

~~To review the use of techniques, methods and tools for planning, selecting, evaluating and implementing NBS,~~

~~To review the socio-economic influence in the implementation of NBS as well as their main benefits and co-benefits, and~~

~~To identify knowledge gaps and proposed future research prospects.~~

2~~3~~ Overview of definitions and theoretical backgrounds

There are several terms and concepts which have been used interchangeably in the literature to date. In terms of NBS, the two most prominent definitions are from International Union for Conservation of Nature (IUCN) and the European Commission. The European Commission defines Nature-Based Solutions as “Solutions that aim to help societies address a variety of environmental, social and economic challenges in sustainable ways. They are actions inspired by, supported by or copied from nature; both using and enhancing existing solutions to challenges, as well as exploring more novel solutions. Nature-based solutions use the features and complex system processes of nature, such as its ability to store carbon and regulate water flows, in order to achieve desired outcomes, such as reduced disaster risk and an environment that improves human well-being and socially inclusive green growth" (European Commission, 2015). The IUCN has proposed a definition of NBS as "actions to protect, sustainably manage and restore natural and modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits" (Cohen-Shacham et al., 2016). Eggermont et al. (2015) proposed a typology characterising NBS into three types: i) NBS that address a better use of natural/protected ecosystems (no or minimal intervention), which fits with how IUCN frames NBS; ii) NBS for sustainability and multi-functionality of managed ecosystems and iii) NBSs for the design and the management of new ecosystems, which is more representative of the definition given by the European Commission.

NBS is a collective term for innovative solutions to solve different types of societal and environmental challenges, based on natural processes and ecosystems. Therefore, it is considered as an "umbrella concept" covering a range of different ecosystem-related approaches and linked concepts (Cohen-Shacham et al., 2016; Nesshöver et al., 2017), that provides an integrated way to look at different issues simultaneously.

Due to the diverse policy origins, NBS terminology has evolved in the literature to emphasize different aspects of natural processes or functions. In this regard, nine different terms are commonly used in the scientific literature in the context of hydro-meteorological risk reduction: Low Impact Developments (LIDs), Best Management Practices (BMPs), Water Sensitive Urban Design (WSUD), Sustainable Urban Drainage Systems (SUDs), Green Infrastructure (GI), Blue-Green Infrastructure (BGI), Ecosystem-based Adaptation (EbA) and Ecosystem-based Disaster Risk Reduction (Eco-DRR). The timeline of each term, based on their appearance in literature is shown in Figure 1 and their definitions are given in Table 1.

~~The common idea behind these terms is the use of landscape for transforming the linear character of conventional stormwater management into a more cyclic approach where drainage, water supply, and ecosystems are treated as part of the same system, mimicking more natural water flows (Liu and Jensen, 2018). The literature to date defines these solutions are more or less equally effective in addressing climate change adaptation and disaster risk reduction.~~ The commonalities between NBS and its sister concepts (i.e., GI, BGI, EbA, Eco-DRR) are that they take participatory, holistic, integrated approaches, using nature to enhance adaptive capacity, reduce hydro-meteorological risk, increase resilience, improve water quality, increase the opportunities for recreation, improve human well-being and health, enhance vegetation growth and connect habitat and biodiversity. More information on the history, scope, application and underlying principle of terms of SUDs, LIDs, BMPs, WSUD and GI can be found in Fletcher et al. (2015) while the relationship between NBS, GI/BGI, and EbA is described in detail by Nesshöver et al. (2017).

Although all terms are based on a common idea, which is embedded in the umbrella concept of NBS, differences in definition reflect their historical perspectives and knowledge base that were relevant at the time of the research (Fletcher et al., 2015). The distinguishing characteristic between NBS and its sister concepts is how they address social, economic and environmental challenges (Faivre et al., 2018). Some terms such as SUDs, LIDs, and WSUD refer to NBS that specifically address stormwater management. They use landscape feature to transform the linear approach of conventional stormwater management into a more cyclic approach where drainage, water supply, and ecosystems are treated as part of the same system, mimicking more natural water flows (Liu and Jensen, 2018). GI/BGI focus more on technology-based infrastructures by applying natural alternatives (Nesshöver et al., 2017) for solving a specific activity (i.e., urban planning or stormwater). EbA looks at long-term changes within the conservation of biodiversity, ecosystem services and climate change, while Eco-DRR is more focused on immediate and medium-term impacts from the risk of weather, climate and non-climate-related hazards. EbA is often seen as a subset of NBS that is explicitly concerned with climate change adaptation through the use of nature (Kabisch et al., 2016). From the above discussion, it can be concluded that EbA, Eco-DRR and GI/BGI provide more specific solutions to more specific issues. One key distinction is that unlike the sister concepts, the concept of NBS is more open to different interpretations, which can be useful to encourage stakeholders to take part in the discussion.

Moreover, features of NBS provide an alternative to work with existing measures or grey infrastructures. Therefore, it is important to note that very often a combination between natural and traditional engineering solutions (a.k.a. "hybrid" solutions) is likely to produce more effective results than any of these measures alone, especially when their co-benefits are taken into consideration. ~~Different from these two terms, NBS offer an integrated way to look at different issues simultaneously. However, it is important to note that very often a combination between natural and traditional engineering solutions (a.k.a. "hybrid" solutions) is likely to produce more effective results than any of these measures alone, especially when their co-benefits are taken into consideration (Alves et al., 2019).~~

An important advance in the science and practice of NBS is given by the EKLIPSE Expert Working Group, which developed the first version of a multi-dimensional impact evaluation framework to support planning and evaluation of NBS projects. The document includes a list of impacts, indicators and methods for assessing the performance of NBS in dealing with some major societal challenges (EKLIPSE, 2017; Raymond et al., 2017). ~~The framework is based on 10 challenges: 1) Climate Mitigation and adaptation, 2) Water Management, 3) Coastal Resilience, 4) Green space Management, 5) Air Quality, 6) Urban Regeneration, 7) Participatory Planning and Governance, 8) Social justice and Social Cohesion, 9) Public health and well-being and 10) Economic opportunities and Green Jobs (Raymond et al., 2017). The fact that the EKPLISE framework was specifically develop for NBS at the urban scale and only deals with challenges faced by cities.~~ Lafortezza et al., (2018) reviewed different case studies around the world where NBS have been applied from micro-scale to macro-scale. Furthermore, an overview of how different NBS measures can regulate ecosystem services (i.e., soil protection, water quality, flood regulation, and water provision) has been carried out by Keesstra et al., (2018).

32 Materials and methodology

The methodology consisted of two phases as schematized in Figure 2. The first phase consisted of the identification of articles satisfying the search criteria discussed in Section 3.1. Next, all articles were screened and filtered based on the selection criteria discussed in section 3.2.

32.1 Search strategy

The review analysis concerned articles from scientific journals written in English. Two main concepts were used in the search: Nature-Based Solutions and hydro-meteorological risk. As the concept of 'Nature-Base Solutions' appears under different names (which more or less relate to the same field of research), articles related to Low Impact Developments (LIDs), Best Management Practices (BMPs), Water Sensitive Urban Design (WSUD), Sustainable Urban Drainage Systems (SuDS), Green Infrastructure (GI), Blue-Green Infrastructure (BGI), Ecosystem-based Adaptation (EbA) and Ecosystem-based Disaster Risk Reduction (Eco-DRR) were included in the identification of relevant articles (see Table 1). The review of hydro-meteorological risk included literature on relevant terms (i.e. disaster, review, hydrology etc.) and different types of risk (i.e. floods, droughts, storm surges and landslides, and the relevant terms.) (Table 1).

During the construction of the queries, the strings were searched only within Index terms and Metadata "titles, abstract, and keywords" in the Scopus database. The search terms for the two concepts were linked with the Boolean operator "AND" while the Boolean operator "OR" was used to link between the possible terms (Table1). An example of a protocol is shown below:

"TITLE-ABS-KEY ("Nature-based solutions" OR "Nature based solutions" OR "Nature Based Solutions" OR "Nature-Based Solutions" OR "Low impact development" OR "Sustainable Urban Drainage Systems" OR "Water Sensitive Urban Design" OR "Best Management Practices" OR "Green infrastructure" OR "Green blue infrastructure" AND "flood") AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "ch") OR LIMIT-TO (DOCTYPE , "re") OR LIMIT-TO (DOCTYPE , "bk")) AND (LIMIT-TO (LANGUAGE , "English"))"

Figure 1. shows the number of articles that have been published on the concepts of NBS, LIDs, SuDS, WSUD, BMPS, GI, and BGI. From Fig. 1, it can be observed that since 2007 the number of scientific articles started increasing significantly. Therefore, the time window selected for the review process was from 2007 onwards.

The findings from Scopus were cross-referenced with other databases such as Web of Science and Google Scholar and the number of publications found in Scopus database was larger than the number of articles found in the other two databases.

The time window selected for the review process was from 1 January 2007 to 1 December 2018. 1407 articles published in scientific journals were found in the Scopus database and 1232 were found in the Web of Science database. The articles from both databases were combined to 2639 articles. Duplicate articles were removed, resulting in a total of 1204 articles to be considered for further evaluation.

32.2 Selection process

As stated in the introduction, this study aims at reviewing the state-of the-art of the research on NBS that specifically address hydro-meteorological risk reduction. In this regard, the key objectives of the present review work were carefully formulated as follows:

1) To assess the state-of-the-art in research concerning both small and large scale NBS for hydro-meteorological risk reduction;
2) To review the use of techniques, methods and tools for planning, selecting, evaluating and implementing NBS for hydro-meteorological risk reduction;
3) To review the socio-economic influence in the implementation of NBS for hydro-meteorological risk reduction as well as their multiple benefits, co-benefits, effectiveness and costs;
4) To identify trends, knowledge gaps and proposed future research prospects with respect to the above three objectives.

These key objectives were defined for the review with the intention that the results could be both quantitative and qualitative.

The 1204 articles resulting from the search query were thus evaluated with respect to these objectives, and those found of little or no relevance with the topic removed. This selection process involved a set of progressive steps as schematized in Figure 2.

Initially, all articles were analysed on the basis of reading titles and keywords and evaluating their relation to the search terms. Articles were discarded if their title and keywords were considered of little or no relevance to the key objectives. This step served to reduce the number of articles from 1204 to 380.

Secondly, a more in-depth analysis was conducted, based on reading the abstract of each article selected in the previous step. The criteria at this step was that the abstract should discuss hydro-meteorological risk reduction. For example, if the abstract focused more on water quality than risk, that paper was excluded. This step served to reduce the number of articles from 380 to 185.

Finally, articles were read in full to identify those that were relevant to the review objectives. Any studies appearing to meet the key objectives (dealing with subjects such as effectiveness of NBS, techniques, method and tools for planning, and others subjects relevant to the key objectives) were included in the review. As a result, the entire selection process resulted in a total of 137 articles relevant to the objectives of the present review.

~~As discussed in Section 2.1, the search process was based upon the following three criteria: (1) articles published in peer-reviewed, scientific journals written in English; (2) articles reported on NBS in terms of hydro-meteorological risk reduction; (3) articles published from year 2007 onwards.~~

~~Initially, the Scopus database search resulted in 1381 articles published in scientific journals. The same search performed in Web of Science and Google Scholar resulted in 1208 and 972 articles, respectively. Hence, the Scopus database was used as a main database for the purposes of the present work. To make the review process more specific, the process depicted in Fig. 2 was applied to select the relevant articles. Firstly, those duplicate articles found from the applied queries were removed. After that, all articles were analysed on the basis of their titles and keywords. Since the search of articles contained some gaps (i.e., there were several missing articles which were already known to the authors) the list of articles was appended with those missing articles. The final step was to read and analyse all selected articles.~~

4 Findings

4.1~~2~~ Lesson from research on small and large scale NBS for hydro-meteorological risk reduction ~~Small and large scale NBS for hydro-meteorological risk reduction~~

In this review, NBS for hydro-meteorological risk reduction have been divided into small and large scale (Fig.3~~5~~). "s~~S~~mall scale NBS" are usually referred to as NBS at the urban or local scale, while NBS in rural areas, river basins and at the regional scale are referred to as "l~~L~~arge scale NBS" (Fig.3~~5~~.).

4.1~~2~~.1 Research on small scale NBS for hydro-meteorological risk reduction ~~Small scale NBS~~

Small scale NBS are usually applied to a specific location such as a single building or a street. However, , for some cases, a single NBS is not sufficient to control a large amount of runoff. Therefore, this review discusses the application and effectiveness of both individual NBS and multiple-NBS combinations. There are 45 articles that have been reviewed on the effectiveness of small scale NBS (Table 3). A majority of these (29 articles) discuss the effectiveness of a single/individual NBS site, while only 16 articles discuss the effectiveness of multiple NBS sites (around 28 percent). A summary of effectiveness, co-benefits and cost of NBS measures at small scale is shown in Table 3.

~~**(1) Effectiveness of a single/individual NBS site**~~

To date, various types of single NBS sites have been studied with objectives such as reduction of the flood peak (Carpenter and Kaluvakolanu, 2011; Ercolani et al., 2018; Liao et al., 2015; Mei et al., 2018; Yang et al., 2018), delay/attenuation of the flood peak (Ishimatsu et al., 2017), reduction of volume of combined sewer overflows (Burszta-Adamiak and Mrowiec, 2013) and reduction of the surface runoff volume (Lee et al., 2013; Shafique and Kim, 2018). The review found just one article, Lottering et al., (2015) that discusses the reduction of drought risk by using NBS to reduce water consumption in suburb areas.

Shafique et al., (2018) described how porous pavement can be very effective in decreasing the possibility of flash floods in the developed area in Seoul. NBS has also been used to improve water quality in Greater Melbourne, Australia (Khastagir and Jayasuriya, 2010) and in Xi' city in China (Li et al., 2018b).

The most common NBS measures in urban areas appear to be intensive green roofs (Burszta-Adamiak and Mrowiec, 2013; Carpenter and Kaluvakolanu, 2011; Ercolani et al., 2018), extensive green roofs (Cipolla et al., 2016; Lee et al., 2013), rain gardens (Ishimatsu et al., 2017), rainwater harvesting (Khastagir and Jayasuriya, 2010), dry detention ponds (Liew et al., 2012), permeable pavements (Shafique et al., 2018), bio-retention (Khan et al., 2013; Olszewski and Allen, 2013), vegetated swales (Woznicki et al., 2018) and trees (Mills et al., 2016). However, the authors of these studies investigated the performance of such measures individually (i.e. at the specific/local/single site) without evaluating it in combination with other NBS sites or in hybrid combinations.

NBS may benefit people in coastal areas by reducing risk from storm surges, wave energy, coastal flooding as well as erosion, as documented by several authors (see for example, Coppenolle, 2018; Joyce et al., 2017; Ruckelshaus et al., 2016; Sutton-Grier et al., 2018). NBS for coastal areas can be implemented either large or small scale. They include dunes, beaches, oyster and coral reefs, mangroves, seagrass beds, and marshes. These measures can also provide habitat for different species such as fish, birds, and other wildlife (Ruckelshaus et al., 2016). However, only few articles focused on the potential benefits of NBS in coastal areas.

The review found just one article that discusses the use of NBS for reduction of drought risk. Lottering et al., (2015) discussed the effectiveness of NBS on reduction of water consumption in suburb areas.

The literature to date acknowledges that the effectiveness of NBS greatly depends on the magnitude and frequency of rainfall events. Green roofs are recognized in reducing peak flows more effectively for smaller magnitude frequent storms than for larger magnitude infrequent storms (see for example, Ercolani et al., 2018). There are also reports that rain gardens are more effective in dealing with small discharges of rainwater (Ishimatsu et al., 2017). Swales and permeable pavements are more effective for flood reduction during heavier and shorter rainfall events. As noted by Qin et al., (2013), small practices may be not sufficient for long duration storm events with consistent rainfall. Hence, a large scale NBS could be a solution for storm events with large magnitude and long duration, which is usually the case for disaster risk reduction applications, and therefore the research in this direction is highly desirable.

Many studies recommend that there is a need to connect an individual NBS with other NBS measures (i.e., a train of NBS) to achieve better runoff control and treat more pollution (see for example, De Risi et al., 2018a; Shafique et al., 2018), to enable more effective long term strategies and to provide a more robust response to larger events with multiple benefits (Webber et

~~al., 2018). Also, Zölch et al., (2017) suggested that the effectiveness of NBS should be directly linked to its ability of increasing as much as possible the storage capacities within the area of interest, while using open spaces that have not been used previously and/or while providing benefits to other areas for urban planning~~

~~**(2) Effectiveness of multiple NBS sites**~~

~~There are s~~Several studies which have evaluated the performance of multiple (or combined) NBS measures (see for example, Damodaram et al., 2010; Earthman et al., 2012; Huang et al., 2014; Luan et al., 2017). One of the most successful international projects in combining several NBS measures at the urban scale is the "Sponge City Programme (SCP)" in China. The SCP project was commissioned in 2014 with the aim to implement both concepts and practices of LIDs/NBS as well as various comprehensive urban water management strategies (Chan et al., 2018). Nowadays, SCP is wildly used as the concept ('Sponge City') for a city that needs to increase resilience to climate change. It also includes combination of several systems such as source control system, urban drainage system, and emergency discharge system.

Porous pavement appears as one of the most popular measures suitable to combine with other NBS for urban run-off management. Examples of this are described in Behroozi et al., (2018) who selected swales and porous pavement to reduce peak flow and mean Total Suspended Solids (TSS) concentration. Hu et al., (2017) used inundation modelling to evaluate the effectiveness of rainwater harvesting and pervious pavement as retrofitting technologies for flood inundation mitigation at urbanized watershed. Damodaram et al., (2010) concluded that rainwater harvesting and permeable pavement is likely to be more effective than pond storage for small storms, while the pond is likely to be more effective to manage runoff from the more intensive storm.

~~Several studies argue that multiple NBS measures can lead to a more significant change in runoff regime than single NBS measures For example, eight scenarios were simulated by changing the percentage of combined green roof and permeable pavement in an urban setting (Wu et al., 2018) . The results show that for a scenario where green roof and permeable pavement were applied at all possible locations, a 28% reduction in maximum inundation can be obtained. In comparison, scenarios implementing either green roof or permeable pavement alone at all possible areas experienced a reduction of 14%. One of the main reasons the superior performances of combined NBS is that they are able to work in parallel, each treating a different portion of run-off generated from the sub-catchment (Pappalardo et al., 2017). For these combinations, the spatial distribution should be carefully considered because it can improve the runoff regime better when compared to centralised NBS (Loperfido et al., 2014).~~

Several studies argue that multiple NBS measures can lead to a more significant change in runoff regime and more effective long term strategies than single NBS measures (Webber et al., 2018). For example, Wu et al. (2018) simulated eight scenarios changing the percentage of combined green roof and permeable pavement in an urban setting. The results show that when green roofs and permeable pavements are applied at all possible locations, a 28% reduction in maximum inundation can be obtained. In comparison, scenarios implementing either green roofs or permeable pavements alone at all possible areas experienced a reduction of 14%. One of the main reasons for the superior performance of combined NBS is that they work in parallel, each treating a different portion of run-off generated from the sub-catchment (Pappalardo et al., 2017). For these combinations, the spatial distribution should be carefully considered because it can improve the runoff regime better when compared to centralised NBS (Loperfido et al., 2014).

Further research on the use of combined green and grey infrastructures (i.e., hybrid measures) is highly desiderative. To date only three contributions were found in the review. Alves et al., (2016) presented a novel method to select, evaluate and place different hybrid measures for retrofitting urban drainage systems. However, only fundamental aspects were touched in the methodology and they suggested that future work should include possibility of considering stakeholders' preferences or flexibility within the method. In the work of Vojinovic et al. (2017), a methodological framework that combines ecosystem services (flood protection, education, art/culture, recreation and tourism) with economic analysis for the selection of multifunctional measures and consideration of small and large scale NBS has been discussed for the case of Ayutthaya in Thailand. Onuma and Tsuge, (2018) compared the cost-benefits and performance between NBS and grey infrastructures, concluding that NBS are likely to be more effective when implemented through cooperation with local people, whereas hybrid solutions are more effective than a single NBS in terms of performance.

The first limitation of the above studies is that they only assess the effectiveness at urban scales. This may not be sufficient for large events as climate change is likely to increase the frequency and intensity of future events. Large scale NBS may provide a more significant impact in different management scenarios than just for an urban watershed (Giacomoni et al., 2012). Although Fu et al., (2018) analysed variations in runoff for different scales and land-uses, the impact of NBS was only examined for the small urban scale. There is only one article that deals with hybrid measures (i.e., NBS/green infrastructure and grey infrastructure) and also with combinations of small and large scale NBS. ~~In the work of Vojinovic et al., (2017), a methodological framework that combines ecosystem services (flood protection, education, art/culture, recreation and tourism) with economic analysis for selection of multifunctional measures and consideration of small and large scale NBS has been discussed for the case of Ayutthaya in Thailand.~~ The third limitation is that none of these contributions have incorporated cost-benefit analyses (CBA). CBA can be used as a tool to support the decision-making process as they serve the feasibility of implementing cost and the potential benefits of NBS.

4.1~~2~~.2 Research on large-scale NBS for hydro-meteorological risk reduction~~Large-scale NBS~~

Large-scale water balance, water fluxes, water management and ecosystem services are affected by future changes such as climate change, large-scale land use changes, water use changes and population growth. Therefore, to address such challenges, large scale NBS are needed to make more space for water to retain, decelerate, infiltrate, bypass, and discharge (Cheng et al., 2017; Thorslund et al., 2017b). Generally, a large-scale NBS combines different NBSs within a larger system to achieve better long-term strategies. There are some examples of NBS measures for DRR which are summarized in McVittie et al., (2018) and a summary of effectiveness, co-benefits and cost of large scale NBS measures is shown in Table 4..

There are very few articles that have addressed combined behaviour of NBS at the large or catchment scale (see also Table 3). One of the possible reasons is that large-scale systems are much more complex than small-scale systems. The most common large-scale NBS are wetlands (Thorslund et al., 2017b), river restoration (Chou, 2016), flood storage basins (De Risi et al., 2018b), preservation and regeneration of forests in flood-prone areas (Bhattacharjee and Behera, 2018) and making more room for the river (Asselman and Klijn, 2016; Klijn et al., 2018).

A classic example of a large-scale NBS implementation is the 'Room for the River Programme' which was implemented along the Rhine and Meuse rivers in the Netherlands (Klijn et al., 2018). The Room for the River Programme consisted of 39 local projects based on nine different types of measures (Klijn et al., 2013). These measures are flood plain lowering, dike relocation, groyne lowering, summer bed deepening, water storage, bypass/floodway, high water channels, obstacles removing and dikes strengthening. The benefits that the programme achieved are more than just reducing the flooding but also increasing opportunities for recreation, habitat and biodiversity in the area (Klijn et al., 2013).

Another case study of a large scale NBS is the Laojie river project in Taoyuan City in Taiwan. The study focused on changing the channelised culverted flood-control watercourse into an accessible green infrastructure corridor for the public (Chou, 2016). The landscape changes resulting from this project have increased recreation activities and improved the aesthetic value in the area.

NBS may benefit people in coastal areas by reducing risk from storm surges, wave energy, coastal flooding as well as erosion, as documented by several authors (see, for example, Coppenolle, 2018; Joyce et al., 2017; Ruckelshaus et al., 2016; Sutton-Grier et al., 2018). NBS for coastal areas can be implemented either at large or small scales. They include dunes, beaches, oyster and coral reefs, mangroves, seagrass beds and marshes. These measures can also provide habitat for different species such as fish, birds, and other wildlife (Ruckelshaus et al., 2016). However, only a few articles of the 137 reviewed focused on the potential benefits of NBS in coastal areas.

Casteller et al. (2018) concluded that native mountain forests could be used to reduce hydro-meteorological risk such as flash floods and landslides. To reduce the impact of large-scale hydro-meteorological events, more research is needed on large-scale NBS and their hybrid combinations designed to attenuate flows and improve drainage. They should be implemented to include improvements in solid waste management, community-based river cleaning programs and reforestation (De Risi et al., 2018b).

~~To fill this gap, in addition to RECONECT other two "sister" Horizon 2020 projects namely PHUSICOS and OPERANDUM were initiated in 2018 to fill the gap in innovation of NBS and to test their efficacy in rural, mountain and in transition lands environments. Specifically, PHUSICOS's main aim is to implement and evaluate NBS at regional scale in three large-scale demonstration sites representative of the typical hazards (floods, droughts, landslides) throughout rural and mountainous~~

regions in Europe. OPERANDUM's main aim is to demonstrate viability of NBS in ten sites in Europe, China and Australia including the testing at coastal areas were coastal erosion and storm surge may occur in present and future climate scenarios. Development of techniques, methods and tools for planning, selecting, evaluating and implementing NBS are among the common products of RECONECT, PHUSICOS and OPERANDUM

4.23 Techniques, methods and tools for planning, selecting, evaluating and implementing NBS

Figure 4. 6. illustrates a typical process for selection and evaluation of NBS (see, for example, (Alves et al., 2016a, 2018). The process starts by selecting possible measures that correspond to the local characteristics and project's target. The next step is concerned with evaluating their performance by numerical models, cost-benefit analysis and/or multi-criteria analysis. However, for more complex system such a large number of scenarios and parameters, optimisation can be used to maximise the benefits and minimise the costs. The processes above are possible to combine in one tool or to use combination of existing tools to select and evaluate NBS. The techniques, methods and tools for planning, selecting, evaluating and implementing NBS that have been used are reviewed in the following section.

4.23.1 Selection of NBS based on local constraints

To date, iUt has been a well-accepted fact that not all NBS are suitable for all conditions. Therefore, it is important to consider the feasibility and constraints at the site at an early stage in the selection process. The first consideration in selecting NBS is to define the objective such as the target area (i.e. urban, rural) and performance requirements such as quantity and/or quality (Romnée and De Herde, 2015; Zhang and Chui, 2018). For example, Pappalardo et al., (2017) chose permeable pavements and green roofs because they can detain runoff or infiltrate it to the subsoil. Many authors suggest restricting the choice of appropriate NBS based on common site constraints such as land use, site characteristics (i.e. soil type, groundwater depth, depth to bedrock), catchment characteristics, political and financial regulations, amenities, environmental requirements and space available (Chen et al., 2013; Eaton, 2018; Joyce et al., 2017; Nordman et al., 2018; Oraei Zare et al., 2012). For example, Eaton (2018) selected bio-retention measures because these are more suitable in low-density residential land use.

Therefore, a screening analysis is necessary to select the NBS measures that are best suited to local constraints and objectives, providing decision-makers with valuable information Also, the study of Reynaud et al., (2017) describes how the type of NBS has an impact on individuals' preference for ecosystem services.

The way forward in the selection of NBS is to consider spatial planning principles to locate the position for measures. Spatial planning principles can facilitate and stimulate discussion among local communities, researchers, policy-makers and government authorities.

4.23.2 Frameworks and methods for evaluation of NBS

There are several frameworks and methods that can be used to evaluate performance indicators of NBS that are discussed in this review. One of the most popular evaluation approach is to analyse, simulate and model hydrology, hydraulics and water balance processes. This information is then used to support decision makers, planners and stakeholders in their evaluation performance and potential of NBS by comparing modelled results against current situation, baseline scenario or targets (Jia et al., 2015). The Curve Number infiltration method can also be used to estimate rainfall runoff based on ground coverage, soil type and precipitation (Maragno et al., 2018).

In addition to the hydrological and hydraulic analysis, cost-benefit analysis is often used to select and implement a cost-effective NBS (Huang et al., 2018; Nordman et al., 2018; Watson et al., 2016; Webber et al., 2018). The common benefits considered include prevented damage costs, omitting infrastructures, profit loss to businesses, prevented erosion damage, and prevented agricultural losses. One cost-benefit approach is to evaluate NBS by applying the whole life cycle costing approach (LCC) including construction, operation, maintenance and opportunity costs (Nordman et al., 2018) and Return on Investment (ROI) (De Risi et al., 2018b).

An alternative method for evaluation of NBS is multi-criteria analysis (MCA), which has the potential to integrate and overcome the differences between social and technical approaches, (Loc et al., 2017). It allows to structure complex issues and help a better comprehension of costs and benefits. Such analysis is useful for decision makers when there are multiple and conflicting criteria to be considered (Alves et al., 2018; Loos and Rogers, 2016). The MCA takes different criteria into account and assigns weights to each criterion. This process can produce ranking of the different measures that can be implemented on the site (Chow et al., 2014; Jia et al., 2015). For examples, Loc et al., (2017) who integrated the results from numerical modelling and social survey into the MCA and ranked the alternatives based on evaluation criteria, which are flood mitigation, pollutant removal and aesthetics. Loos and Rogers, (2016) applied multi-attribute utility theory (MAUT) to assess utility values for each alternative by assuming that preference and utility are independent from each other. Petit-Boix et al., (2017) recommended that future research should combine the economic value of the predicted material and ecological damage, risk assessment models and environmental impacts of NBS.

Since not all assessments can be done with modelling alone, interviews and fieldwork are often neccessary. For instance, Chou (2016) used eighteen open questions from six topics, namely: accessibility; activities; public facilities; environmental quality; ecological value; and flood prevention. These questions are used to evaluate the qualitative performance of river restoration. However, some of the methods are only appropriate for small scale applications and cannot be applied in large catchments. Yang et al., (2018) proposed Relative Performance Evaluation (RPE) methods, which use a score to calculate the performance for all alternatives. This score is calculated as the weighted sum of the scores of individual indicators.

From the discussion above, it can be observed that there are still challenges in evaluating intangible benefits of NBS and incorporating stakeholders' preferences into the process. For complex systems with a large number of scenarios and parameters, simple trial-and-error methods may not be the feasible approach. In such cases, an automated optimisation method could be effectively applied to handle these tasks and to combine the above mentioned methods. There is also a challenge in combining a range of aspects that can and cannot be expressed in monetary terms into the same framework of analysis.

4.2~~3~~.3 Optimal configuration of NBS

In order to implement NBS, typical selection factors include the number of NBS measures, size, location, and potential combinations of NBS. Optimisation of NBS strategies has been increasingly used in the urban stormwater management context. Most of the studies to date focus on minimising water quantity and improving water quality by selecting the type, design, size and location of NBS (Behroozi et al., 2018; Gao et al., 2015; Giacomoni and Joseph, 2017; Zhang and Chui, 2018). Zhang and Chui (2018) have systematically reviewed optimisation models that have different structures, objectives and allocation components. This section reviews some examples of using optimisation to assess NBS.

~~**(1) Comprehensive modelling systems**~~

A comprehensive modelling system typically refers to an optimisation package tool that integrates an "easy-to-use" user interface with physically based deterministic models. Examples include SUSTAIN (the System for Urban Stormwater Treatment and Analysis IntegratioN) (Zhang and Chui, 2018) and Best Management Practice Decision Support (BMPDSS) (Gao et al., 2015). The SUSTAIN model was developed by the United States Environmental Protection Agency (US EPA) and it aims to provide decision makers with support in the process of selection and placement of NBS measures, and to optimise the hydrological performance and cost-effectiveness of NBS in the urban watershed (Leslie et al., 2009; Li et al., 2018a). There are several studies that apply SUSTAIN with the attempt to minimise the cost of NBS for both runoff quantity (flow volume, peak flow) and runoff quality (pollutant removal) (Gao et al., 2015; Li et al., 2018c).

It is however important to note that comprehensive modelling systems are not always easy to modify to fit with specific needs of users.

~~**(2) Tools based on integration between optimization algorithms and numerical models**~~

Another optimisation tool approach is ~~I~~integrated model-algorithm tools combine numerical (hydrological-hydrodynamic) models with optimisation algorithms. A popular optimisation method used to evaluate NBS performance is a multialgorithm, genetically adaptive multiobjective (AMALGM) method using the multilevel spatial optimisation (MLSOP) framework (Liu et al., 2016). ~~AMALGM includes Non-dominated Sorting Genetic Algorithm II (NSGA-II), Adaptive metropolis search (AMS), particle swarm optimisation (PSO), and differential evolution (DE) (Wang et al., 2015).~~

In the reviewed articles, Non-dominated Sorting Genetic Algorithm II (NSGA-II) ~~NSGA-II~~ is used in most of the studies to date. Wang et al., (2015) concluded that NSGA-II remains as one of the most popular multiobjective evolutionary algorithms (MOEAs) despite limited parameter tuning features, and generally outperformed the other MOEAs in relation to the set of solutions generated. ~~even with limited parameter tuning, and generally outperformed the other MOEAs concerning the number of solutions contributing to the best-known nondominated set of each problem.~~ There are several examples of the use of NSGA-II. Oraei Zare et al., (2012) minimised run-off quantity while maximizing the improvement of water quality and maximising reliability. Karamouz and Nazif, (2013) minimised cost of flood damage as well as minimising BMP cost in order to improve system performance in dealing with the emerging future condition under climate change impact, Yazdi and Salehi Neyshabouri, (2014) optimised cost-effect, which focused on land use change strategies including orchard, brush and seeding measure in a different part of the watershed. All of the above mentioned studies coupled NSGA-II with the Storm Water Management Model (SWIMM) developed by US EPA (Cipolla et al., 2016; Li et al., 2018b; Mei et al., 2018; Tao et al., 2017; Wu et al., 2018; Yang et al., 2018; Zhu and Chen, 2017) to address the optimisation problems.

There are two different optimisation methods of Particle Swarm Optimization (PSO) which have been found in the course of this review. The modified Particle Swarm Optimization (NPSO) is used by (Duan et al., 2016) to solve the Multi-Objective Optimal (MOO) of the cost-effectiveness of NBS based detention tank design. Similarly, Behroozi et al., (2018) used the multi-objective particle swarm optimisation (MOPSO) to deal with multi-objective optimisation problem by coupling it with SWMM to optimise the peak flow and mean TSS concentration reduction by changing the combinations of NBS.

Another algorithm that is used for optimising the performance of NBS is Simulated Annealing (SA) (Kirkpatrick et al., 1983). SA is a general probability optimisation algorithm that applies thermodynamic theories in statistics. An example of a study with SA is given by Huang et al., (2018) who automatically linked SA with SWMM to maximise cost-benefit for flood mitigation and layout design. The cost-benefit analysis is computed using annual cost, which includes both annual fixed cost and annual maintenance cost. Another study that applied SA is Chen et al., (2017) who combined SA with SWMM to locate NBS in Hsinchu County in northern Taiwan by considering three objective functions. These were minimising depths, durations, and the number of inundation points in the watershed.

It can be observed that most of the optimisation models to date (both comprehensive modelling system and model algorithms) are coupled with SWMM for urban storm management. There is still a lack of research that uses optimisation to maximise the efficiency of NBS on a large scale as well as combining other co-benefits in optimisation (Table 3). Furthermore, there is a lack of research that employs 2 dimensional models in the optimisation analysis. This is particularly important when considering estimation of flood damages and other flood propagation-related impacts.

4.2~~3~~.4 Tools for selection, evaluation and operation of NBS

Recently, several selection and evaluation tools (both standalone and web-based) have been developed in order to assist stakeholders in screening, selecting and visualising NBS measures. Examples of web-based applications which are developed to screen urban NBS measures are Green-blue design tool (atelier GROENBLAUW, 2019), PEARL KB (Karavokiros et al., 2016; PEARL, 2019b), Climate Adaptation App (Bosch Slabbers et al., 2019) and Naturally resilient communities solutions (Naturally Resilient Communities, 2019). These web-based tools allow the user to filter NBS in relation to their problem type, measure, land use, scale, and location.

In addition to the above, there are also tools that combine both the selection and evaluation processes together to use as planning support systems tool.~~.~~ An example ~~of such tools which is used to evaluate the performance of NBS~~ is SuDS selection and location (SUDSLOC) tool, which is a GIS tool linked to an integrated 1D hydraulic sewer model and a 2D surface model. ~~Planning support tool is known as~~ UrbanBEATS (the Urban Biophysical Environments and Technologies Simulator), which aims to support the planning and implementation of WSUD infrastructure in urban environments (Bach et al., 2018). Other tools that can be used to select and evaluate potential NBS interventions are Long-Term Hydrologic Impact Assessment-Low Impact Development (L-THIA-LID) (Purdue University, 2019) in a web-based application ~~-~~(Ahiablame et al., 2012; Liu et al., 2015) and the GIS-based tool called Adaptation Support Tool (AST) (van de Ven et al., 2016; Voskamp and Van de Ven, 2015). Although these tools could be useful in assisting decision makers, some of them may not be suitable for every location and scale. For example, source data required into L-THIA-LID cover only United States and QUADEAU (Romnée and De Herde, 2015) is only suitable for urban stormwater management in a public space scale.

In addition to the above, other models such as MIKE packages developed by DHI (Semadeni-Davies et al., 2008)~~Model of Urban Sewers (MOUSE), nowadays known as MIKE URBAN, MIKE FLOOD and MIKE SHE developed by DHI (Semadeni-Davies et al., 2008),~~ Soil and Water Assessment (SWAT) (Cheng et al., 2017), IHMORS (Herrera et al., 2017), and Urban Water Optioneering Tool (UWOT) (Rozos et al., 2013) can be effectively used in the analysis of NBS.

To date, only few tools have been developed to calculate multiple benefits of NBS in monetary terms as well as to address their qualitative benefits. Some examples are Benefits of SuDS Tool (BeST), ~~which is an Excel-Based decision support tool that~~ provides a structured approach to evaluating potential benefits of NBS (Digman et al., 2016; Donnell et al., 2018), Blue-Green Cities toolbox which is a GIS toolbox to evaluate multi-benefits, including flood damage reduction, water quality, attractiveness, property prices, habitat size, carbon dioxide sequestration, and reduction in air and noise pollution (BGC, 2016), and the MUSIC tool (Model for Urban Stormwater Improvement Conceptualization) which is a conceptual planning and design tool that also contains a life cycle costing module for different NBS that are implemented in Australia (Jayasooriya et al., 2016; Khastagir and Jayasuriya, 2010; Schubert et al., 2017).

There are also other tools that can be used for modelling stormwater management options and/or to perform assessment of economic aspects of NBS in urban areas. These are documented in the work of Jayasooriya and Ng, (2014). However, most of these tools only focus on small-scale NBS such as bio-retentions, pervious pavements, green roofs, swales, constructed wetlands, extended retention basins, retention ponds, sand filters, biofiltration tree planters and rainwater harvesting. There are only few tools that can address river and coastal flood protection measures and droughts while none of tools can be used to reduce the risk from landslides and storm surges. A lack of information systems, information clusters and platforms for exchange information between authorities and practitioners has been recognized by Kabisch et al., (2016).

There is also the need to explore the use of sensors, regulators, telemetry and Supervisory Control and Data Acquisition (SCADA) systems for efficient and effective operation and real-time control of NBS. Such configuration, which is based on the use of real-time control technology for operation of NBS, can be referred to as "SMART NBS". The value of exploring SMART NBS configuration may be particularly beneficial for hybrid systems, where NBS sites need to be configured to work closely with different kinds of measures (e.g., traditional grey infrastructure measures).

4.34 Socio-economic influence on implementation of NBS

Investing in NBS for hydro-meteorological risk reduction is essential to ensure the capability for future socio-economic development (Faivre et al., 2018). In this respect, European Commission has been investing considerably in the research and innovation of NBS or EbA and some recent efforts are placed on practical demonstration of NBS for climate change adaptation and risk prevention (Faivre et al., 2017).

The European Commission is dedicated to bringing innovative 'sciences-policy-society' mechanisms, open consultations, and knowledge-exchange platforms to engage society in improving the condition for implementation of NBS (Faivre et al., 2017). There are some inventories of web-portals, networks and initiatives that address NBS at European, national and sub-national levels (Table 4).

Denjean et al., (2017) noted that the people who propose NBS are in many cases ecologists and biologists who have been trained within a very different scientific paradigm and then speak a 'different language' than the key decision makers, who are often civil and financial engineers, contractors and financing officers. Hence, this may limit the feasibility of implementation of NBS.

Very few articles study actions or processes in relation to stakeholder participation (Table 3). However, those that do so they stress the importance of involving stakeholders in the evaluation and implementation of NBS and the current practical limitations of implementing NBS. One of the important reasons for these is to ensure that stakeholders and local government are fully aware of multiple benefit of NBS so that they can integrate them better into planning for sustainable cities (Ishimatsu et al., 2017). For example, Liu and Jensen, (2018) and Chou, (2016) claim that the implementation of NBS with visible benefits on the landscape and the liveability of the city in terms of amenities, recreation, green growth, and microclimate can create positive attitudes among stakeholders towards applying NBS. Moreover, as the implementation of NBS is often a costly investment for local communities and the facilities are expected to be in place for a decade, it is essential to know the effectiveness of NBS (Semadeni-Davies et al., 2008). The involvement of researchers and stakeholders is important for monitoring, assessing and forecasting scenarios (Stanev et al., 2014). A case study of Great Plains in the US, Vogel et al., (2015) addressed how local perceptions of NBS effectiveness and applicability limit its adoption. One of the factors was a lack of awareness of NBS and support from stakeholders and authorities. Another case in Portland, Oregon, USA, Thorne et al., (2018) concluded that the limited adoption of NBS is caused by the lack of confidence in public preferences and socio-political structures as well as the uncertainty regarding scientific evidence related to physical processes. To solve this, they suggested that both socio-political and biophysical uncertainties must be identified and managed within the framework for designing and delivering sustainable urban flood risk management.

Schifman et al., (2017) proposed a Framework for Adaptive Socio-Hydrology (FrASH) that can be used in NBS planning and implementation by bringing ideas together from socio-hydrology, the capacity for adaptation, participation and inclusiveness, and organised action. The framework also helps in creating a connected network between municipalities, public works departments, organisations and people in the community. This potentially allows for the management of resilience in the system at multiple scales.

Often, it is not as easy to address socio-economic issues as technical questions. These socio-economic issues include perception and acceptance, policies, interdisciplinary nature of LID, education, and documenting the economic benefit of NBS implementation (Vogel et al., 2015). Nevertheless, qualitative research (i.e. surveys, interviews, and focus groups) helps to review and gain insights about the obstacles and motivations for implementing NBS as well as to understand a community's resilience and adaptive capacity (Matthews et al., 2015). For instance, bringing the findings to stakeholders and community members to discuss on what level of flood hazards is acceptable and what level of climate change adaptation capacity the community plans to achieve (Brown et al., 2012). Moreover, socio-political dynamics in NBS is still lacking, there are only few case studies available that critically evaluate the politics of NBS in the role of community mobilization (Triyanti and Chu, 2018).

Not only it is essential to involve stakeholders in the selection, planning, design and implementation of NBS, but it is also important for bridging gaps between researchers, engineers, politicians, managers and stakeholders. This may help to improve our capacity for using both small and large scale NBS. There is well documented range of policy arrangements, scientific niches and current status of governance studies of NBS that was reviewed by Scarano, (2017) and Triyanti and Chu, (2018).

4.45 Multiple-benefits of NBS

The literature on NBS, SuDs, BMPS, LIDs, GI, EbA, and Eco-DRR increasingly refers to multiple benefits on social, economic and environmental enhancements. The reason for that is that NBS are regarded as sustainable solutions that use ecosystem services to provide multiple benefits for human well-being and environment, which differ from grey infrastructure. One of the processes that could provide these benefits is to give more significant consideration to landscape and adaptive and multi-functionality design (Lennon et al., 2014; Vojinovic et al., 2017).

The literature to date shows that multiple challenges can be continually addressed through NBS. These include reducing flood risk (Song et al., 2018), storing and infiltrating rainfall run-off, delaying and reducing surface runoff, reducing erosion and particulate transport (Loperfido et al., 2014) recharging groundwater discharge, reducing pollution from surface water (Donnell et al., 2018), increasing nutrient retention and removal (Loperfido et al., 2014), maintaining soil moisture, and enhancing vegetation growth.

Beyond water management, the case for these natural capital approaches includes their ability to provide additional benefits on improving socio-economic aspects and human well-being through recreational areas and aesthetic value (Song et al., 2018), as well as encouraging tourism through the access to nature (Sutton-Grier et al., 2018). Green space can also provide a safe area for physical activity such as walking, jogging and cycling (Fan et al., 2011). Wheeler et al., (2010) quantified the volume and intensity of children's physical activity in greenspace and found that time in greenspace is more likely to lead to greater activity intensity amongst children. The use of NBS can bring economic benefits in different ways such as reduced/prevented damage cost from hydro-meteorological events (Klijn et al., 2015), economic benefit from the reduction of stormwater that typically needs to be treated in a public sewerage system and energy and carbon savings from reduced building energy consumption (heating and cooling) (Soares et al., 2011).

The environmental benefits of NBS measures can have various positive impacts. Some of the most important are the ability to enhance environmental and ecosystem services by connecting habitat and biodiversity (Hoang et al., 2018; Reguero et al., 2018; Thorslund et al., 2017b), increasing carbon consequences, reducing air and noise pollution (Donnell et al., 2018); and improving urban heat island effect mitigation (Raymond et al., 2017).

Zhang and Chui, (2019) reviewed the hydrological and bio-ecological benefits of NBS across spatial scales and suggested that there should be more research at the catchment scale to consider the full benefits of NBS. The hydrological and water quality benefits of NBS have been widely reviewed and discussed, but there are few articles that focus on the assessment of multi-benefits of NBS. Hoang et al., (2018) proposed a new integrated methodology using a GIS approach to assess benefits and disadvantages of NBS, which include habitat connectivity, recreational accessibility, traffic movement, noise propagation, carbon sequestration, pollutant trapping and water quality. Donnell et al., (2018) used BEST and the Blue-Green Cities toolbox to assess benefits, and Mills et al., (2016) assessed air pollution reduction based on tree canopy.

Alves et al., (2019) presented a novel methodology for valuing co-benefit for NBS application in urban contexts. In order to evaluate benefits effectively, Fenner, (2017) recommended that their spatial distribution should be assessed through multi-functional design making possible to identify how this is valuable to stakeholders and where the overall aggregated benefits occur. There is still a need for deeper understanding of assessment of multi-benefits in managing stormwater (Liu et al., 2017). A challenge is the lack of information on the values of ecosystem and multi-related ecosystems economic valuation (Bennett et al., 2009).

4.5~~1~~ Trends, knowledge gaps and future research prospects

The literature reviewed in this study showed that NBS have not been equally applied to all hydro-meteorological risk reduction contexts. The search strategy adopted in this review (Section 3.1) identified a total of 1204 Journal articles from 2007 to the end of 2018. However, only 85 out of 1204 articles (i.e., 7%) explicitly used the term "Nature-Based Solution" for hydro-meteorological risk reduction (Fig. 5a). This can be explained by the fact that the term NBS has been used only from 2008 (MacKinnon et al., 2011) while other terms have been used earlier in different countries (Figure 1). However, the significant increase of published articles in recent years shows how NBS is a rapidly growing research area (Fig. 5a).

Of the 1204 articles, only 137 publications specifically address NBS for hydro-meteorological risk reduction (Section 3.2). Among those, only 13 articles deal with large scale NBS, mostly focusing on river and coastal flooding (Table 6). The review of the 137 articles indicates that most of the research to date has been carried out in an urban context, whereas the contexts concerning river and coastal floods, droughts and landslides are the least addressed. More specifically, 88% of all articles deal with runoff reduction or flood risk reduction in urban areas (Fig. 5b). It is worthwhile to notice that two out of the ten search terms in Table 2 contain the word "urban". This was in order to include two popular concepts linked to NBS for hydro-meteorological risk, which are WSUD and SUDs (cf. the overview of terminology given in Section 2). Nevertheless, the literature sourced using these two search terms only accounts for 2.9% of the total 88% urban cases shown in Figure 5b. Therefore, no significant bias was introduced in our findings by the inclusion of the word "urban" through these two search terms.

An overview of quantitative results, some research gaps and future research prospects are given in Table 6 and some of the key challenges are summarised below.

There is a clear gap between the amount of research on small scale NBS in urban areas and large scale NBS at the catchment (river basin), rural, and regional scale. The reason for this is that a large-scale system is more complex than a small system. Therefore, research and frameworks that deal with reducing hydro-meteorological risk by upscaling NBS from urban scale to catchment (river basin) scale would be beneficial. It would be also beneficial to understand both the natural processes of large scale NBS and how they change over time. Furthermore, there are only a few studies that combine NBS at both small- and large-scale, and further research in this direction is highly desirable.

Obviously, there is no single NBS solution that can solve all problems. Every project needs to be designed to address a particular challenge in its local context and in its respective community. Therefore, an understanding of site conditions is necessary for NBS to achieve the target of the project.

Based on the findings of the literature review, there are still challenges in relation to methods and tools for planning and implementing NBS. These include improving and developing methods for assessing co-benefits (especially socio and ecological benefits, i.e. aesthetic values, community liveability, and human health), frameworks and methods for evaluating large-scale NBS and “hybrid measures” (i.e. combinations of grey infrastructure and small and large scale NBS).

There are also challenges in incorporating local stakeholder participation within the framework and models and within the assessment and implementation process. Other challenges regarding governance are to develop guidance on effective models of governance, provide insight information on actors, institutions and legal instruments and other requirements that are relevant for implementing NBS. The reason for this is the lack of workable frameworks that can bring together a variety of stakeholder groups. Moreover, there is still a lack of finance studies and guidelines for cost-effective implementation, maintenance and operation of NBS projects, and mechanisms that can be used to promote new business and finance models for successful implementation of NBS.

There should also be more efforts in the development of assessment tools that incorporate new technologies such as real-time control systems, forecast models, and coupled models to provide more active and integrated operational solutions (i.e., SMART NBS). There is a need for the development of databases that include functions, benefits, and costs of large and small scale NBS to facilitate future research.

The literature material reviewed in this study showed that NBS have not been equally applied to all hydro-meteorological risk reduction contexts. The review identified in total 1381 Journal articles from 2007 to the end of 2018. The patterns of all terminologies of NBS were analysed using 166 publications for hydro-meteorological risk reduction. An overview of some research gaps and future research prospects is given in Table 3.

Most of the literature to date is about NBS in urban areas whereas those contexts concerning river and coastal floods, droughts and landslides are the least addressed. 88% of all articles were concerned with runoff reduction or flood risk reduction in urban areas (Fig. 4a.). Also, only 62 out of 1381 articles (i.e., 4.5%) explicitly used the term “Nature-Based Solution” for hydro-meteorological risk reduction. This can be explained due to difference in terms used in different countries while the term NBS has been used only from 2008 (Fig. 3). However, the significant increase of published articles in recent years testifies how NBS is a rapidly growing research area (Fig. 4b).

In terms of the other relevant literature (i.e., literature that is not published in scientific journals but found to be relevant for the subject matter) the following documents were identified: EKLIPSE, 2017; Asian Development Bank, 2016; Sekulova and Anguelovski, 2017; Kabisch et al., 2017; Renaud et al., 2016.

5 Conclusions

The present paper provides a critical review of the literature and identifies future research prospects based on the current knowledge gaps in the area of Nature-Based Solutions for hydro-meteorological risk reduction. The review process started by analysing 1407 articles sourced from Scopus and 1232 articles form Web of Science from 1st January 2007 to 1st December 2018. The final full analysis was performed on 137 articles. The systematic review has shown that considerable achievements have been made to date. However, there are still many challenges and opportunities in extending the knowledge of NBS, and that will play an important role in the coming years. Some examples of research gaps are; combining small scale and large scale NBS, the effectiveness of NBS in reducing risk at the regional and catchments scale, the frameworks, methods, and tools for assessing co-benefits, involvement local stakeholders in the selection, assessment and implementation process, integration of NBS with new technologies and development of NBS databases.

The review process started by analysing 1381 articles sourced from Scopus from 2007 onwards. The articles sourced from Scopus were also cross-referenced with the articles from Web of Science and Google Scholar. The final full analysis was performed on 159 closely related articles.

The systematic review has shown that considerable achievements have been made to date. However, there are still many challenges and opportunities in extending the knowledge in NBS and that will play an important role in the coming years. Some of the key concluding remarks are summarised below.

There is a clear gap between the amount of research on small scale NBS in urban areas and large scale NBS at the catchment (river basin), rural, and regional scale. The reason for this is that a large-scale system is more complex than a small system. Therefore, the research and frameworks that deal with the problem of reducing hydro-meteorological risk with upscaling NBS from urban scale to catchment (river basin) scale would be beneficial, and it would be also beneficial to understand both the natural processes of large scale NBS and how they change over time. Furthermore, there are only few studies that combine NBS at both small- and large-scale and further research in this direction is highly desirable.

Obviously, there is no single NBS solution that can solve all problems. Every project needs to be designed to address a particular challenge in its local contexts and in its respective community. Therefore, an understanding of site conditions is necessary for NBS to achieve the target of the project.

Based on the findings of the literature review, there are still challenges in relation to methods and tools for planning and implementing NBS. These include improving and developing methods for assessing co-benefits (especially socio and ecological benefits i.e. aesthetics values, community livability, and human health), frameworks and methods for evaluating large-scale NBS and “hybrid measures” (i.e. combinations of grey infrastructure and small and large scale NBS).

There are also challenges in incorporating local stakeholder participation within the framework and models and within the assessment and implementation process. Other challenges regarding governance are to develope guidance on effective models of governance, provide insights information on actors, institutions and legal instruments and other requirements that are relevant for implementing NBS. The reason for this is the lack of workable frameworks that can bring together variety of stakeholder groups. Moreover, there is still a lack of finance studies and guidelines for cost-effective implementation, maintenance and operation of NBS projects and mechanisms that can be used to promote new business and finance models for successful implementation of NBS.

There should be also more efforts in the development of assessment tools that incorporate new technologies such as real-time control systems, forecast models, and coupled models to provide more active and integrated operational solutions (i.e., SMART NBS). There is the need for the development of databases that include functions, benefits, and costs of large and small scale NBS to facilitate future research.

Overall, investments in NBS will benefit society by providing cost-effective measures and adaptive strategies that protect their communities and achieve a range of co-benefits. Therefore, bridging the gaps between researchers, engineers and stakeholders will help to improve the capacity of NBS in reducing hydro-meteorological risk as well as considering the multitude of opportunities and benefits of NBS for co-creation and co-development in intensive participation process. Strengthening this aspect maybe beneficial in improving acceptance at local level.

The effectiveness, benefits and acceptances of NBS are dependent on the implementation purposes, local context and cultural setting. For example, small scale NBS (i.e., swales, green roofs, or porous pavements) are more suitable for urban flooding while large scale NBS (river restoration, dunes, or wetlands) are more suitable for river floods, coastal floods, droughts and landslides. Small scale NBS are more effective in reducing peak for smaller magnitude frequent storms (i.e., 2-year return period) than larger magnitude infrequent storms (i.e., 10-year return period). Large scale NBS can provide more benefits compared to small scale NBS because they encompass larger space, thus more function can be included in the design process. For example, Laojie river project in Taoyuan City in Taiwan changed the channel into an accessible green corridor. This project helps in reducing flood risk, improving riverside landscapes, increasing recreation area, increasing the aesthetic value in the area, and improving river water quality. On the other hand, small scale NBS need less area because most of the measures can be implemented in the free space. For example, green roofs can be implemented on the roofs of buildings, and permeable pavements can be implemented in car parks. Investments in NBS will benefit society by providing cost-effective measures and adaptive strategies that protect their communities and achieve a range of co-benefits. Therefore, bridging the gaps between researchers, engineers and stakeholders will help to improve the capacity of NBS in reducing hydro-meteorological risk as well as increasing their benefits. Strengthening these aspects may be beneficial for improving acceptance of NBS at the local level.

Three Horizon 2020 projects including, RECONECT, PHUSICOS and OPERANDUM were initiated in 2018 to bridge the gaps in the innovation of NBS and to test their efficacy in rural, mountain and transition land environments. Development of techniques, methods and tools for planning, selecting, evaluating and implementing NBS are among the common products of RECONECT, PHUSICOS and OPERANDUM.

6 Acknowledgements

Production of this article received funding from the European Union's Horizon 2020 Research and Innovation programme under grant agreement No 776866 for the research RECONECT (Regenerating ECOsystems with Nature-based solutions for hydro-meteorological risk rEduCTion) project. It was also supported by the European Union's Horizon 2020 Research and Innovation programme under grant agreement No 776848 for OPERANDUM and under grant agreement No 776681 for PHUSICOS. The study reflects only the authors' view and the European Union is not liable for any use that may be made of the information contained herein.

Appendix

Appendix A: Abbreviations

AMS	Adaptive metropolis search
AST	Adaptation Support Tool
BeST	Benefits of SuDS Tool
BGI	Blue-Green Infrastructure
BMPDSS	Best Management Practice Decision Support
BMPs	Best Management Practices
CBA	Cost-benefit analyses
CBD	Convention on Biological Diversity
CCA	Climate change adaptation
CEM	Commission on Ecosystem Management
DE	Differential evolution
DRR	Disaster risk reduction
EbA	Ecosystem-based Adaptation
Eco-DRR	Ecosystem-based Disaster Risk Reduction
EC	European Commission
FrASH	Framework for Adaptive Socio-Hydrology
GI	Green Infrastructure
IIED	International Institute for Environment and Development
IUCN	International Union for Conservation of Nature

LCC	Life cycle costing
LID	Low Impact Development
MAUT	Multiattribute utility theory
MCA	Multi-criteria analysis
MLSOP	Multilevel spatial optimization
MOEA	Most popular multiobjective evolutionary algorithms
MOO	Multi-Objective Optimal
MOPSO	Multi-objective particle swarm optimisation
MOUSE	Model of Urban Sewers
MUSIC	Model for Urban Stormwater Improvement Conceptualization
NBS	Nature-Based Solutions
NSGA-II	Non-dominated Sorting Genetic Algorithm II
PSO	Particle swarm optimisation
RECONECT	Regenerating ECOsystems with Nature-based solutions for hydro-meteorological risk rEduCTion
ROI	Return on Investment
RPE	Relative Performance Evaluation
SA	Simulated Annealing
SCADA	Supervisory Control and Data Acquisition
SCP	Sponge City Programme
SDGs	Sustainable Development Goals
SEI	Stockholm Environment Institute
SFDRR	Sendai Framework for Disaster Risk reduction
SuDS	Sustainable Urban Drainage Systems
SUSTAIN	System for Urban Stormwater Treatment and Analysis IntegratioN
SWAT	Soil and Water Assessment
SWIMM	Storm Water Management Model
TSS	Total Suspended Solids
UN	United Nations
UNFCCC	UN Framework Convention on Climate Change
US EPA	United States Environmental Protection Agency
UWOT	Urban Water Optioneering Tool
WCPA	World Commission on Protected Areas
WSUD	Water Sensitive Urban Design

References

Abbott, C. L. and Comino-Mateos, L.: In Situ Performance Monitoring of an Infiltration Drainage System and Field Testing of Current Design Procedures, Water Environ. J., 15(3), 198–202, doi:10.1111/j.1747-6593.2001.tb00333.x, 2001.

Ahiablame, L. M., A. Engel, B. and Chaubey, I.: Representation and Evaluation of Low Impact Development Practices with L-THIA-LID: An Example for Site Planning, Environ. Pollut., 1(2), 1–13, doi:10.5539/ep.v1n2p1, 2012.

Albert, C., Schröter, B., Haase, D., Brillinger, M., Henze, J., Herrmann, S., Gottwald, S., Guerrero, P., Nicolas, C. and Matzdorf, B.: Addressing societal challenges through nature-based solutions: How can landscape planning and governance research contribute?, Landsc. Urban Plan., 182(September 2017), 12–21, doi:10.1016/j.landurbplan.2018.10.003, 2019.

Alves, A., Sanchez, A., Gersonius, B. and Vojinovic, Z.: A Model-based Framework for Selection and Development of Multi-functional and Adaptive Strategies to Cope with Urban Floods, Procedia Eng., 154(December), 877–884, doi:10.1016/j.proeng.2016.07.463, 2016a.

Alves, A., Sanchez, A., Vojinovic, Z., Seyoum, S., Babel, M. and Brdjanovic, D.: Evolutionary and holistic assessment of green-grey infrastructure for CSO reduction, Water (Switzerland), 8(9), doi:10.3390/w8090402, 2016b.

Alves, A., Gersonius, B., Sanchez, A., Vojinovic, Z. and Kapelan, Z.: Multi-criteria Approach for Selection of Green and Grey Infrastructure to Reduce Flood Risk and Increase CO-benefits, Water Resour. Manag., 1–18, doi:10.1007/s11269-018-1943-3, 2018.

Alves, A., Gersonius, B., Kapelan, Z., Vojinovic, Z. and Sanchez, A.: Assessing the Co-Benefits of green-blue-grey infrastructure for sustainable urban flood risk management, J. Environ. Manage., 239, 244–254, doi:10.1016/j.jenvman.2019.03.036, 2019.

Asian Development Bank: Nature-Based Solutions for Building Resilience in Towns and Cities: Case Studies from the Greater Mekong Subregion. [online] Available from: https://www.adb.org/sites/default/files/publication/215721/nature-based-solutions.pdf, 2016.

Asselman, N. E. M. and Klijn, F.: Making room for rivers: quantification of benefits from a flood risk perspective, E3S Web Conf., 7(January), 12001, doi:10.1051/e3sconf/20160712001, 2016.

atelier GROENBLAUW: Green-blue design tool, [online] Available from: https://www.urbangreenbluegrids.com/design-tool/ (Accessed 1 February 2019), 2019.

Bach, P. M., Deletic, A., Urich, C. and McCarthy, D. T.: Modelling characteristics of the urban form to support water systems planning, Environ. Model. Softw., 104, 249–269, doi:10.1016/j.envsoft.2018.02.012, 2018.

Barlow, D., Burrill, G. and Nolfi, J.: Research report on developing a community level natural resource inventory system, Center for Studies in Food Self-Sufficiency., 1977.

Behroozi, A., Niksokhan, M. H. and Nazariha, M.: Developing a simulation-optimisation model for quantitative and qualitative control of urban run-off using best management practices, J. Flood Risk Manag., 11, S340–S351, doi:10.1111/jfr3.12210, 2018.

Bennett, E. M., Peterson, G. D. and Gordon, L. J.: Understanding relationships among multiple ecosystem services, Ecol. Lett., 12(12), 1394–1404, doi:10.1111/j.1461-0248.2009.01387.x, 2009.

Bhattacharjee, K. and Behera, B.: Does forest cover help prevent flood damage? Empirical evidence from India, Glob. Environ. Chang., 53(June), 78–89, doi:10.1016/j.gloenvcha.2018.09.004, 2018.

Biggers, D. J., Hartigan, J. P. and Bonuccelli, H. A.: Urban Best Management Practices (BMP's): Transition from Single-Purpose to Multipurpose Stormwater Management, Proc. Int. Symp. Urban Storm Runoff, 1980.

Biodivera: BiodivERsA, [online] Available from: https://www.biodiversa.org/ (Accessed 5 March 2019), 2019.

BISE: BISE - Biodiversity Information System for Europe — Biodiversity Information system for Europe, [online] Available from: https://biodiversity.europa.eu/ (Accessed 5 March 2019), 2019.

Bosch Slabbers, Deltares, Swexo, Witteveen+Bos and KNMI: Climate Adaptive Solutions, [online] Available from: http://www.climateapp.nl/ (Accessed 1 February 2019), 2019.

Bozovic, R., Maksimovic, C., Mijic, A., Smith, K. M., Suter, I. and van Reeuwijk, M.: Blue Green Solutions: A Systems Approach to Sustainable, Resilient and Cost-Efficient Urban Development, Imp. Coll., (March), 52, doi:10.13140/RG.2.2.30628.07046, 2017.

Brown, C., Ghile, Y., Laverty, M. and Li, K.: Decision scaling: Linking bottom-up vulnerability analysis with climate projections in the water sector, Water Resour. Res., 48(9), 1–12, doi:10.1029/2011WR011212, 2012.

Burszta-Adamiak, E. and Mrowiec, M.: Modelling of Green roofs' hydrologic performance using EPA's SWMM, Water Sci. Technol., 68(1), 36–42, doi:10.2166/wst.2013.219, 2013.

Carpenter, D. D. and Kaluvakolanu, P.: Effect of Roof Surface Type on Storm-Water Runoff from Full-Scale Roofs in a Temperate Climate, J. Irrig. Drain. Eng., 137(3), 161–169, doi:10.1061/(ASCE)IR.1943-4774.0000185, 2011.

CBD: CONNECTING BIODIVERSITY AND CLIMATE CHANGE MITIGATION AND ADAPTATION : Report of the Second Ad Hoc Technical Expert Group on Biodiversity and Climate Change., 2009.

Chan, F. K. S., Griffiths, J. A., Higgitt, D., Xu, S., Zhu, F., Tang, Y. T., Xu, Y. and Thorne, C. R.: "Sponge City" in China—A breakthrough of planning and flood risk management in the urban context, Land use policy, 76(May 2017), 772–778, doi:10.1016/j.landusepol.2018.03.005, 2018.

Chen, J., Brissette, F. P., Chaumont, D. and Braun, M.: Finding appropriate bias correction methods in downscaling precipitation for hydrologic impact studies over North America, Water Resour. Res., 49(7), 4187–4205, doi:10.1002/wrcr.20331, 2013.

Chen, P. Y., Tung, C. P. and Li, Y. H.: Low impact development planning and adaptation decision-making under climate change for a community against pluvial flooding, Water (Switzerland), 9(10), doi:10.3390/w9100756, 2017.

Cheng, C., Yang, Y. C. E., Ryan, R., Yu, Q. and Brabec, E.: Assessing climate change-induced flooding mitigation for adaptation in Boston's Charles River watershed, USA, Landsc. Urban Plan., 167(October 2016), 25–36, doi:10.1016/j.landurbplan.2017.05.019, 2017.

Chou, R. J.: Achieving successful river restoration in dense urban areas: Lessons from Taiwan, Sustain., 8(11), doi:10.3390/su8111159, 2016.

Chow, J. F., Savić, D., Fortune, D., Kapelan, Z. and Mebrate, N.: Using a systematic, multi-criteria decision support framework to evaluate sustainable drainage designs, Procedia Eng., 70(0), 343–352, doi:10.1016/j.proeng.2014.02.039, 2014.

Cipolla, S. S., Maglionico, M. and Stojkov, I.: A long-term hydrological modelling of an extensive green roof by means of SWMM, Ecol. Eng., 95, 876–887, doi:10.1016/j.ecoleng.2016.07.009, 2016.

Climate ADAPT: Climate ADAPT:SHARING ADAPTATION INFORMATION ACROSS EUROPE, [online] Available from: https://climate-adapt.eea.europa.eu/ (Accessed 5 March 2019), 2019.

ClimateScan: ClimateScan, [online] Available from: https://climatescan.nl/ (Accessed 25 March 2019), 2019.

Cohen-Shacham, E., Walters, G., Janzen, C. and Maginnis, C.: Nature-based solutions to address global societal challenges, IUCN Commission on Ecosystem Management (CEM) and IUCN World Commission on Protected Areas (WCPA), Switzerland., 2016.

Coppenolle, R. Van: Contribution of Mangroves and Salt Marshes to Nature-Based Mitigation of Coastal Flood Risks in Major Deltas of the World, , 1699–1711, 2018.

County, P. G.: Low-Impact Development Design Strategies - An Integrated Design Approach, Department of Environmental Resources, Programs and Planning Division, Prince George’s County, Maryland., 1999.

Damodaram, C., Giacomoni, M. H., Prakash Khedun, C., Holmes, H., Ryan, A., Saour, W. and Zechman, E. M.: Simulation of combined best management practices and low impact development for sustainable stormwater management, J. Am. Water Resour. Assoc., 46(5), 907–918, doi:10.1111/j.1752-1688.2010.00462.x, 2010.

Denjean, B., Denjean, B., Altamirano, M. A., Graveline, N., Giordano, R., Van der Keur, P., Moncoulon, D., Weinberg, J., Máñez Costa, M., Kozinc, Z., Mulligan, M., Pengal, P., Matthews, J., van Cauwenbergh, N., López Gunn, E., Bresch, D. N. and Denjean, B.: Natural Assurance Scheme: A level playing field framework for Green-Grey infrastructure development, Environ. Res., 159(July), 24–38, doi:10.1016/j.envres.2017.07.006, 2017.

Digman, C. J., Horton, B., Ashley, R. M. and Gill, E.: BeST (Benefits of SuDS Tool) W045d BeST – User Manual., 2016.

Donnell, E. C. O., Woodhouse, R. and Thorne, C. R.: Evaluating the multiple benefits of a sustainable drainage scheme in Newcastle , UK, , 171, 191–202, 2018.

DRMKC: European Commission-Disaster Risk Management Knowledge Centre, [online] Available from: https://drmkc.jrc.ec.europa.eu/ (Accessed 25 March 2019), 2019.

Duan, H. F., Li, F. and Yan, H.: Multi-Objective Optimal Design of Detention Tanks in the Urban Stormwater Drainage System: LID Implementation and Analysis, Water Resour. Manag., 30(13), 4635–4648, doi:10.1007/s11269-016-1444-1, 2016.

Earthman, C. P., Beckman, L. M., Masodkar, K. and Sibley, S. D.: Enhancing future resilience in urban drainage system: Green versus grey infrastructure, Int. J. Obes., 36(3), 387–396, doi:10.1016/j.watres.2017.07.038, 2012.

Eaton, T. T.: Approach and case-study of green infrastructure screening analysis for urban stormwater control, J. Environ. Manage., 209, 495–504, doi:10.1016/j.jenvman.2017.12.068, 2018.

Eckart, K., McPhee, Z. and Bolisetti, T.: Performance and implementation of low impact development – A review, Sci. Total Environ., 607–608, 413–432, doi:10.1016/j.scitotenv.2017.06.254, 2017.

EEA: Exploring nature-based solutions-The role of green infrastructure in mitigating the impacts of weather- and climate change-related natural hazards, EEA Technical report No 12/2015., 2015.

EEA: Climate change, impacts and vulnerability in Europe 2016— An indicator-based report, Report 15/., Climate change adaptation and disaster risk reduction in Europe - Enhancing coherence of the coherence of the knowledge base., 2017.

EKLIPSE: An impact evaluation framework to support planning and evaluation of nature-based solutions projects., 2017.

Ercolani, G., Antonio, E., Gandolfi, C., Castelli, F. and Masseroni, D.: Evaluating performances of green roofs for stormwater runoff mitigation in a high flood risk urban catchment, J. Hydrol., 566(June), 830–845, doi:10.1016/j.jhydrol.2018.09.050, 2018.

Estrella, M. and Saalismaa, N.: Ecosystem-based disaster risk reduction (Eco-DRR): An overview, in The Role of Ecosystems in Disaster Risk Reduction, edited by F. G. Renaud, K. Sudmeier-Rieux, and M. Estrella, pp. 26–54. [online] Available from: https://books.google.fr/books?hl=fr&lr=&id=9mTRjKmN1LwC&oi=fnd&pg=PA26&dq=Ecosystem-based+disaster+risk+reduction+(Eco-DRR):+An+overview&ots=n1jAyDcaHa&sig=YOKWr-z6EUuXe24NE-xpLTv_i30, 2013.

Estrella, M., Renaud, F. G. and Sudmeier-Rieux, K.: Opportunities, challenges and future perspectives for ecosystem-based disaster risk reduction, Role Ecosyst. Disaster Risk Reduct., 437–456, 2013.

European Commission (EC): Nature- Based Solutions and Re-Naturing Cities. Final Report of the Horizon 2020 Expert Group on Nature-Based Solutions and Re-Naturing Cities. Final report of hte Horizon 2020 Expert Group on Nature-Based Solutions and Re-Naturing Cities., 2015.

Faivre, N., Fritz, M., Freitas, T., de Boissezon, B. and Vandewoestijne, S.: Nature-Based Solutions in the EU: Innovating with nature to address social, economic and environmental challenges, Environ. Res., 159(September), 509–518, doi:10.1016/j.envres.2017.08.032, 2017.

Faivre, N., Sgobbi, A., Happaerts, S., Raynal, J. and Schmidt, L.: Translating the Sendai Framework into action: The EU approach to ecosystem-based disaster risk reduction, Int. J. Disaster Risk Reduct., 32(June 2017), 4–10, doi:10.1016/j.ijdrr.2017.12.015, 2018.

Fan, Y., Das, K. V. and Chen, Q.: Neighborhood green, social support, physical activity, and stress: Assessing the cumulative impact, Heal. Place, 17(6), 1202–1211, doi:10.1016/j.healthplace.2011.08.008, 2011.

Fenner, R.: Spatial evaluation of multiple benefits to encourage multi-functional design of sustainable drainage in Blue-Green cities, Water (Switzerland), 9(12), doi:10.3390/w9120953, 2017.

Fletcher, T. D., Shuster, W., Hunt, W. F., Ashley, R., Butler, D., Arthur, S., Trowsdale, S., Barraud, S., Semadeni-Davies, A., Bertrand-Krajewski, J. L., Mikkelsen, P. S., Rivard, G., Uhl, M., Dagenais, D. and Viklander, M.: SUDS, LID, BMPs, WSUD and more – The evolution and application of terminology surrounding urban drainage, Urban Water J., 12(7), 525–542, doi:10.1080/1573062X.2014.916314, 2015.

Fu, J. C., Jang, J. H., Huang, C. M., Lin, W. Y. and Yeh, C. C.: Cross-analysis of land and runoff variations in response to urbanization on basin, watershed, and city scales with/without green infrastructures, Water (Switzerland), 10(2), doi:10.3390/w10020106, 2018.

Gao, J., Wang, R., Huang, J. and Liu, M.: Application of BMP to urban runoff control using SUSTAIN model: Case study in an industrial area, Ecol. Modell., 318, 177–183, doi:10.1016/j.ecolmodel.2015.06.018, 2015.

Giacomoni, M. H. and Joseph, J.: Multi-objective evolutionary optimization and Monte Carlo simulation for placement of low impact development in the catchment scale, J. Water Resour. Plan. Manag., 143(9), 04017053, doi:10.1061/(ASCE)WR.1943-5452.0000812., 2017.

Giacomoni, M. H., Zechman, E. M. and Brumbelow, K.: Hydrologic footprint residence: Environmentally friendly criteria for best management practices, J. Hydrol. Eng., 17(1), 99–108, doi:10.1061/(ASCE)HE.1943-5584.0000407., 2012.

Gill, S. E., Handley, J. F., Ennos, A. R. and Pauleit, S.: Adapting cities for climate change: The role of the green infrastructure, Built Environ., doi:10.2148/benv.33.1.115, 2007.

Herrera, J., Bonilla, C. A., Castro, L., Vera, S., Reyes, R. and Gironás, J.: A model for simulating the performance and irrigation of green stormwater facilities at residential scales in semiarid and Mediterranean regions, Environ. Model. Softw., 95, 246–257, doi:10.1016/j.envsoft.2017.06.020, 2017.

Hoang, L., Fenner, R. A. and Skenderian, M.: A conceptual approach for evaluating the multiple benefits of urban flood management practices, J. Flood Risk Manag., 11, S943–S959, doi:10.1111/jfr3.12267, 2018.

Hu, M., Sayama, T., Zhang, X., Tanaka, K., Takara, K. and Yang, H.: Evaluation of low impact development approach for mitigating flood inundation at a watershed scale in China, J. Environ. Manage., 193, 430–438, doi:10.1016/j.jenvman.2017.02.020, 2017.

Huang, C., Hsu, N., Liu, H. and Huang, Y.: Optimization of low impact development layout designs for megacity fl ood mitigation, J. Hydrol., 564(February 2016), 542–558, doi:10.1016/j.jhydrol.2018.07.044, 2018.

Huang, J. J., Li, Y., Niu, S. and Zhou, S. H.: Assessing the performances of low impact development alternatives by long-term simulation for a semi-arid area in Tianjin, Northern China, Water Sci. Technol., 70(11), 1740–1745, doi:10.2166/wst.2014.228, 2014.

Ishimatsu, K., Ito, K., Mitani, Y., Tanaka, Y., Sugahara, T. and Naka, Y.: Use of rain gardens for stormwater management in urban design and planning, Landsc. Ecol. Eng., 13(1), 205–212, doi:10.1007/s11355-016-0309-3, 2017.

Jayasooriya, V. M. and Ng, A. W. M.: Tools for modeling of stormwater management and economics of green infrastructure practices: A review, Water. Air. Soil Pollut., 225(8), doi:10.1007/s11270-014-2055-1, 2014.

Jayasooriya, V. M., Ng, A. W. M., Muthukumaran, S. and Perera, B. J. C.: Optimal Sizing of Green Infrastructure Treatment

Trains for Stormwater Management, Water Resour. Manag., 30(14), 5407–5420, doi:10.1007/s11269-016-1497-1, 2016.

Jia, H., Yao, H., Tang, Y., Yu, S. L., Field, R. and Tafuri, A. N.: LID-BMPs planning for urban runoff control and the case study in China, J. Environ. Manage., 149, 65–76, doi:10.1016/j.jenvman.2014.10.003, 2015.

Joyce, J., Chang, N., Harji, R., Ruppert, T. and Imen, S.: Environmental Modelling & Software Developing a multi-scale modeling system for resilience assessment of green-grey drainage infrastructures under climate change and sea level rise impact, Environ. Model. Softw., 90, 1–26, doi:10.1016/j.envsoft.2016.11.026, 2017.

Kabisch, N., Frantzeskaki, N., Pauleit, S., Naumann, S., Davis, M., Artmann, M., Haase, D., Knapp, S., Korn, H., Stadler, J., Zaunberger, K. and Bonn, A.: Nature-based solutions to climate change mitigation and adaptation in urban areas: perspectives on indicators, knowledge gaps, barriers, and opportunities for action, Ecol. Soc., 21(2), art39, doi:10.5751/ES-08373-210239, 2016.

Kabisch, N., Korn, H., Stadler, J. and Aletta, B.: Nature-Based Solutions to Climate Change Adaptation in Urban Areas : Linkages between Science, Policy and Practice, edited by D. Loorbach, H. Shiroyama, J. M. Wittmayer, J. Fujino, and S. Mizuguchi, Springer International Publishing, Cham., 2017.

Karamouz, M. and Nazif, S.: Reliability-Based Flood Management in Urban Watersheds Considering Climate Change Impacts, J. Water Resour. Plan. Manag., 139(5), 520–533, doi:10.1061/(ASCE)WR.1943-5452.0000345, 2013.

Karavokiros, G., Lykou, A., Koutiva, I., Batica, J., Kostaridis, A., Alves, A. and Makropoulos, C.: Providing evidence-based, intelligent support for flood resilient planning and policy: The PEARL knowledge base, Water (Switzerland), 8(9), doi:10.3390/w8090392, 2016.

Khan, U. T., Valeo, C., Chu, A. and He, J.: A data driven approach to bioretention cell performance: Prediction and design, Water (Switzerland), 5(1), 13–28, doi:10.3390/w5010013, 2013.

Khastagir, A. and Jayasuriya, L. N. N.: Impacts of using rainwater tanks on stormwater harvesting and runoff quality, , 324–329, doi:10.2166/wst.2010.283, 2010.

Kirkpatrick, S., Gelatt, C. D. and Vecchi, M. P.: Optimization by Simulated Annealing, Science (80-.)., 220(4598), doi:10.1126/science.220.4598.671, 1983.

Klijn, F., Bruin, D. De, Hoog, M. C. De, Jansen, S., Sijmons, D. F., Klijn, F., Bruin, D. De, Hoog, M. C. De, Jansen, S. and Sijmons, D. F.: Design quality of room-for-the-river measures in the Netherlands : role and assessment of the quality team (Q-team) assessment of the quality team (Q-team), , 5124, doi:10.1080/15715124.2013.811418, 2013.

Klijn, F., Mens, M. J. P. and Asselman, N. E. M.: Flood risk management for an uncertain future: economic efficiency and system robustness perspectives compared for the Meuse River (Netherlands), Mitig. Adapt. Strateg. Glob. Chang., 20(6), 1011–1026, doi:10.1007/s11027-015-9643-2, 2015.

Klijn, F., Asselman, N. and Wagenaar, D.: Room for Rivers: Risk Reduction by Enhancing the Flood Conveyance Capacity of The Netherlands' Large Rivers, Geosciences, 8(6), 224, doi:10.3390/geosciences8060224, 2018.

Lafortezza, R., Davies, C., Sanesi, G. and Konijnendijk, C. C.: Green infrastructure as a tool to support spatial planning in

European urban regions, IForest, 6(1), 102–108, doi:10.3832/ifor0723-006, 2013.

Lafortezza, R., Chen, J., van den Bosch, C. K. and Randrup, T. B.: Nature-based solutions for resilient landscapes and cities, Environ. Res., 165(December 2017), 431–441, doi:10.1016/j.envres.2017.11.038, 2018.

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. and Wright, N.: Delivering and evaluating the multiple flood risk benefits in Blue-Green cities: An interdisciplinary approach, WIT Trans. Ecol. Environ., 184(JUNE), 113–124, doi:10.2495/FRIAR140101, 2014.

Lee, J. Y., Moon, H. J., Kim, T. I., Kim, H. W. and Han, M. Y.: Quantitative analysis on the urban flood mitigation effect by the extensive green roof system, Environ. Pollut., 181, 257–261, doi:10.1016/j.envpol.2013.06.039, 2013.

Lennon, M., Scott, M. and O'Neill, E.: Urban Design and Adapting to Flood Risk: The Role of Green Infrastructure, J. Urban Des., 19(5), 745–758, doi:10.1080/13574809.2014.944113, 2014.

Leslie, S., John, R. J., Khalid, A., Jenny, X. Z., Sabu, P. and Teresa, R.: SUSTAIN - A Framework for Placement of Best Management Practices in Urban Watersheds to Protect Water Quality, Environmental Protection Agency, Washington, DC., 2009.

Li, C., Liu, M., Hu, Y., Han, R., Shi, T., Qu, X. and Wu, Y.: Evaluating the hydrologic performance of low impact development scenarios in a micro Urban catchment, Int. J. Environ. Res. Public Health, 15(2), doi:10.3390/ijerph15020273, 2018a.

Li, J., Deng, C., Li, H., Ma, M. and Li, Y.: Hydrological Environmental Responses of LID and Approach for Rainfall Pattern Selection in Precipitation Data-Lacked Region, Water Resour. Manag., 32(10), 3271–3284, doi:10.1007/s11269-018-1990-9, 2018b.

Li, N., Qin, C. and Du, P.: Optimization of China Sponge City Design : The Case, Water (Switzerland), (Lid), doi:10.3390/w10091189, 2018c.

Liao, Z. L., Zhang, G. Q., Wu, Z. H., He, Y. and Chen, H.: Combined sewer overflow control with LID based on SWMM: An example in Shanghai, China, Water Sci. Technol., 71(8), 1136–1142, doi:10.2166/wst.2015.076, 2015.

Liew, Y. S., Selamat, Z., Ghani, A. A. and Zakaria, N. A.: Performance of a dry detention pond: Case study of Kota Damansara, Selangor, Malaysia, Urban Water J., 9(2), 129–136, doi:10.1080/1573062X.2011.644567, 2012.

Liu, L. and Jensen, M. B.: Green infrastructure for sustainable urban water management: Practices of five forerunner cities, Cities, 74(January), 126–133, doi:10.1016/j.cities.2017.11.013, 2018.

Liu, Y., Bralts, V. F. and Engel, B. A.: Evaluating the effectiveness of management practices on hydrology and water quality at watershed scale with a rainfall-runoff model, Sci. Total Environ., 511, 298–308, doi:10.1016/j.scitotenv.2014.12.077, 2015.

Liu, Y., Theller, L. O., Pijanowski, B. C. and Engel, B. A.: Optimal selection and placement of green infrastructure to reduce impacts of land use change and climate change on hydrology and water quality: An application to the Trail Creek Watershed, Indiana, Sci. Total Environ., 553, 149–163, doi:10.1016/j.scitotenv.2016.02.116, 2016.

Liu, Y., Engel, B. A., Flanagan, D. C., Gitau, M. W., McMillan, S. K. and Chaubey, I.: A review on effectiveness of best management practices in improving hydrology and water quality: Needs and opportunities, Sci. Total Environ., 601–602, 580–593, doi:10.1016/j.scitotenv.2017.05.212, 2017.

Loc, H. H., Duyen, P. M., Ballatore, T. J., Lan, N. H. M. and Das Gupta, A.: Applicability of sustainable urban drainage systems: an evaluation by multi-criteria analysis, Environ. Syst. Decis., 37(3), 332–343, doi:10.1007/s10669-017-9639-4, 2017.

Loos, J. R. and Rogers, S. H.: Understanding stakeholder preferences for flood adaptation alternatives with natural capital implications, Ecol. Soc., 21(3), doi:10.5751/ES-08680-210332, 2016.

Loperfido, J. V., Noe, G. B., Jarnagin, S. T. and Hogan, D. M.: Effects of distributed and centralized stormwater best management practices and land cover on urban stream hydrology at the catchment scale, J. Hydrol., 519(PC), 2584–2595, doi:10.1016/j.jhydrol.2014.07.007, 2014.

Lottering, N., du Plessis, D. and Donaldson, R.: Coping with drought: The experience of water sensitive urban design (WSUD) in the George Municipality, Water SA, 41(1), 1–8, doi:10.4314/wsa.v41i1.1, 2015.

Luan, Q., Fu, X., Song, C., Wang, H., Liu, J. and Wang, Y.: Runoff effect evaluation of LID through SWMM in typical mountainous, low-lying urban areas: A case study in China, Water (Switzerland), 9(6), doi:10.3390/w9060439, 2017.

MacKinnon, K., Sobrevila, C. and Hickey, V.: Biodiversity, Climate Change and Adaptation : Nature-Based Solutions from the World Bank Portfolio, Washington, DC. [online] Available from: https://www.ahajournals.org/doi/10.1161/01.RES.0000259564.92792.93, 2008.

Maragno, D., Gaglio, M., Robbi, M., Appiotti, F., Fano, E. A. and Gissi, E.: Fine-scale analysis of urban flooding reduction from green infrastructure: An ecosystem services approach for the management of water flows, Ecol. Modell., 386(July), 1–10, doi:10.1016/j.ecolmodel.2018.08.002, 2018.

Matthews, T., Lo, A. Y. and Byrne, J. A.: Reconceptualizing green infrastructure for climate change adaptation: Barriers to adoption and drivers for uptake by spatial planners, Landsc. Urban Plan., 138, 155–163, doi:10.1016/j.landurbplan.2015.02.010, 2015.

McVittie, A., Cole, L. and Wreford, A.: Assessing Adaptation Knowledge in Europe: Ecosystem-Based Adaptation Final Report, [online] Available from: https://ec.europa.eu/clima/sites/clima/files/adaptation/what/docs/climate_change_vulnerability_en.pdf, 2017.

McVittie, A., Cole, L., Wreford, A., Sgobbi, A. and Yordi, B.: Ecosystem-based solutions for disaster risk reduction: Lessons from European applications of ecosystem-based adaptation measures, Int. J. Disaster Risk Reduct., 32(September 2017), 42–54, doi:10.1016/j.ijdrr.2017.12.014, 2018.

Mei, C., Liu, J., Wang, H., Yang, Z., Ding, X. and Shao, W.: Integrated assessments of green infrastructure for fl ood mitigation to support robust decision-making for sponge city construction in an urbanized watershed, Sci. Total Environ., 639, 1394–1407, doi:10.1016/j.scitotenv.2018.05.199, 2018.

Mills, G., Mills, G., Anjos, M., Brennan, M., Williams, J., McAleavey, C. and Ningal, T.: The green 'signature' of Irish cities:

An examination of the ecosystem services provided by trees using i-Tree Canopy software, Irish Geogr., 48(2), 62–77, doi:10.2014/igj.v48i2.625, 2016.

Moura, N. C. B., Pellegrino, P. R. M. and Martins, J. R. S.: Best management practices as an alternative for flood and urban storm water control in a changing climate, J. Flood Risk Manag., 9(3), 243–254, doi:10.1111/jfr3.12194, 2016.

Mouritz, M.: Sustainable urban water systems: policy and professional praxis, Murdoch University. [online] Available from: http://researchrepository.murdoch.edu.au/id/eprint/211/, 1996.

Naturally Resilient Communities: Naturally Resilient Communities solutions, [online] Available from: http://nrcsolutions.org/strategies/#solutions (Accessed 1 February 2019), 2019.

Nature-based Solutions Initiative: Nature-Based Solutions Policy Platform, [online] Available from: http://nbspolicyplatform.org/ (Accessed 5 March 2019), 2019.

nature4cities: European Horizon 2020 NBS project, [online] Available from: https://www.nature4cities.eu/h2020-nbs-projects (Accessed 11 February 2019), 2019.

NATURVATION: Urban Nature Atlas | NATURVATION, [online] Available from: https://naturvation.eu/atlas (Accessed 5 March 2019), 2019.

Naumann, S., McKenna, D., Kaphengst, T., Pieterse, M., Rayment, M. and Davis, M.: Design, implementation and cost elements of Green Infrastructure projects. Final report to the European Commission, DG Environment, DG Environment., 2011.

Nordman, E. E., Isely, E., Isely, P. and Denning, R.: Benefit-cost analysis of stormwater green infrastructure practices for Grand Rapids , Michigan , USA, J. Clean. Prod., 200, 501–510, doi:10.1016/j.jclepro.2018.07.152, 2018.

NWRM: Natural Water Retention Measures, [online] Available from: http://nwrm.eu/ (Accessed 1 March 2019), 2019.

Olszewski, J. M. and Allen, P. D.: Comparing the Hydrologic Performance of a Bioretention Cell with Predevelopment Values, J. Irrig. Drain. Eng., 1(11), 124–130, doi:10.1061/(ASCE)IR.1943-4774.0000504, 2013.

Onuma, A. and Tsuge, T.: Comparing green infrastructure as ecosystem-based disaster risk reduction with gray infrastructure in terms of costs and benefits under uncertainty: A theoretical approach, Int. J. Disaster Risk Reduct., 32(January), 22–28, doi:10.1016/j.ijdrr.2018.01.025, 2018.

Oppla: Natural capital • Ecosystem services • Nature-based solutions | Oppla, [online] Available from: https://oppla.eu/ (Accessed 25 March 2019), 2019.

Oraei Zare, S., Saghafian, B. and Shamsai, A.: Multi-objective optimization for combined quality-quantity urban runoff control, Hydrol. Earth Syst. Sci., 16(12), 4531–4542, doi:10.5194/hess-16-4531-2012, 2012.

Ossa-Moreno, J., Smith, K. M. and Mijic, A.: Economic analysis of wider benefits to facilitate SuDS uptake in London, UK, Sustain. Cities Soc., 28, 411–419, doi:10.1016/j.scs.2016.10.002, 2017.

Pappalardo, V., La Rosa, D., Campisano, A. and La Greca, P.: The potential of green infrastructure application in urban runoff control for land use planning: A preliminary evaluation from a southern Italy case study, Ecosyst. Serv., 26(April), 345–354, doi:10.1016/j.ecoser.2017.04.015, 2017.

PEARL: PEARL | Preparing for Extreme And Rare events in coastaL regions, [online] Available from: http://www.pearl-fp7.eu/ (Accessed 25 November 2018a), 2019.

PEARL: PEARL Knowledge Base Filter, [online] Available from: http://pearl-kb.hydro.ntua.gr/filter (Accessed 1 February 2019b), 2019.

PEDRR: Demonstrating the Role of Ecosystems-based Management for Disaster Risk Reduction. [online] Available from: https://www.preventionweb.net/english/hyogo/gar/2011/en/bgdocs/PEDRR_2010.pdf, 2010.

Petit-Boix, A., Sevigné-Itoiz, E., Rojas-Gutierrez, L. A., Barbassa, A. P., Josa, A., Rieradevall, J. and Gabarrell, X.: Floods and consequential life cycle assessment: Integrating flood damage into the environmental assessment of stormwater Best Management Practices, J. Clean. Prod., 162(2017), 601–608, doi:10.1016/j.jclepro.2017.06.047, 2017.

Purdue University: Low-Impact Development L-THIA, [online] Available from: https://engineering.purdue.edu/mapserve/LTHIA7/lthianew/lidIntro.php (Accessed 1 February 2019), 2019.

Qin, H., Li, Z. and Fu, G.: The effects of low impact development on urban flooding under different rainfall characteristics, J. Environ. Manage., 129, 577–585, doi:10.1016/j.jenvman.2013.08.026, 2013.

Rangarajan, S., Marton, D., Montalto, F., Cheng, Z. J. and Smith, G.: Measuring the flow: Green infrastructure grows in Brooklyn, Curr. Opin. Environ. Sustain., 17, 36–41, doi:10.1016/j.cosust.2015.09.001, 2015.

Raymond, C. M., Frantzeskaki, N., Kabisch, N., Berry, P., Breil, M., Nita, M. R., Geneletti, D. and Calfapietra, C.: A framework for assessing and implementing the co-benefits of nature-based solutions in urban areas, Environ. Sci. Policy, 77(June), 15–24, doi:10.1016/j.envsci.2017.07.008, 2017.

RECONECT: RECONECT – Nature-based-solutions for hydro-meteorological risk reduction, [online] Available from: http://www.reconect.eu/ (Accessed 25 November 2018), 2019.

Reguero, B. G., Beck, M. W., Bresch, D. N., Calil, J. and Meliane, I.: Comparing the cost effectiveness of nature-based and coastal adaptation: A case study from the Gulf Coast of the United States, PLoS One, 13(4), 1–24, doi:10.1371/journal.pone.0192132, 2018.

Renaud, F. G., Sudmeier-Rieux, K., Estrella, M. and Nehren, U.: Ecosystem-Based Disaster Risk Reduction and Adaptation in Practice, edited by F. G. Renaud, K. Sudmeier-Rieux, M. Estrella, and U. Nehren, Springer International Publishing, Cham., 2016.

Reynaud, A., Lanzanova, D., Liquete, C. and Grizzetti, B.: Going green? Ex-post valuation of a multipurpose water infrastructure in Northern Italy, Ecosyst. Serv., 27, 70–81, doi:10.1016/j.ecoser.2017.07.015, 2017.

De Risi, R., De Paola, F., Turpie, J. and Kroeger, T.: Life Cycle Cost and Return on Investment as complementary decision variables for urban flood risk management in developing countries, Int. J. Disaster Risk Reduct., 28(October 2017), 88–106, doi:10.1016/j.ijdrr.2018.02.026, 2018a.

De Risi, R., De Paola, F., Turpie, J. and Kroeger, T.: Life Cycle Cost and Return on Investment as complementary decision variables for urban flood risk management in developing countries, Int. J. Disaster Risk Reduct., 28(February), 88–106, doi:10.1016/j.ijdrr.2018.02.026, 2018b.

Romnée, A. and De Herde, A.: Hydrological efficiency evaluation tool of urban Stormwater best management practices, Int. J. Sustain. Dev. Plan., 10(4), 435–452, doi:10.2495/SDP-V10-N4-435-452, 2015.

Rozos, E., Makropoulos, C. and Maksimovic, C.: Rethinking urban areas : an example of an integrated blue-green approach, , 1534–1542, doi:10.2166/ws.2013.140, 2013.

Ruckelshaus, M. H., Guannel, G., Arkema, K., Verutes, G., Griffin, R., Guerry, A., Silver, J., Faries, J., Brenner, J. and Rosenthal, A.: Evaluating the Benefits of Green Infrastructure for Coastal Areas: Location, Location, Location, Coast. Manag., 44(5), 504–516, doi:10.1080/08920753.2016.1208882, 2016.

Scarano, F. R.: Ecosystem-based adaptation to climate change: concept, scalability and a role for conservation science, Perspect. Ecol. Conserv., 15(2), 65–73, doi:10.1016/j.pecon.2017.05.003, 2017.

Schifman, L. A., Herrmann, D. L., Shuster, W. D., Ossola, A., Garmestani, A. and Hopton, M. E.: Situating Green Infrastructure in Context: A Framework for Adaptive Socio-Hydrology in Cities, Water Resour. Res., 53(12), 10139–10154, doi:10.1002/2017WR020926, 2017.

Schubert, J. E., Burns, M. J., Fletcher, T. D. and Sanders, B. F.: A framework for the case-specific assessment of Green Infrastructure in mitigating urban flood hazards, Adv. Water Resour., 108, 55–68, doi:10.1016/j.advwatres.2017.07.009, 2017.

SEI: Stockholm Environment Institute: weADAPT | Climate adaptation planning, research and practice, [online] Available from: https://www.weadapt.org/ (Accessed 5 March 2019), 2019.

Sekulova, F. and Anguelovski, I.: The Governance and Politics of Nature-Based Solutions., 2017.

Semadeni-Davies, A., Hernebring, C., Svensson, G. and Gustafsson, L. G.: The impacts of climate change and urbanisation on drainage in Helsingborg, Sweden: Suburban stormwater, J. Hydrol., 350(1–2), 114–125, doi:10.1016/j.jhydrol.2007.11.006, 2008.

Shafique, M. and Kim, R.: Recent progress in low-impact development in South Korea: Water-management policies, challenges and opportunities, Water (Switzerland), 10(4), doi:10.3390/w10040435, 2018.

Shafique, M., Kim, R. and Kyung-Ho, K.: Rainfall runoff mitigation by retrofitted permeable pavement in an urban area, Sustain., 10(4), 1–10, doi:10.3390/su10041231, 2018.

Soares, A. L., Rego, F. C., McPherson, E. G., Simpson, J. R., Peper, P. J. and Xiao, Q.: Benefits and costs of street trees in Lisbon, Portugal, Urban For. Urban Green., 10(2), 69–78, doi:10.1016/j.ufug.2010.12.001, 2011.

Song, K., You, S. and Chon, J.: Simulation modeling for a resilience improvement plan for natural disasters in a coastal area, Environ. Pollut., 242, 1970–1980, doi:10.1016/j.envpol.2018.07.057, 2018.

Stanev, E., Meinke, I., Emeis, K., Ratter, B. M. W., Weisse, R., von Storch, H., Wirtz, K., Matthias, V. and Kannen, A.: Making coastal research useful – cases from practice, Oceanologia, 57(1), 3–16, doi:10.1016/j.oceano.2014.09.001, 2014.

Strecker, E. W., Quigley, M. M., Urbonas, B. R., Jones, J. E. and Clary, J. K.: Determining Urban Storm Water BMP

Effectiveness, J. Water Resour. Plan. Manag., 127(3), 144–149, doi:10.1061/(ASCE)0733-9496(2001)127:3(144), 2001.

Stürck, J., Schulp, C. J. E. and Verburg, P. H.: Spatio-temporal dynamics of regulating ecosystem services in Europe- The role of past and future land use change, Appl. Geogr., 63, 121–135, doi:10.1016/j.apgeog.2015.06.009, 2015.

Sutton-Grier, A. E., Gittman, R. K., Arkema, K. K., Bennett, R. O., Benoit, J., Blitch, S., Burks-Copes, K. A., Colden, A., Dausman, A., DeAngelis, B. M., Hughes, A. R., Scyphers, S. B. and Grabowski, J. H.: Investing in natural and nature-based infrastructure: Building better along our coasts, Sustain., 10(2), 1–11, doi:10.3390/su10020523, 2018.

Tao, J., Li, Z., Peng, X. and Ying, G.: Quantitative analysis of impact of green stormwater infrastructures on combined sewer overflow control and urban flooding control, Front. Environ. Sci. Eng., 11(4), 1–12, doi:10.1007/s11783-017-0952-4, 2017.

The Nature of Cities: The Nature of Cities, [online] Available from: https://www.thenatureofcities.com/ (Accessed 5 March 2019), 2019.

ThinkNature: ThinkNature | Platform for Nature-Based Solutions, [online] Available from: https://www.think-nature.eu/ (Accessed 5 March 2019), 2019.

Thorne, C. R., Lawson, E. C., Ozawa, C., Hamlin, S. L. and Smith, L. A.: Overcoming uncertainty and barriers to adoption of Blue-Green Infrastructure for urban flood risk management, J. Flood Risk Manag., 11, S960–S972, doi:10.1111/jfr3.12218, 2018.

Thorslund, J., Jarsjo, J., Jaramillo, F., Jawitz, J. W., Manzoni, S., Basu, N. B., Chalov, S. R., Cohen, M. J., Creed, I. F., Goldenberg, R., Hylin, A., Kalantari, Z., Koussis, A. D., Lyon, S. W., Mazi, K., Mard, J., Persson, K., Pietro, J., Prieto, C., Quin, A., Van Meter, K. and Destouni, G.: Wetlands as large-scale nature-based solutions: Status and challenges for research, engineering and management, Ecol. Eng., 108, 489–497, doi:10.1016/j.ecoleng.2017.07.012, 2017a.

Thorslund, J., Jarsjo, J., Jaramillo, F., Jawitz, J. W., Manzoni, S., Basu, N. B., Chalov, S. R., Cohen, M. J., Creed, I. F., Goldenberg, R., Hylin, A., Kalantari, Z., Koussis, A. D., Lyon, S. W., Mazi, K., Mard, J., Persson, K., Pietro, J., Prieto, C., Quin, A., Van Meter, K. and Destouni, G.: Wetlands as large-scale nature-based solutions: Status and challenges for research, engineering and management, Ecol. Eng., 108, 489–497, doi:10.1016/j.ecoleng.2017.07.012, 2017b.

Triyanti, A. and Chu, E.: A survey of governance approaches to ecosystem-based disaster risk reduction: Current gaps and future directions, Int. J. Disaster Risk Reduct., 32(November 2017), 11–21, doi:10.1016/j.ijdrr.2017.11.005, 2018.

van de Ven, F. H. M., Snep, R. P. H., Koole, S., Brolsma, R., van der Brugge, R., Spijker, J. and Vergroesen, T.: Adaptation Planning Support Toolbox: Measurable performance information based tools for co-creation of resilient, ecosystem-based urban plans with urban designers, decision-makers and stakeholders, Environ. Sci. Policy, 66, 427–436, doi:10.1016/j.envsci.2016.06.010, 2016.

Vogel, J. R., Moore, T. L., Coffman, R. R., Rodie, S. N., Hutchinson, S. L., McDonough, K. R., McLemore, A. J. and McMaine, J. T.: Critical Review of Technical Questions Facing Low Impact Development and Green Infrastructure: A Perspective from the Great Plains, Water Environ. Res., 87(9), 849–862, doi:10.2175/106143015X14362865226392, 2015.

Vojinovic, Z.: Flood Risk : The Holistic Perspective, IWA Publishing, London, UNITED KINGDOM. [online] Available from: http://ebookcentral.proquest.com/lib/delft/detail.action?docID=3425859, 2015.

Vojinovic, Z., Keerakamolchai, W., Weesakul, S., Pudar, R., Medina, N. and Alves, A.: Combining Ecosystem Services with Cost-Benefit Analysis for Selection of Green and Grey Infrastructure for Flood Protection in a Cultural Setting, Environments, 4(1), 3, doi:10.3390/environments4010003, 2017.

Voskamp, I. M. and 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, Build. Environ., 83, 159–167, doi:10.1016/j.buildenv.2014.07.018, 2015.

Walmsley, A.: Greenways and the making of urban form, Landsc. Urban Plan., 33(1–3), 81–127, doi:10.1016/0169-2046(95)02015-L, 1995.

Wang, Q., Guidolin, M., Savic, D. and Kapelan, Z.: Two-Objective Design of Benchmark Problems of a Water Distribution System via MOEAs: Towards the Best-Known Approximation of the True Pareto Front, J. Water Resour. Plan. Manag., 141(3), 04014060, doi:10.1061/(ASCE)WR.1943-5452.0000460, 2015.

Watson, K. B., Ricketts, T., Galford, G., Polasky, S. and O'Niel-Dunne, J.: Quantifying flood mitigation services: The economic value of Otter Creek wetlands and floodplains to Middlebury, VT, Ecol. Econ., 130, 16–24, doi:10.1016/j.ecolecon.2016.05.015, 2016.

Webber, J. L., Fu, G. and Butler, D.: Rapid surface water intervention performance comparison for urban planning, Water Sci. Technol., 77(8), 2084–2092, doi:10.2166/wst.2018.122, 2018.

Wheeler, B. W., Cooper, A. R., Page, A. S. and Jago, R.: Greenspace and children's physical activity: A GPS/GIS analysis of the PEACH project, Prev. Med. (Baltim)., 51(2), 148–152, doi:10.1016/j.ypmed.2010.06.001, 2010.

Whelans consultants, Hawthorn, M. and Thompson, P.: Planning & management guidelines for water sensitive urban (residential) design : consultants report prepared for the Department of Planning and Urban Development, State Planning Commission., 1994.

World Bank, GFDRR and Deltares: Natural Hazards – Nature-based Solutions, [online] Available from: https://naturebasedsolutions.org/ (Accessed 5 March 2019), 2019.

Woznicki, S. A., Hondula, K. L. and Jarnagin, S. T.: Effectiveness of landscape-based green infrastructure for stormwater management in suburban catchments, Hydrol. Process., 32(15), 2346–2361, doi:10.1002/hyp.13144, 2018.

Wu, J., Yang, R. and Song, J.: Effectiveness of low-impact development for urban inundation risk mitigation under different scenarios: A case study in Shenzhen, China, Nat. Hazards Earth Syst. Sci., 18(9), 2525–2536, doi:10.5194/nhess-18-2525-2018, 2018.

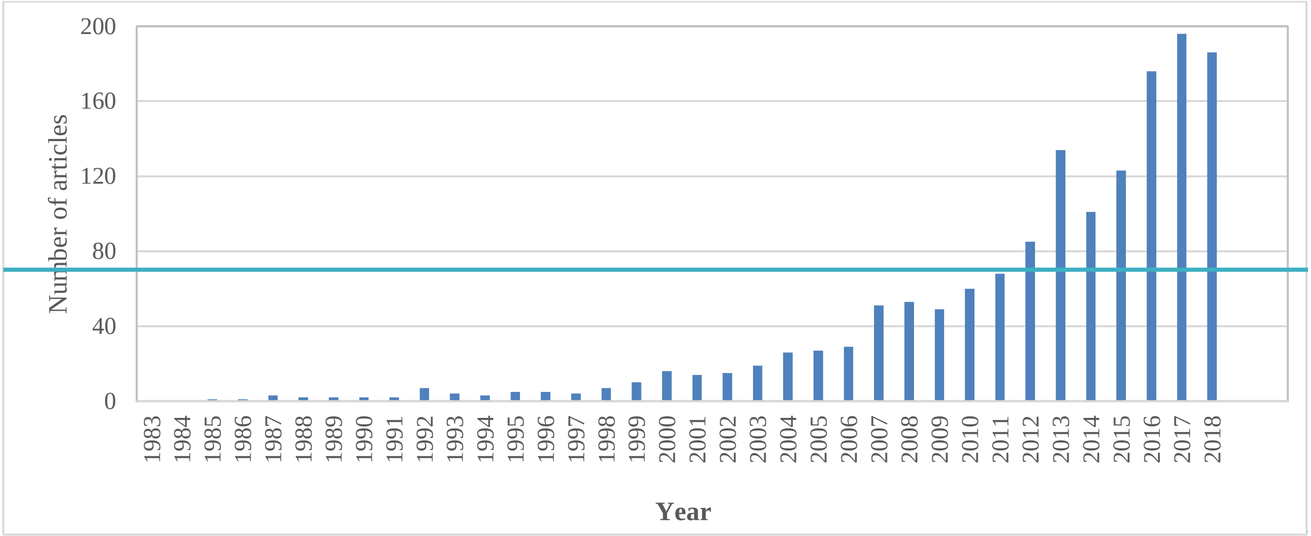
Yang, Y., Fong, T. and Chui, M.: Integrated hydro-environmental impact assessment and alternative selection of low impact development practices in small urban catchments, J. Environ. Manage., 223(June), 324–337, doi:10.1016/j.jenvman.2018.06.021, 2018.

Yazdi, J. and Salehi Neyshabouri, S. A. A.: Identifying low impact development strategies for flood mitigation using a fuzzyprobabilistic approach, Environ. Model. Softw., 60, 31–44, doi:10.1016/j.envsoft.2014.06.004, 2014.

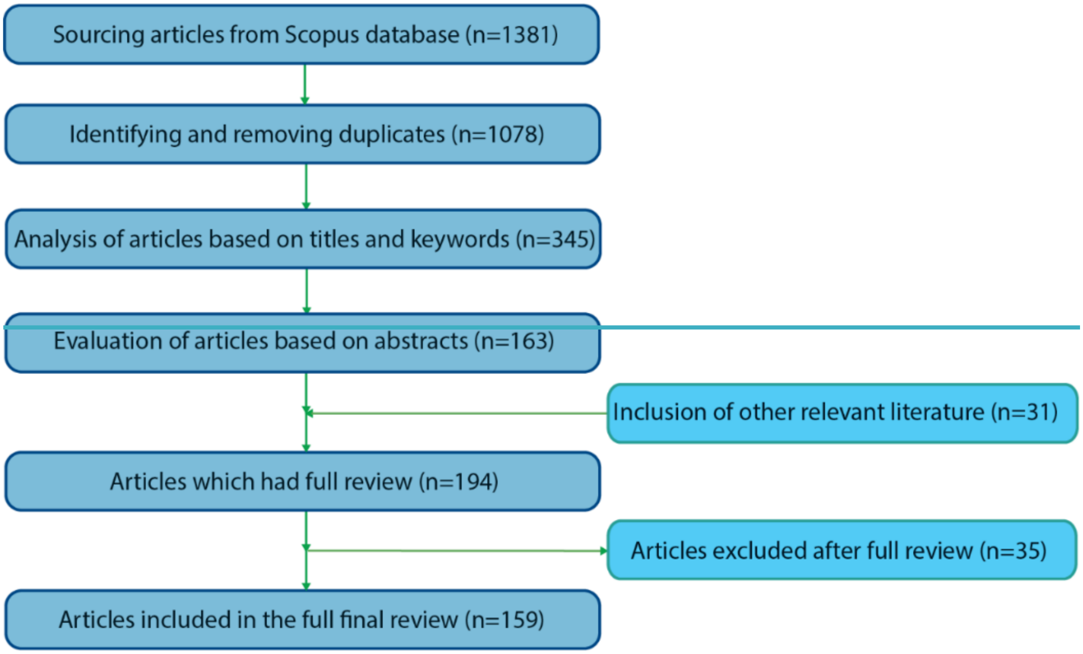
Zhang, K. and Chui, T. F. M.: A comprehensive review of spatial allocation of LID-BMP-GI practices: Strategies and optimization tools, Sci. Total Environ., 621, 915–929, doi:10.1016/j.scitotenv.2017.11.281, 2018.

Zhang, K. and Chui, T. F. M.: Linking hydrological and bioecological benefits of green infrastructures across spatial scales – A literature review, Sci. Total Environ., 646, 1219–1231, doi:10.1016/j.scitotenv.2018.07.355, 2019.

Zhu, Z. and Chen, X.: Evaluating the effects of low impact development practices on urban flooding under different rainfall intensities, Water (Switzerland), 9(7), doi:10.3390/w9070548, 2017.



~~Figure 1: Number of articles per year on Nature Based Solutions for hydro-meteorological risk reduction sourced from Scopus over the period 1983-2018.~~



~~**Figure 2: Process of article selection on Nature Based Solutions for hydro-meteorological risk reduction. The process started with sorting 1381 articles and 31 other documents. The final number of fully reviewed articles is 159.**~~

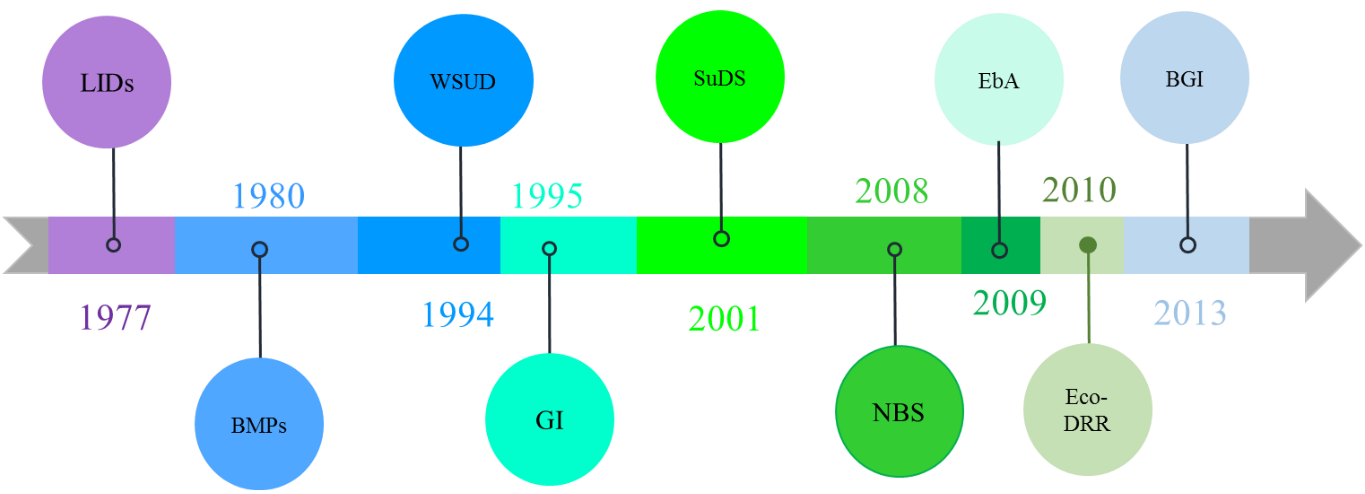


Figure ~~3~~1: Timeline/year of origin of each terminology (Low Impact Developments (LIDs), Best Management Practices (BMPs), Water Sensitive Urban Design (WSUD), Green Infrastructure (GI), Sustainable Urban Drainage Systems (SuDS), Nature-Based Solitions (NBS), Ecosystem-based Adaptation (EbA), Ecosystem-based Disaster Risk Reduction (Eco-DRR) and Blue-Green Infrastructure (BGI)) based on their appearance in publications

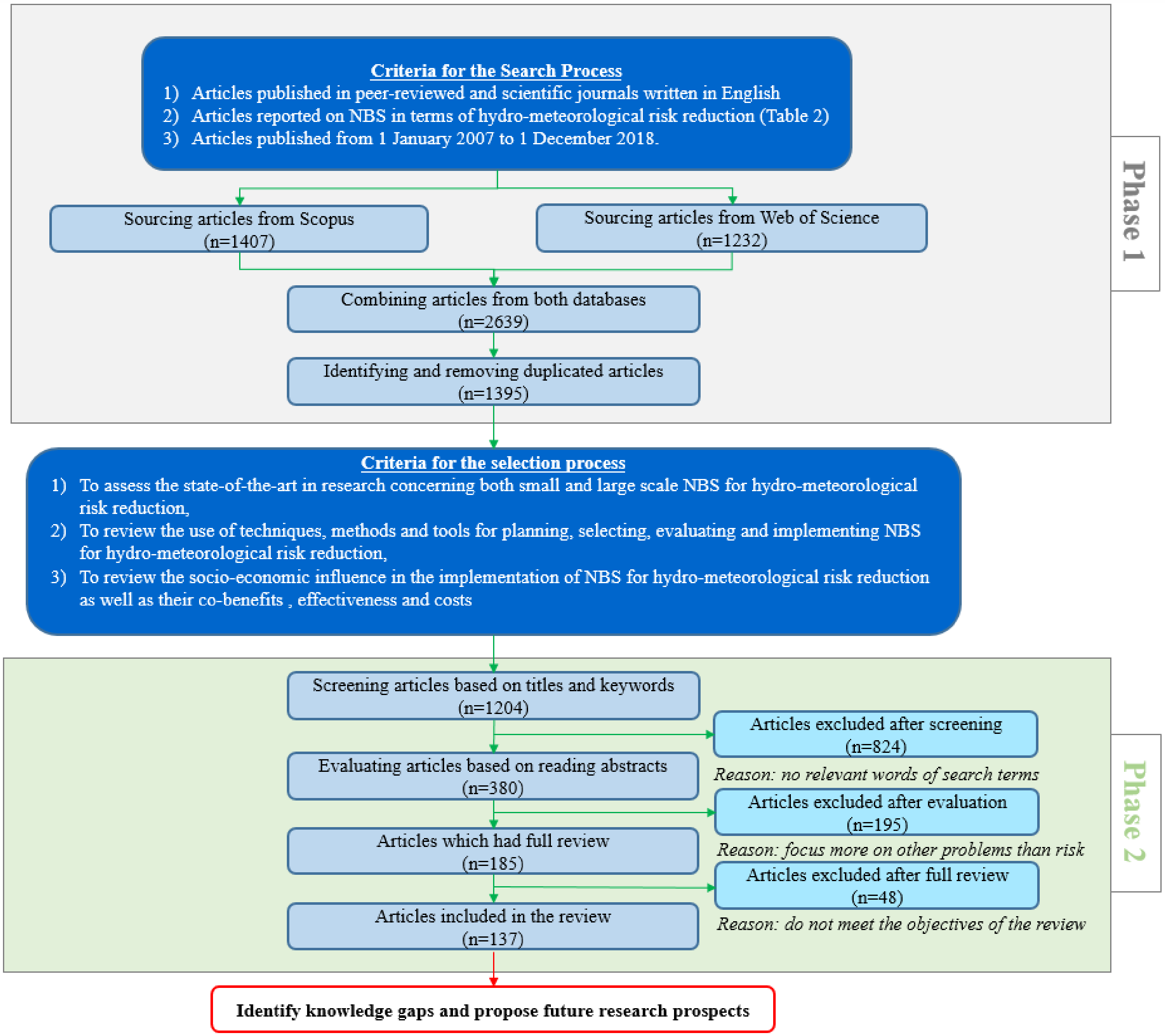


Figure 2: Process of article selection on Nature Based Solutions for hydro-meteorological risk reduction. The final number of fully reviewed articles is 137

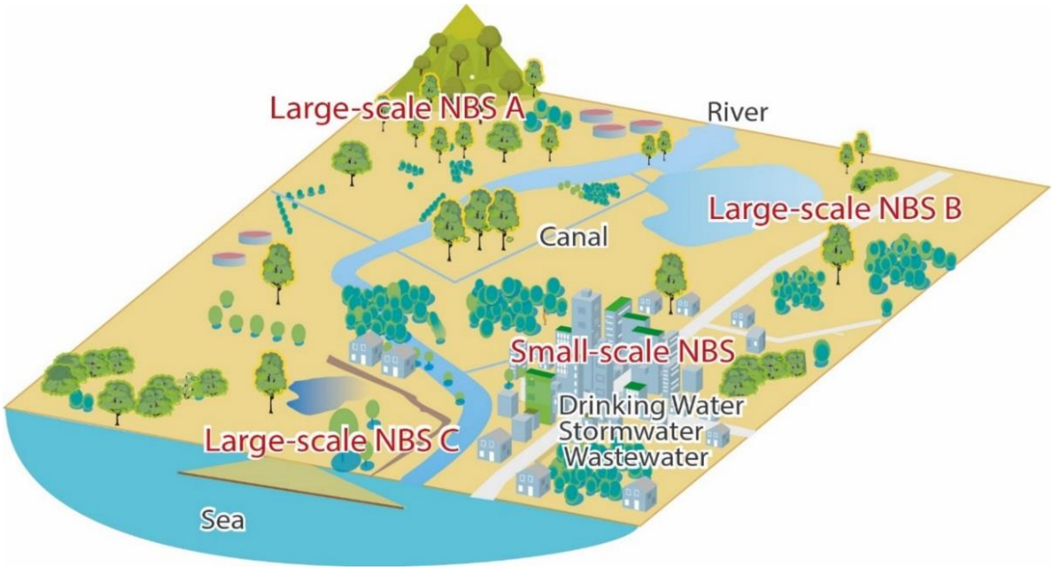


Figure ~~5~~3: Illustration of large and small scale Nature-Based-Solutions (NBS); Large-scale NBS A illustrates NBS in mountainous regions (e.g., afforestation, reforestation, slope stabilization, etc.), Large-scale NBS B illustrates NBS along river corridors (e.g., dike relocation, retention basins, etc.) and Large-scale NBS C illustrates NBS in coastal regions (e.g., sand dunes, protection dikes/walls, marshes, etc.); Typical examples of Small-scale NBS are green roofs, green walls, rain gardens, porous/permeable pavements, swales, bio-retention, etc.

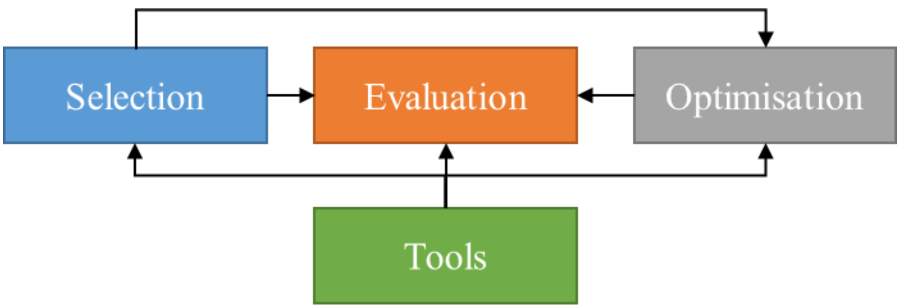
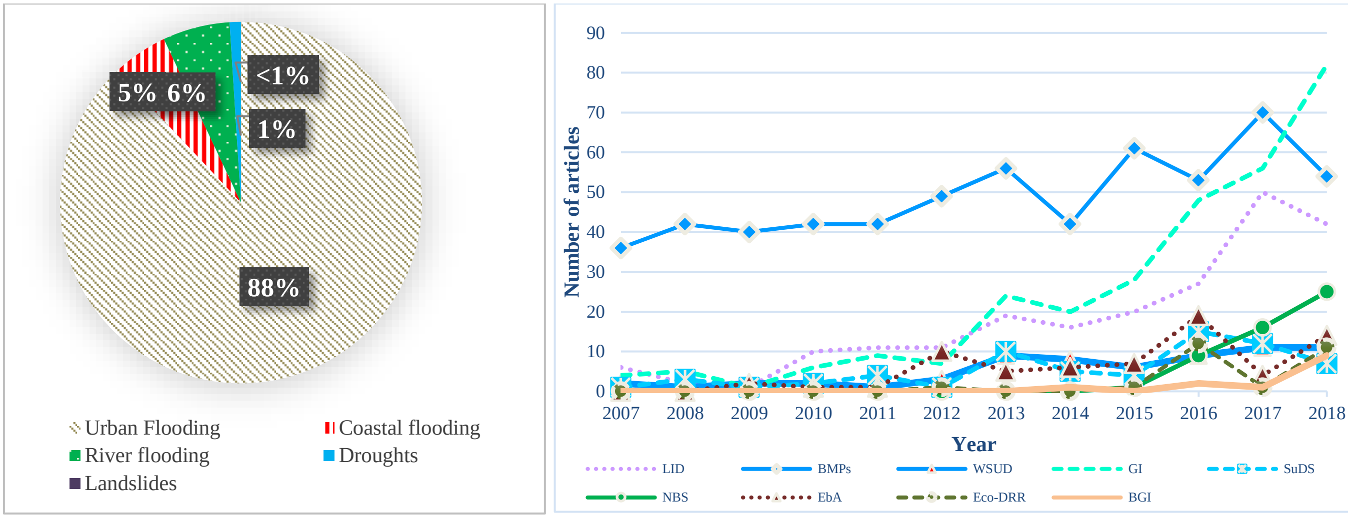


Figure ~~6~~4: Evaluation process of Nature-Based Solutions



(a) (b)

Figure ~~4~~5: An overview of published articles on Nature-Based Solutions for hydro-meteorological risk reduction: (a) percentage of published articles that have been studied for reducing urban flooding, coastal flooding, river flooding, droughts and landslides and (b) number/trend of published articles for Low Impact Developments (LIDs), Best Management Practices (BMPs), Water Sensitive Urban Design (WSUD), Green Infrastructure (GI), Sustainable Urban Drainage Systems (SuDS), Nature-Based Solitions (NBS), Ecosystem-based Adaptation (EbA), Ecosystem-based Disaster Risk Reduction (Eco-DRR) and Blue-Green Infrastructure (BGI)

Table ~~2~~1: Glossary of terminologies and their geographical usage

Terminology	Definition/Objectives/Purpose	Commonly used in	Reference
Low Impact Development (LIDs)	*"LID is used as a retro- fit designed to reduce the stress on urban stormwater infrastructure and/or create the resiliency to adapt to climate changes, LID relies heavily on infiltration and evapotranspiration and attempts to incorporate natural features into design."*	- United States - New Zealand	(Barlow et al., 1977; County, 1999; Eckart et al., 2017)
Best management practices (BMPs)	*"A device, practice or method for removing, reducing, retarding or preventing targeted stormwater runoff constituents, pollutants and contaminants from reaching receiving waters"*	- United States - Canada	(Biggers et al., 1980; Moura et al., 2016; Strecker et al., 2001)
Water Sensitive Urban Design (WSUD)	*"Manage the water balance, maintain and where possible enhance water quality, encourage water conservation and maintain water-related environmental and recreational opportunities".*	- Australia	(Lottering et al., 2015; Mouritz, 1996; Whelans consultants et al., 1994)
Sustainable Urban Drainage Systems (SuDS)	*"Replicate the natural drainage processes of an area – typically through the use of vegetation-based interventions such as swales, water gardens and green roofs, which increase localised infiltration, attenuation and/or detention of stormwater"*	- United Kingdom	(Abbott and Comino-Mateos, 2001; Ossa-Moreno et al., 2017)

Terminology	Definition/Objectives/Purpose	Commonly used in	Reference
Green Infrastructure (GI)	*"The network of natural and semi-natural areas, features and green spaces in rural and urban, and terrestrial, freshwater, coastal and marine areas, which together enhance ecosystem health and resilience, contribute to biodiversity conservation and benefit human populations through the maintenance and enhancement of ecosystem services"*	- United states - United Kingdom	(Gill et al., 2007; Lafortezza et al., 2013; Naumann et al., 2011; Walmsley, 1995)
Ecosystem-based Adaptation (EbA)	*"The use of biodiversity and ecosystem services as part of an overall adaptation strategy to help people to adapt to the adverse effects of climate change."*	- Canada - Europe	(CBD, 2009; McVittie et al., 2017; Scarano, 2017)
Ecosystem-based disaster risk reduction (Eco-DRR)	*"The sustainable management, conservation, and restoration of ecosystems to reduce disaster risk, with the aim of achieving sustainable and resilient development"*	- Europe - United states	(Estrella and Saalismaa, 2013; PEDRR, 2010; Renaud et al., 2016)
Blue-Green Infrastructure (BGI)	*"BGI provides a range of services that include; water supply, climate regulation, pollution control and hazard regulation (blue services/goods), crops, food and timber, wild species diversity, detoxification, cultural services (physical health, aesthetics, spiritual), plus abilities to adapt to and mitigate climate change"*	- United Kingdom	(Bozovic et al., 2017; Lawson et al., 2014; PEDRR, 2010; Rozos et al., 2013)
Nature-Based Solution	*"NBS aim to help societies address a variety of environmental, social and economic challenges in sustainable ways. They are actions inspired by, supported by or copied from nature; both using and enhancing existing solutions to challenges, as well as exploring more novel solutions."*	- Europe	(Cohen-Shacham et al., 2016; European Commission (EC), 2015; Faivre et al., 2017; MacKinnon et al., 2008; Stürck et al., 2015)

Table 21: Selected concepts and terms used to search relevant literature on NBS for hydro-meteorological risk reduction

No	Research words		
	First concept (Nature-Based Solutions)	**Connection**	**Second concept (Hydro-meteorological risk)**
1	"Nature-based solutions" OR	AND	"Flood"
2	"Nature-Based Solutions" OR	AND	"Drought"
3	"Low impact development" OR	AND	"Storm surge"
4	"Sustainable Urban Drainage Systems" OR	AND	"Landslide"
5	"Water Sensitive Urban Design" OR	AND	"Hydro-meteorological"
6	"Best Management Practices" OR	AND	"Disaster"
7	"Green infrastructure" OR	AND	"Review"
8	"Green blue infrastructure" OR	AND	"Hydrology"
9	"Ecosystem-based Adaptation " OR	AND	"Coastal"
10	"Ecosystem-based disaster risk reduction "		

Table 3 Summary of effectiveness, co-benefits and costs of small scale NBS measures

Measures	References	Case studies	Area/ volume covered by NBS	Effectiveness		Co-benefits	Cost/ m²*	Remark
				Runoff volume reduction	Peak flow reduction			
Porous pavement	Shafique et al., (2018)	Seoul, Korea	1050 m^2	~30–65%	-	• Removing diffuse pollution • Enhancing recharge to groundwater	~$252	• More effective in heavier and shorter rainfall events.
	Damodaram et al., 2010	Texas, USA	2.99 km^2	-	~10% - 30%			
Green roofs	(Burszta-Adamiak and Mrowiec, 2013)	Wroclaw, Poland	2.88 m^2	-	54%-96%	• Reducing nutrient loadings. • Saving energy • Reducing air pollution • Increasing amenity value	~$564	• More efficient in smaller storm events than larger storm events
	(Ercolani et al., 2018)	Milan, Italy	0.39 km^2	~15%-70%	~10-80%			
	(Carpenter and Kaluvakolanu, 2011)	Michigan, USA	325. 2 m^2	~68.25%	~88.86%			
Rain gardens	(Ishimatsu et al., 2017)	Japan	1.862 m^2	~36-100%	-	• Providing a scenic amenity. • Increasing the median property value • Increasing biodiversity	~$501	• More effective in dealing with small discharges of rainwater
	(Goncalves et al., 2018)	Joinville, Brazil	34,139 m^2	50%	48.5%			
Vegetated swales	(Luan et al., 2017)	Beijing, China	157 m^3	~0.3–3.0%.	2.2%	• Reducing concentrations of pollutants • Increasing biodiversity	~$371	• More effective in heavier and shorter rainfall events. • Not suitable in mountains areas
	(Huang et al., 2014)	Haihe River basin, China	1,500 m^3	9.60%	23.56%			
Rainwater harvesting	(Khastagir and Jayasuriya, 2010)	Melbourne, Australia	1 m^3 -5 m^3	~57.8%-78.7%	-	• Improving water quality (TN was reduced around 72%-80%)	~$865 /$m^3$	
	(Damodaram et al., 2010)	Texas, USA	1.5 km^2	-	~8%-10%			
Dry detention pond	(Liew et al., 2012)	Selangor, Malaysia	65,000 m^2	-	33-46%	• Providing recreational benefits.		• Delaying the time to peak by 40-45 min
Detention pond	(Damodaram et al., 2010)	Texas, USA	73,372 m^3	-	~20%	• Providing biodiversity benefits • Providing recreational benefits.	~$60	
	(Goncalves et al., 2018)	Joinville, Brazil	9,700 m^3	55.7%	43.3%			
Bio-retention	(Luan et al., 2017)	Beijing, China	945.93 m^3	~10.2–12.1%.	-	• Reducing TSS pollution • Reducing TP pollution	~$534	Measure has a better reduction effectiveness in various rainfall intensities.
	(Huang et al., 2014)	Haihe River basin, China	1,708.6 m^3	9.10%	41.65%			
	Khan et al., 2013;	Calgary	48 m^3	~90%	-			
Infiltration trench	(Huang et al., 2014)	Haihe River, China	3,576 m^3	30.80%	19.44%	• Reducing water pollutant • Improving surface water quality.	~$74	

Measures	References	Case studies	Area/ volume covered by NBS	Effectiveness		Co-benefits	Cost/ m²*	Remark
				Runoff volume reduction	Peak flow reduction			
	(Goncalves et al., 2018)	Joinville, Brazil	34,139 m^2	55.9%	53.4%			
Green roof and Porous pavement	(Damodaram et al., 2010)	Texas, USA	4.49 km^2	-	~10%-35%	• Saving energy • Increasing amenity value		• More effective in smaller events
Swale and Porous pavement	(Behroozi et al., 2018)	Tehran, Iran	-	5%-32%	~10%-21%	• Decreasing TSS pollution 50-60%		• More effective in smaller events
Rainwater harvesting and Porous pavement	(Damodaram et al., 2010)	Texas, USA	4.49 km^2	-	20%-40%	• Removing diffuse pollution		• More effective in smaller events
Detention pond and Raingarden	(Goncalves et al., 2018)	Joinville, Brazil	18,327 m^2	70.8%	60.0%	• Providing a scenic amenity.		•
Detention pond and Infiltration trench	(Goncalves et al., 2018)	Joinville, Brazil	18,327 m^2	75.1%	67.8%	Improving surface water quality.		•

***Remark** Cost of each measure is based on (CNT, 2009; Nordman et al., 2018; De Risi et al., 2018)

Table 4: Summary of effectiveness, co-benefits and costs of large scale NBS measures

Measures	References	Case studies	Area/ volume covered by NBS	Effectiveness	Co-benefits	Cost/ Unit*
De-culverting (river restoration)	(Chou, 2016)	Laojie River, Taiwan	3 km	• It can reduce flood risk up to 100 year return period	• Increasing landscape value • Increasing recreational value	~$18.6 million
Floodplain lowering	(Klijn et al., 2013).	Deventer Netherlands	5.01 km^2	• It can reduce water level 19 cm	• Increasing nature area • Increasing agriculture value	~€136.7 million
Dike relocation/floodplain lowering	(Klijn et al., 2013).	Nijmegen/ Lent, Netherlands	2.42 km^2	• It can reduce water level 34 cm	• Increasing floodplain area • Increasing recreational value	~€342.60 million
Floodwater storage	(Klijn et al., 2013).	Volkenrak-Zoommeer	200 million m^3	• It can reduce water level 50 cm	• Increasing habitat and biodiversity in the area • Increasing recreational value	~€386.20 million
Green floodway	(Klijn et al., 2013).	Veessen-Wapenveld	14.10 km^2	• It can reduce water level 71 cm	• Increasing floodplain area • Increasing recreational value	
Wetlands (Mangroves and salt Marshes)	(Coppenolle, 2018; Gedan et al., 2011)			• It can mitigate storm surge 80% • It can protect against tsunami impacts	• Providing shoreline protection services	

Table 45: An overview of web-portals, networks and initiatives that address Nature-Based Solutions

Name	References/ Website	Terminology used	Scale level	Funded by	Proposes
OPPLA	(Oppla, 2019)	Nature-Based Solution, Natural capital, Ecosystem services	Europe	FP7 (EC)	A new knowledge marketplace - EU repository of NBS; a place where the latest thinking on ecosystem services, natural capital and nature-based solutions is brought together.
BiodivERsA	(Biodivera, 2019)	Ecosystem services	Europe	Horizon 2020 (EC)	A network of funding organizations promoting research on biodiversity and ecosystem services.
BISE	(BISE, 2019)	Ecosystem services, Green infrastructures	Europe	EC	A single entry point for data and information on biodiversity supporting the implementation of the EU strategy and the Aichi targets in Europe.
ThinkNature	(ThinkNature, 2019)	Nature-Based Solution	Europe	Horizon 2020 (EC)	A multi-stakeholder communication platform that supports dialog and understanding of NBS.
ClimateADAPT	(Climate ADAPT, 2019)	EbA, Nature-Based Solution, GI	Europe	EC, EEA	A platform that supports Europe in adapting to climate change by helping users to access and share data and information relevant for CCIVA.
Natural Water Retention Measures	(NWRM, 2019)	Natural water retention measures	Europe	EC	A platform that gathers information on NWRM at EU level.
Urban Nature Atlas	(NATURVATION, 2019)	Nature-Based Solution	Europe	Horizon 2020 (EC)	A platform that contains around 1000 examples of Nature-Based Solutions from across 100 European cities.
Disaster Risk Management	(DRMKC, 2019)	Eco-DRR	Europe	EC	A platform that provides a networked approach to the science-policy interface in DRM.

Name	References/ Website	Terminology used	Scale level	Funded by	Proposes
Knowledge Centre					
Natural Hazards – Nature Based Solutions	(World Bank et al., 2019)	Nature-Based Solution	Global	The World Bank	A project map that provides a list of nature-based projects that are sortable by implementing organisation, targeted hazard, and type of nature-based solution, geographic location, cost, benefits, and more.
Nature-based Solutions Initiative	(Nature-based Solutions Initiative, 2019)	Nature-Based Solution	Global	International Institute for Environment and Development (IIED)	The global policy platform that provides information about climate change adaptation planning across the globe openly available and easy to explore.
weADAPT	(SEI, 2019)	Ecosystem-based Adaptation	Global	Stockholm Environment Institute (SEI)	A collaborative platform on climate adaptation issues, which allows practitioners, researchers and policy-makers to access credible, high-quality information and connect.
Nature of Cities	(The Nature of Cities, 2019)	Green Infrastructures	Global		An international platform for transdisciplinary dialogue concerning urban solutions.
ClimateScan	(ClimateScan, 2019)	Blue-Green Infrastructures	Global	EC	Global online tool which acts as a guide for projects and initiatives on urban resilience, climate proofing and climate adaptation around the world.
Partnership for Environment and Disaster Risk Reduction (PEDRR)	(PEDRR, 2019)	Ecosystem-based Adaptation	Global		PEDRR aims to promote and scale-up implementation of Eco-DRR and ensure it is mainstreamed in development planning at global, national and local levels, in line with the SFDRR.
PANORAMA	(PANORAMA, 2019)	Ecosystem-based Adaptation,	Global	IUCN, GIZ, UNDP	It aims to document and promote examples of inspiring solutions across development topics, to enable cross-sectoral learning and upscaling of successes

Table 36: Overview of knowledge gaps and potential future research prospects

Subject	Number of publications	Knowledge Gaps	Future research prospects
1. The effectiveness of small scale NBS	45	- Combination of small and large scale NBS with grey infrastructure.	• Development of a framework and methods to upscale NBS from small to large scale. • Development of a framework, methods and tools to select, evaluate, and design hybrid measures for hydro-meteorological risk reduction
		- NBS for droughts, landslides and storm surges.	• Application of NBS to reduce the risk of droughts, landslides and storm surges.
2. The effectiveness of large scale NBS	**13**	- Application to hydro-meteorological risk reduction;	• Development of a framework, methods and tools to select, evaluate, and design large scale NBS individually and in hybrid combinations for hydro-meteorological risk reduction • Development of typologies and guidelines for NBS design, implementation, operation and maintenance.

Subject	Number of publications	Knowledge Gaps	Future research prospects
		- Combination of large scale NBS with grey infrastructure	
3. Selection and assessment of NBS with the focus on risk reduction	29	Framework for selection of NBS	• Defining the role of ecosystems in terms of risk reduction, socio-economic and hydro-geomorphological settings • Combining spatial planning and stakeholders participation in the co-selection process
		Framework for cost analysis	• Combining economic value of ecological damage and environmental impact, including the "invisible" ecosystem services (see also Estrella et al., 2013) • Application of the whole life cycle costing and return on investment within the cost-benefit analysis of NBS • Comparing costs and benefits between NBS, GI and hybrid measures • Defining opportunity costs and trade-offs of NBS implementation
		Framework for optimal configuration of NBS	• Use of optimisation techniques to maximise the main benefit and co-benefits of NBS while minimising their costs. • Use of optimisation techniques to maximise the efficiency of NBS and to define their best configurations within hybrid solutions. • Assessing the effectiveness of solutions on short and long terms
		Combination between multi-criteria and qualitative research	• Use of multi-criteria and qualitative research in evaluation of NBS. • How to combine quantitative and qualitative data and research methods. • Application of qualitative research methods and interviews to effectiveness of NBS
4. Multi-benefits of NBS	21	Assessment of multi-benefits of NBS	• Quantification of co-benefits. • Development of a framework, methods and tools to evaluate wide ranging intangible and tangible benefits. • Gaining deeper understanding of NBS benefits for human well-being
		Assessment of ecosystem capacity	• Assessing ecosystem capacity to maintain services over a longer period of time (see Estrella and Saalismaa, 2013) • Long–term monitoring and evaluation of ecosystem performance and function before and after the disaster • Addressing the complexity of coupled social and ecological systems

Table 3: Overview of knowledge gaps and potential future research prospects (continue)

Subject	Number of publications	Knowledge Gaps	Future research prospects
5. Application of tools	19	Application of new technologies and concepts (e.g., high resolutions numerical	• Integration of real-time monitoring and control technologies for NBS operation. • A trade-off between high resolution numerical models and accuracy of results.

		models, complex, crowdsourcing tools, real-time control system)	• Use of novel modelling techniques such as complex adaptive systems models and serious games.
		Web-based decision support tools/systems	• Development of databases of small and large scale NBS for hydro-meteorological risk reduction. • Development of platforms, info-systems and clusters for exchange knowledge (see also Kabisch et al., 2016). • Development of tools to support decision makers in selecting and evaluating hybrid measures. • Development of tools to assess the multiple-benefits for small and large scale NBS and their hybrid combinations.
6. Multifunctional design	2	Framework for multifunctional design	• Development of a framework and methods to support multifunctional design. • Application of novel landscape design techniques. • Combining the knowledge from landscape architecture and water engineering (Kabisch et al., 2016).
7. Stakeholders participation	8	Frameworks for effective stakeholder involvement and co-creation	• Frameworks for involvement of stakeholders in the selection, evaluation, design, implementation, and monitoring of NBS (i.e., the co-called co-creation process).
8. Financing, governance and policy	5	Desirable governance structures to support effective implementation and operation of NBS at different scales and contexts	• Information concerning legal instruments and requirements. • Development of effective governance structures • Compilation of data and information concerning multiple actors and institutions which are relevant for implementation of NBS • Understanding water governance structures, drivers, barriers and mechanism for enabling system transformation (see also Albert et al., 2019) • Development of methods for evaluation of social, political and institutional dimensions of NBS (see also Triyanti and Chu, 2018)
		Desirable finance models (e.g., public-private partnerships, blended financing, etc.)	• Development of finance guidance for implementing maintaining and operating NBS projects • Guidelines concerning development of new business and finance models (see also Kabisch et al., 2016) • Development of financial mechanisms to engage public and private sectors in the implementation of NBS
		Bridging gaps between science-practice-policy	• Bridging gaps between researchers, engineers, authorities and local stakeholders. • Bridging the policy and institutional gaps. • Bringing innovation to engage society in implementing and improving NBS.