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# The use of Nature-Based Solutions in the fight against Urban Floods: trends, actors and solutions adopted

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***SUMMARY***

*The growing and accelerated population concentration in urban areas, which was not accompanied by proper planning, resulted in several problems, which are even more profound in developing countries. With the elimination of natural vegetation cover, the waterproofing of the soil and other human actions that did not respect environmental dynamics, it is possible to observe increases in the number of occurrences and in the intensity of phenomena, such as floods and urban floods. Such problems affect especially the population layer in conditions of greater socio- environmental vulnerability, since they often occupy risk areas, such as the river plains. In order to combat this problem, alternative actions are being used to the detriment of conventional actions linked to gray infrastructure. In this sense, Nature-Based Solutions emerge as an alternative way to avoid and reduce the intrinsic impacts of urban floods in cities, as well as being implemented in different ways and in different locations. Therefore, this work sought to identify actions that are being used by several cities in the world with ways to combat urban floods through Nature- Based Solutions. Therefore, a Systematic Literature Review was carried out, with bibliometric analysis, in order to identify processes, actors and trends related to the theme. In this way, it is concluded that, despite the importance given to the subject having grown in the last 6 years, mainly due to the increase in scientific production and the amount of solutions implemented in several countries, such trends are concentrated, to a large extent, in European cities and observed by European actors.*

***KEYWORDS:*** *Green Infrastructure. Urban Planning. Urban Waters.*

## 1. INTRODUCTION

According to the report presented by the Department of Economic and Social Affairs of the United Nations (UNITED NATIONS, 2015), currently, 54% of the world's population lives in cities. However, this number, in 1950, was only 30%, and according to the projections prepared by the Department, it will reach 66% in the year 2050. However, the urban transition over time has not been processed homogeneously among the different countries around the globe. According to Santos (2014), the urbanization of the countries of the South, according to the name adopted by the author, was characterized by accelerated development and the lack of planning that resulted in the uncontrolled growth of cities (QUARESMA et al.,2017).

In this sense, this accelerated process of urbanization was not accompanied at the same pace by urban planning, resulting in negative environmental impacts, in view of the changes in use and occupation that altered the immediate ecosystems. This alteration was developed by the suppression of most of the natural vegetation cover, with consequent changes in the climate, and in particular, the variables related to rainfall and temperature. (QUARESMA et al., 2017).

Arising from this scenario, urban floods occur when the waters of rivers, streams or storm sewers leave their drainage channels, due to the lack of transport capacity on the part of one of these systems, and end up occupying areas destined for housing, transport, recreation, commerce, industry, etc. (TUCCI, 2004). This phenomenon has caused economic, environmental and social damage in cities (KALANTARI et al., 2018), in addition to the loss of human lives, affecting, in a special way, vulnerable populations from a socio-environmental point of view.

Faced with such social, economic and environmental impacts, water management measures are necessary, especially regarding the control and fight against urban flooding. In this sense, gray infrastructure (which is characterized by traditional and conventional engineering works) is being predominantly used to the detriment of other forms of combating the effects caused by urban flooding in cities (FERREIRA et al., 2015). It is noteworthy, however, that although there are positive points to be observed, civil engineering infrastructures have higher financial costs and take longer to be implemented compared to other non-structural measures. In addition to these factors, gray infrastructure can result in undesirable impacts on the environment (CARVALHO, 2015).

Such conventional solutions, therefore, are composed of structural measures that cover engineering works, as well as non-structural measures, which include the planning of land occupation and use according to risk areas, taking into account the improvement of legislation and safety in combating disasters related to urban flooding (FARIA; SANTORO, 2015).

In this way, non-structural measures have characteristics of a legal and institutional nature that aim to reduce the impacts of disasters caused by floods (SÃO PAULO, 2012). Such measures aim, from the development and urban planning, to manage the risks of floods, as well as: regulation of land occupation, forecasting system, and flood warning and insurance (SÁ et al., 2016). Structural measures, on the other hand, portray interventions in the flow characteristics (SÃO PAULO, 2012), with a focus on reducing the risk of urban flooding by controlling the flow of water. Therefore, it consists of actions ranging from heavy civil engineering, with a structural character, to solutions considered natural, that is, from gray solutions to solutions based on nature (JHA; BLOCH; LAMOND, 2012).

On the other hand, currently, as an alternative to traditional gray solutions, numerous initiatives have emerged that highlight the potential of using nature in the control and mitigation of risks and problems related to flooding in urban areas (KALANTARI et al., 2018). As an example, according to Gutierrez and Ramos (2017), can be cited the BMP (Best Management Practices), LID (Low Impact Development), SUDS (Sustainable Urban Drainage Systems), WSUD (Water Sensitive Urban Design) and the GI (Green Infrastructure).

Nature-Based Solutions, therefore, provide opportunities to face the challenges of water management in order to be more sustainable and effective. There is a growing use of sustainable practices based on nature to face floods in urban areas in countries such as China, the United States and Spain, which have invested in these practices as part of their urban planning. Therefore, Nature Based Solutions (NbS), "are inspired and supported by nature and use, or mimic, natural processes to effectively contribute to better water management" (UNESCO, 2018).

From another perspective, Dushkova and Haase (2020) indicate that there is no consensus regarding the use of the term. For Cohen-Shacham et al. (2016, p.5) NbS's are "actions to protect, sustainably manage and restore natural or modified ecosystems that address social challenges effectively and adaptively, while simultaneously providing human well-being and benefits from biodiversity". In this sense, there are measures based on nature to combat urban flooding, such as green spaces, restoration of river plains, eco-efficient neighborhoods with a focus on rainwater management, permeable pavements, areas that allow rapid drainage and infiltration , private rainwater collection systems, sustainable water drainage systems (HERZOG; ROZADO, 2019), urban parks, corridors, streets, facades and green roofs (REYNAUD et al., 2017).

Therefore, in general, nature-based practices are being used around the world to mitigate and adapt to extreme events that generate floods. In this sense, the implementation of projects has grown, mainly in European and Chinese cities, ranging from specific actions to the creation of broader concepts that integrate cities and the environment, such as the "green cities" exposed by Herzog and Rozado (2019), and the "sponge cities" mentioned by Sousa (2019) and Chan et al. (2018).

Therefore, the present work sought to identify actions that are being used by several cities in the world with ways to combat urban flooding through Nature-Based Solutions. However, as mentioned, measures related to gray infrastructure are still being widely implemented to combat urban flooding, therefore, the research question of this work goes towards understanding the following question: how are Nature-Based Solutions being used as a alternative measures for flood management in urban areas?

Such concern, in general terms, is inserted in a context of total relevance, considering that, taking into account the Sustainable Development Goals (SDGs), knowing the initiatives of Nature-Based Solutions is fundamental for the generation of knowledge beyond the gray infrastructure solutions that have been used on a larger scale and at the local level. In this way, this work becomes important in contributing to the generation of knowledge about NbS's, as well as in subsidizing future actions and public policies to be adhered to by decision makers and by the public authorities, in general.

Finally, with regard to a theoretical perspective, it is important to make clear that the behavior of watercourses can result in floods, floods and inundations. In this way, there are divergences of interpretation, both in the scientific and in the technical environment, for the events of hydrological natural disasters.

As set out in the Brazilian Disaster Codification (BRASIL, 2020), flooding is defined as: "Submergence of areas outside the normal limits of a watercourse in areas that are not normally submerged. The overflow occurs gradually, usually caused by prolonged rains [...]" (BRASIL, 2007a). Flooding, on the other hand, is characterized by the normal and temporary increase in the water level in the drainage channel, due to the increase in flow, however, without generating overflow (BRASIL, 2007a). Therefore, when referring to urban floods, this work takes into account the definition set out in the Brazilian Codification of Disasters, as mentioned above.

In this sense, floods, according to Sausen and Narvaes (2015) and Amaral and Ribeiro (2015), are the most prevalent natural disasters in the world, and are probably the most frequently occurring. For Tucci (2007), the urbanization process and natural flooding in riverside areas, caused due to the lack of planning for the occupation of the population on the banks of rivers, are two examples of processes that result in urban flooding. In addition to the observations made by Tucci (2007), other factors addressed by Sausen and Narvaes (2015) that contribute to the understanding of floods are the duration and intensity of precipitation, deforestation, obstruction of channels and inadequate practices of land use and occupation.

## 2. METHODOLOGY

Regarding its objective, the methodology adopted in the present work can be classified as exploratory, considering that it sought to provide greater familiarity with the problem addressed, in order to make it more explicit, constitute hypotheses and improve ideas or discover intuitions (SLLTIZ; WRIGHTSMAN; COOK, 1967; SEVERINO, 2017).

Regarding the technical procedures used (Gil, 2009), the research is based on two main processes: the first, based on a bibliographic survey along the lines of a Systematic Literature Review (RSL) (XIAO; WATSON, 2017), so that bibliometric analyzes could be carried out in order to identify trends, stakeholders and their correlations (SPINAK, 1996). In a second moment, other works were included that helped in the process of discussing the results arising from the initial search.

Thus, following the methodology adopted by Zhou et al. (2018), the use of the concept "Nature Based Solutions" was compiled, synthesized and analyzed, considering, as a temporal cut, the scientific production between the years 2015 and 2020, corresponding to a period of 06 years. For this purpose, the Scopus database was adopted, as this database is multidisciplinary, encompassing areas such as technology and social sciences, in addition to having more than 22,000 peer-reviewed journal titles and 5,000 publishers, providing content diversity (ELSEVIER, 2016).

The process carried out to that database took place in December 2020, using the following proposed combinations of strings: “Nature Based Solutions” AND “flood”; “Nature Based Solutions” AND “inundation”; “Nature Based Solutions” AND “flooding”. With such a correlation between the variables, it was possible to find works that observed the problem of flooding in urban areas through the prism of solutions based on nature, analyzing them as the main measures to deal with the issue. Furthermore, it is worth mentioning that the search was restricted to the fields “title”, “keywords” and “abstract”, and returned a total of 94 scientific articles.

In this sense, Chart 1 summarizes the eligibility criteria used to form the documental corpus that served as the basis for the literature review and for the bibliometric analyses.

Chart 1 - Eligibility Criteria

| Criterion | Criteria Description | Number of Articles |
|---|---|---|
| **Eligibility** | **A.** Articles with a maximum of 06 years (2015-2020);<br>**B.** Articles found in the SCOPUS database;<br>***C.*** Search for strings in the fields “title”, “abstract” and “keywords”;<br>***D.*** Strings: “Nature Based Solutions” AND “flood”; “Nature Based Solutions” AND “innundation”; “Nature Based Solutions” AND “flooding”. | 94 |

Source: prepared by the authors (2022)

Thus, all 94 selected articles were read in full, so that bibliometric analyzes and discussion of results could be carried out. With regard to the other works included, all were selected taking into account the same time frame used in the main search (2015-2020) and, for the most part, refer to open documents from the European Commission, IUCN (International Union for Conservation of Nature), Unesco and the United Nations, given that they are entities linked to the theme, and that served as a basis for explaining the subject.

## 3. DISCUSSION OF THE RESULTS

According to the literature identified in the initial search of the Scopus database and the number of articles returned using the established criteria, it was possible to infer that the study of solutions based on nature and urban floods shows a growth trend, as illustrated in the Figure 1, mainly due to the 120% growth when comparing the years 2019 and 2020 to the other selected periods.

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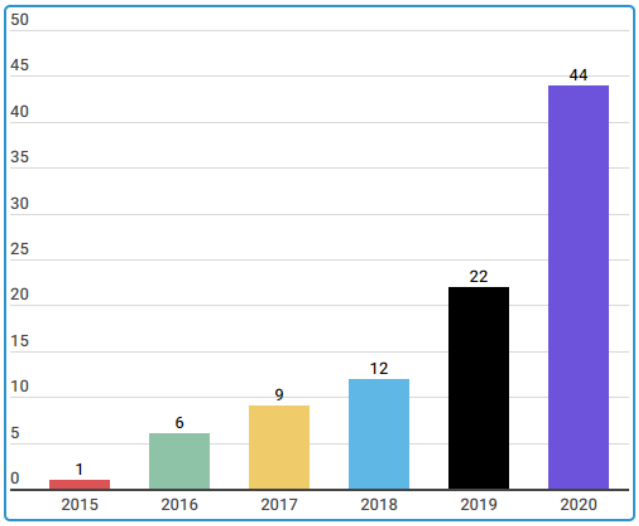
Figure 1 - Articles published by year




Source: prepared by the authors (2022)

From the analysis of Figure 1, it is possible to state that there was a significant increase in relation to the number of scientific productions, taking into account the period between 2015 and 2020. Another important factor concerns the language present in these works, considering that, based on the evaluation of the 94 selected articles, it was found that the English language was the most used in the publications, being present in 98% of them.

Therefore, according to the analyzed articles, when observing the information about the countries of affiliation of the authors, 30 different countries were identified, and 3 of these articles were classified as undefined. When consulting them, it was identified that, in 1 of the 3 articles, the authors had an affiliation with Brazil, but the work was registered in the Scopus base without illustrating the name of the country, only with the name of the city. Therefore, the analysis was adjusted, leaving a total of 2 articles in which it was not possible to identify the nature of the authors.

As illustrated in Table 1, it is noted that the largest number of publications was given by authors belonging to the European continent (74.46%), followed by countries in America (10.63%), Asia (8.50%), Oceania (4.25%) and Africa (2.12%).

Table 1- Number of authors per continent

| Continent | Grand total | Grand total |
|---|---|---|
| Europe | 70 | 74,46% |
| America | 10 | 10,63% |
| Asia | 8 | 8,50% |
| Oceania | 4 | 4,25% |
| Africa | 2 | 2,12% |
| Grand Total | 94 | 100% |

Source: prepared by the authors (2022)

When considering Table 1, it is possible to identify that the numbers presented converge with the investments made by European and Chinese cities in solutions based on nature and, thus, the data corroborate those presented by Herzog and Rozado (2019), Sousa (2019) and Chan et al. (2018), between others.

In 45.7% of the articles, the establishment of several international partnerships was evidenced, reflected by the diversity of countries and authors in the same production. Thus, 2.2% of the evaluated articles involved 5 countries, 1.1% (4 countries), 6.5% (3) and 35.9% (2). With regard to productions prepared by only one author and, consequently, represented by only 1 country, 50 articles (54.3%) were identified, disregarding the 2 articles classified as undefined.

Therefore, the countries with the most linked articles were the United Kingdom (14), the Netherlands (12) and Italy (9). These are the top 3 in the list of 30 countries observed by scientific productions, with Brazil in 15th place, with a total number of 2 published scientific articles. This position shows, especially if observed in Table 2, the low Brazilian production in academic works that observe solutions based on nature and their correlation with issues related to urban flooding. Furthermore, in 1 of the works produced in Brazil there was collaboration with other authors from the United Kingdom.

Table 2 - Number of authors per country

| Countries | Quantity of Articles | Countries | Quantity of Articles |
|---|---|---|---|
| UK | 14 | Slovenia | 1 |
| Netherlands | 12 | Canada | 1 |
| Italy | 9 | India | 1 |
| USA | 8 | Norway | 1 |
| Germany | 6 | Senegal | 1 |
| Sweden | 5 | Austria | 1 |
| China | 5 | Cyprus | 1 |
| France | 4 | Belgium | 1 |
| Greece | 3 | Russia | 1 |
| Spain | 3 | French Polynesian | 1 |
| Australia | 2 | Serbia | 1 |
| Ireland | 2 | Poland | 1 |
| South Africa | 2 | Denmark | 1 |
| thailand | 2 | Portugal | 1 |
| Brazil | 2 | New Zealand | 1 |
| Subtotal | **79** | **Subtotal** | **15** |
| Total | **94** | | |

Source: prepared by the authors (2022)

### 3.1 Cases of Nature-Based Solutions applied to urban flood control.

As shown in Chart 2, it is noted that the works arising from the research of the SCOPUS database (2015-2020), as well as the inclusion of other external productions (2015-2020) and which

also addressed the theme, demonstrated the wide variety of actions that can be adopted in relation to urban flooding and Nature-Based Solutions, from small to large scales.

Chart 2 - Summary of solutions with the respective countries that implemented them

| Solution | Local | Author |
|---|---|---|
| Green roofs, permeable floors, areas for rapid drainage and infiltration, sustainable water drainage systems | Germany | Herzog and Rozado (2019) |
| Templehof city park | Berlin | Herzog and Rozado (2019), Davies et al. (2017) |
| Green bigbelt | China | Liu and Jensen (2017) |
| Sponge city | China | Chan et al. (2018) |
| Urban parks | China and Cyprus | Médici and Macedo (2020), Davies et al. (2017), Giannakis et al. (2016) |
| Rain gardens, dry and wet basins, ditches next to roads, grassy bio-culverts, green roofs, urban parks, green corridors, changing vegetation to improve water absorption, replacing asphalt paving in parks with green zones | Denmark | Herzog and Rozado (2019), Davies et al. (2017) |
| Parque Larragorr, reuse of rainwater for irrigation of facades and green roofs, internal green belts, green roof and facades | Spain | Herzog and Rozado (2019) |
| Eco-efficient neighborhood | Finland | Herzog and Rozado (2019) |
| Revegetation of soil and slopes, planting trees, hedges and grass strips | Greece | Lilli et al. (2020) |
| Bentheplein Square | Netherlands | Médici and Macedo (2020) |
| Restoration of the river plains, with diversion of the course of the river, or with the formation of areas for natural storage | Netherlands | Lombardo (2018) |
| Vertical forest, Gorla water park, corridors and green streets | Italy and Portugal | Herzog and Rozado (2019), Reynaud et al., 2017) |
| Urban park (Parco Urbano Gavoglio), green spaces, restoring waterways, facades, and green roofs | Netherlands | Herzog and Rozado (2019) |
| Chulalongkorn Park | Thailand | Médici and Macedo (2020) |
| Green roofs and walls, parks, restoration of rivers, urban forests | Australia | Fastenrath, Bush and Coenen (2020) |
| Renaturalization of water bodies and revegetation in urban areas, restoration of riverside and wetland vegetation | Slovenia and Germany | Santoro et al. (2019) and Albert et al., (2019) |

Source: prepared by the authors (2022)

According to Chart 2, the mention of these terms in the analyzed literature can be observed,

at first, in the light of the work of Herzog and Rozado (2019) which highlighted the creation of an urban park (Parco Urbano Gavoglio) in a former barracks located in the Netherlands, with the aim of improving water management, green spaces and climate resilience. Among other actions, infiltration basins, groups of trees, xerophytic pastures with flowers and gabions, with stone and vegetation were implemented.

From another point of view, as pointed out by Fastenrath, Bush and Coenen (2020), solutions such as green roofs and walls, parks, restoration of rivers, urban forests, are in the way of the elaboration of public policies and urban planning and that observe aspe cts related to nature as a measure to overcome urban problems, mainly related to floods.

Second Médici and Macedo (2020), in Thailand, the Chulalongkorn park was built, located in the city of Bangkok. In a similar way, the construction of the park of Qunli, in China, can be observed. In that regard, Herzog and Rozado (2019) mention old areas in Berlin that could be transformed into parks, such as Templehof, the old airport that was transformed into an urban park. The 20 greenways project represents more than 500 km of selected areas separated from road traffic, which connect residential zones to recreation areas.

In the city of Beijing, in the Local Flooding Control Plan (LFCP) prepared by Beijing Municipal Planning and Design Institute (BMPDI), Liu and Jensen (2017) mentioned alternatives such as greenbelt for flood control and to increase infiltration, rainwater harvesting, combined with a conventional solution to improve discharge capacity, pipelines and pumping stations.

Copenhagen managed to implement practices to manage rainwater and reduce the risk of flooding, based on the amendment of national legislation to obtain resources to finance natural solutions as a measure adopted for water management, among them: rain gardens, dry basins and wet areas, ditches close to roads, transport and infiltration of water into the ground, and grassy bio-culverts. Other actions such as green roofs, urban parks, green corridors, changing vegetation to improve water absorption, replacing asphalt paving in parks with green areas, complemented the practices (HERZOG; ROZADO, 2019).

In Italy, close to the Porta Nova district, 900 trees and more than 20,000 plants were placed on the façade of a pair of towers, improving the air and biodiversity. The Gorla Water Park has the characteristic of presenting a multipurpose green infrastructure, that is, it has an area for leisure/recreation, an area for the elimination of pollutants and another for flood prevention. Green corridors and streets associated with natural water retention measures were implemented in Lisbon, in total there were more than 30,000 trees 78 planted in the streets between 2013 and 2017 (HERZOG; ROZADO, 2019; REYNAUD et al., 2017).

In Spain, actions for transition towards a sustainable environment have been adopted in the city of Vitoria-Gasteiz, especially in 2012, showing results such as green zones, a third of the municipal area being covered with forest, trips that rely on two tram lines , bicycle and pedestrian paths. Among the latest projects implemented is Parque Larragorr, which reuses rainwater for irrigation of facades and green roofs, internal green belts and recovery of buildings, including green roofs and facades (HERZOG; ROZADO, 2019).

Likewise, the challenge of improving the management of rainwater is present in the goals of the Netherlands, with this Eindhoven sought to implement in areas of the city center, green spaces, facades and green roofs, as well as to restore existing water courses. (HERZOG; ROZADO, 2019).

Médici and Macedo (2020) elucidated that the Benthemplein Square was built in Rotterdam, a type of swimming pool composed of basins that fill up after a period of storage, and that favor the infiltration of water and the replenishment of groundwater reservoirs.

According to Lombardo (2018), In 2009, the program was created "Room for the River", a Dutch initiative, budgeted at €2.5 billion. The objective of this program was to restore river plains, revegetate stretches along rivers and correct river courses, when necessary. The restoration of the landscape along the rivers, functioning as "natural water sponges", in which the actions included increasing the depth of the rivers, relocating dikes, reducing spurs (a structure built in rivers that hinders the flow of water) and removing of polders.

In this way, considered as a green city, Freiburg is a city located in Germany, and which, for the management of its rainwater, adopted green roofs, permeable floors, areas that allow rapid drainage and infiltration, water drainage systems that operate sustainably and private rainwater collection systems (HERZOG; ROZADO, 2019). Likewise, as explained by Herzog and Rozado (2019), Finland intended to create, by 2021, the project of an eco-efficient neighborhood in Vuores, focused on the management of rainwater.

In the cities of Taizhou and Jinhua, parks were placed to replace the concrete walls that channeled rivers (MÉDICI; MACEDO, 2020). Similar practices are being adopted around the world in cities such as Berlin, Copenhagen and Bangkok. Corroborating with the actions pointed out in the study of Davies et al. (2017), in which mention is made of planting trees to combat flooding, as they are much more efficient, given their absorption and transpiration processes.

The concept of sponge city, presented by Chan et al. (2018), addresses the possibility of using engineering infrastructure to control and store rainwater in extreme rainfall episodes. The aforementioned authors also mention that China has invested in new ideas in this regard.

In the watershed of the Koiliaris River, located in Western Crete, Greece, solutions classified as systems for erosion control, revegetation of soil and slopes, planting of trees, hedges and grass strips to intercept surface water runoff were implemented. and to take advantage of the vegetation already located along the basin (LILLI et al., 2020).

Santoro et al (2019) identified in Slovenia actions for "renaturalization" of urban water bodies, reduction of canalization works, revegetation of urban areas, restoration of riparian vegetation, construction of dry retention areas over plains areas, creation of water bodies for temporary water storage and wetland restoration. Also in Germany, Albert et al (2019) mentioned actions such as the restoration of swamps, the revitalization of floodplains, the protection of flora, fauna and riparian vegetation that support the fight against floods, in addition to providing social and environmental benefits.

## 4. CONCLUSION

The identification of cases in the application of NbS's to combat urban flooding, which were analyzed based on the literature, showed the diversity of measures that can be applied from green infrastructure projects.

Based on the results, it is possible to point out that the measures vary in terms of the spatial scale of implementation. Thus, in some cases, there is a need to dispose of large areas, such as urban parks. On the other hand, in certain situations, the solutions can be applied in smaller spaces, such as rain gardens. Another point highlighted by this study is the identification of benefits arising from the use of green solutions for society and the environment.

However, when observing the results of the bibliometric analyses, it was identified that most of the Nature-Based Solutions implemented in urban areas are located in European cities and analyzed by scientific productions coming from the same region. Based on these findings, it is possible

to conclude that developing countries, which are the most affected by structural problems arising from rapid, and improperly planned, urbanization, have demonstrated a lower degree of implementation of solutions based on nature compared to cities from developed countries. In addition, the low number of scientific productions produced by these countries was also identified, a fact that corroborates the aforementioned lack of initiative in the use of green infrastructure for flood management in such urban areas.

In general, the results presented make it possible to contribute to future studies that are interested in alternatives and solutions to urban flooding problems, which will promote greater sustainability, combating a problem that especially afflicts the most vulnerable population and contributing to the expansion of green areas that play a fundamental role in improving the quality of the environment and life in cities.

For future studies, it is suggested that the authors expand the scope of the propositions intrinsic to this work, especially in three main points: 1) By strengthening the Systematic Literature Review protocol, taking into account the insertion of inclusion and exclusion criteria , qualitative ranking of included studies, among other actions characteristic of RSL; 2) By extending the time frame of analysis beyond 2020, given that, due to the pandemic of the new coronavirus and the geopolitical changes that occurred in the International System, it is important to observe the use of Nature-Based Solutions from this new situation ; and 3) When taking into account the interface between NbS's and Climate Change, taking into account that the use of green solutions in this area can have positive impacts on issues related to climate change, such as, for example, in the fight against urban flooding, air pollution, increasing the well-being of cities, trapping CO2, reducing the effects of heat islands and global warming.

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