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URBAN VULNERABILITY AND THE TOOLS REQUIRED FOR HYDRO-METEOROLOGICAL RISK DISASTER MANAGEMENT

Fernanda Santa Barbara Vissirini[1] Paula Thaise Bermudez dos Reis[2] Fabrício Pimenta da Cunha[3] Fabio Ribeiro Gondim[4] Alfredo Akira Ohnuma Jr.[5] Rosa Maria Formiga Johnson[6]

Abstract

Introduction: The advent of climate change has raised new challenges for cities and made it necessary to adopt strategic policies for mitigating its impact and allowing them to adapt more effectively to extreme events.
Objectives: To establish the concept of urban vulnerability and examine the measures adopted by towns and cities for the reduction of hydro-meteorological risks and their adaptation to climate change.
Methodology: A systematic review of the literature was carried out which can be found in the *Science Direct* e *Scielo* database for the period 2011-2021 and this makes it possible to trace the evolutionary path of the concept of "urban vulnerability".
Uniqueness/Significance: Urban vulnerability has become a key factor in the current assessment of climate change and studies in this area must be strengthened. As well as this, there is a need to determine the links between attempts to adapt to climate change and the measures available to find solutions for disaster risk reduction (DRR).
Results: An evolutionary trend for the term "urban vulnerability" was noted, and this has been applied in several articles as a key variable in establishing an equation for disaster risk reduction. In 2020 there was evidence of progress that had been made in studies related to urban vulnerability regarding adaptations to climate change, new ideas about risk assessment and methods that could be employed at the local level (for towns and cities).
Social contributions on the part of the management: At present, when faced with climate change, the DRR has become an emergency service which is aimed at protecting human lives and material goods. This is because, while expanding, many of our towns and cities have incorporated areas that are vulnerable to extreme events; this has led to an understanding of how essential urban planning is to mitigate the possible risks of hydro-meteorological disasters.

Keywords: Urban Vulnerability; Risk Management; Disasters; Climate Change.

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Special Edition Guest Editors - Mudanças climáticas e planejamento urbano: cenários e desafios

Profa. Dra. Tatiana Tucunduva Philippi Cortese
Prof. Dr. Juarês José Aumond
Profa. Dra. Débora Sotto

[1] State University of Rio de Janeiro, Faculty of Engineering, Department of Sanitary and Environmental Engineering – Doctorate in Environmental Engineering) / Rio de Janeiro (RJ) - Brazil - PhD student and Master in Environmental Engineering at the State University of Rio de Janeiro / Area in Natural Resources and Public Policies for Sustainability.- fernandavissirini@gmail.com - Main contact for correspondence
[2] State University of Rio de Janeiro / Graduate Program in Environment / São João de Meriti (RJ) - Brazil - PhD student in Environmental at the State University of Rio de Janeiro / Master Environmental Engineering at the State University of Rio de Janeiro - paulatbdr@hotmail.com
[3] State University of Rio de Janeiro, Faculty of Engineering, Department of Sanitary and Environmental Engineering – Doctorate in Environmental Engineering / Petrópolis (RJ) - Brazil - PhD student and Master in Environmental Engineering at the State University of Rio de Janeiro / Area in Natural Resources and Public Policies for Sustainability - jfabricio.pimenta.cunha@gmail.com
[4] Institute of Environment and Water Resources of Bahia – INEMA / State University of Rio de Janeiro, Faculty of Engineering, Department of Sanitary and Environmental Engineering – Doctorate in Environmental Engineering / Rio de Janeiro (RJ) - Brazil - Civil Servant of INEMA/BA / PhD student in Environmental Engineering – UERJ / Master in Environmental and Forestry Sciences – UFRRJ - gondimfr@gmail.com
[5] State University of Rio de Janeiro, Faculty of Engineering, Department of Sanitary and Environmental Engineering / Rio de Janeiro (RJ) – Brazil. Civil Engineer graduated from UFSCar - Federal University of São Carlos (2000), Master's (2005) and Doctorate in Environmental Engineering Sciences from USP / EESC - University of São Paulo (2008), School of Engineering of São Carlos, Department of Hydraulics and Sanitation. He is an Associate Professor at the State University of Rio de Janeiro (UERJ), in the Department of Sanitary and Environmental Engineering. He teaches courses in Civil Engineering and Environmental and Sanitary Engineering, in the Postgraduate Professional Master's Program in Environmental Engineering (PEAMB) and Doctorate in Environmental Engineering (DEAMB), at UERJ - akira@eng.uerj.br
[6] State University of Rio de Janeiro, Faculty of Engineering, Department of Sanitary and Environmental Engineering / Rio de Janeiro (RJ)) – Brazil. PhD and Master in Environmental Sciences and Techniques from the Université de Paris-Est Créteil (France) and associate professor at the State University of Rio de Janeiro (UERJ) / Department of Sanitary and Environmental Engineering (DESMA) since 2006. She was Director of Water and Land Management at INEA-RJ (State Institute for the Environment), between 2009 and 2015 - rosa.formiga@eng.gov.br

VULNERABILIDADE URBANA E FERRAMENTAS APLICADAS NA GESTÃO DE RISCO DE DESASTRES HIDROMETEOROLÓGICOS

Resumo

Introdução: O advento das mudanças climáticas apresenta novos desafios para as cidades, tornando necessário o desenvolvimento de políticas estratégicas para reduzir os impactos e melhorar a adaptação aos eventos extremos.
Objetivo: Apresentar o conceito de vulnerabilidade urbana e as medidas adotadas nas cidades para a redução dos riscos hidrometeorológicos e adaptação às mudanças climáticas.
Metodologia: Realizou-se uma revisão sistemática da literatura presente nas bases de dados *Science Direct* e *Scielo* entre o período de 2011 a 2021, sendo possível apresentar a evolução do conceito de "vulnerabilidade urbana".
Originalidade/Relevância: A vulnerabilidade urbana passa a ser tópico-chave na avaliação das mudanças climáticas atualmente e estudos sobre o tema devem ser fortalecidos. Além da necessidade da identificação das conexões entre a adaptação às mudanças climáticas e os esforços para promover soluções para a redução de risco de desastres (RRD).
Resultados: Notou-se uma evolução do termo "vulnerabilidade urbana", aplicado nos diversos artigos como variável importante na equação para a redução do risco de desastres. Em 2020 ficou evidenciado o avanço dos estudos relacionando a vulnerabilidade urbana com adaptações ao clima, novas propostas para a avaliação e métodos utilizados ao nível local (cidades).
Contribuições sociais / para a gestão: A RRD frente às mudanças climáticas se torna emergencial na atualidade, a fim de se preservar vidas humanas e bens materiais, já que muitas das nossas cidades se expandiram para áreas suscetíveis aos eventos extremos, sendo a compreensão dos possíveis riscos de desastres hidrometeorológicos crucial para o planejamento urbano.

Palavras-chave: Vulnerabilidade Urbana. Gestão de Risco. Desastres. Mudanças Climáticas.

VULNERABILIDAD URBANA Y HERRAMIENTAS APLICADAS EN LA GESTIÓN DEL RIESGO DE DESASTRES HIDROMETEOLÓGICOS

Resumen

Introducción: El advenimiento del cambio climático presenta nuevos desafíos para las ciudades, lo que hace necesario desarrollar políticas estratégicas para reducir impactos y mejorar la adaptación a eventos extremos.
Objetivo: Presentar el concepto de vulnerabilidad urbana y las medidas adoptadas en las ciudades para reducir los riesgos hidrometeorológicos y adaptarse al cambio climático.
Metodología: Se realizó una revisión sistemática de la literatura en las bases de datos Science Direct y Scielo entre 2011 y 2021, que permitió presentar la evolución del concepto de "vulnerabilidad urbana".
Originalidad/Relevancia: La vulnerabilidad urbana es ahora un tema clave en la evaluación del cambio climático y se deben fortalecer los estudios sobre el tema. Además de la necesidad de identificar las conexiones entre la adaptación al cambio climático y los esfuerzos para promover soluciones para la reducción de desastres.
Resultados: Hubo una evolución del término "vulnerabilidad urbana", aplicado en varios artículos como una variable importante en la ecuación para la reducción del riesgo de desastres. En 2020 se evidenciaron los avances de los estudios que relacionan la vulnerabilidad urbana a las adaptaciones climáticas, nuevas propuestas de evaluación y métodos utilizados a nivel local (ciudades).
Aportes sociales / de gestión: La reducción de riesgos ante el cambio climático se convierte en una emergencia hoy en día, para preservar vidas humanas y bienes materiales, ya que

muchas de nuestras ciudades se han expandido hacia áreas susceptibles a eventos extremos, y la comprensión de los posibles riesgos de eventos hidrometeorológicos. desastres cruciales para la planificación urbana.

Palabras-clave: Vulnerabilidad Urbana. Gestión de riesgos. Desastres. Cambios climáticos.

Introduction

The emergency caused by climate change has posed serious new challenges to towns and cities which require the adoption of strategic policies to mitigate the impacts of climate and adapt more effectively to changed circumstances (Shandas et al., 2020; Hobbie & Grimm, 2020). Its implications are now recognised as having led to one of the most urgent situations facing mankind since it affects the lives of billions of people around the world, despite all their efforts to mitigate the risks (Adapted from IPCC, 2022). Only in 2020, more than 50 million people were affected by incidents related to water and climate, while they were struggling against the effects of COVID-19 (UNDRR, 2021).

Impact of climate change in cities

Urban areas are particularly vulnerable to climate change (Leal Filho et al., 2019). In the first place, this is because more than 50% of the world population live in spaces at risk and it is expected that by 2050 this percentage could increase to 75% (UNDRR, 2019). Secondly, since urban densification leads to an increase in watertight areas, this adds to vulnerability and causes floods during periods of heavy rainfall (Rosenberger et al., 2021).

As a result of these factors, there has been an increase, by society, in demands for improvements in infrastructure and local government services (Li et al., 2019), which affects the capacity of towns and cities to adapt to and mitigate climate change (Corsi et al., 2022).

With regard to the climate, there have been signs of an increase in the intensity and frequency of severe weather events - heavy rainfall, intense heat and droughts (EEA, 2012), which has resulted in floods, stress caused by the heat of very high temperatures and the damaging effects of drought. Urbanization can in turn be linked to risk factors such as population concentration, high demographic density and disorderly occupation (Ramos, 2018; Pereira et al, 2020). Population growth, the increase in the extent of waterproofed surfaces and the high concentration of a wide range of productive activities, are among the main factors that cause urban vulnerability since they aggravate the dire effects of climate change in various urban systems (EEA, 2016, 2017).

From the standpoint of climate risk management, it is believed that the links and interactions between urban sub-systems and extreme climate events can trigger disasters, and this can affect the vulnerability of cities by damaging and affecting their capacity to resist and recover from events of this kind (Cardona, 2005, Cutter et al., 2010, IPCC, 2012).

As a means of understanding these tendencies, it is essential to avoid potential damage and reduce the impact of the cities themselves on the global environment, since these complex relationships represent huge challenges for planning how to make adjustments to climate change at the level of the city itself (IPCC, 2014).

Objectives

As several studies have shown (Greiving et al., 2011; Swart et al., 2012; Timmerman et al., 2017, Reis et al., 2020; Alves, 2021), when assessing climate change, urban vulnerability has become a key topic and an area that needs to be enhanced so that the interactions of the human systems with the environment and its mutual influences can be fully explored. The aim of this study is to set out the way the evolving concept of urban vulnerability can be understood and to outline what measures are being adopted in big cities to mitigate hydro-meteorological risks. This article seeks to find answers to the following questions:

- What is the best definition for urban vulnerability?
- What are the established links and current agreements for DRR in towns and cities?
- What are the changing scenarios and measures currently being adopted in big cities for mitigating the risk of hydro-meteorological disasters?

Methodology

According to Tranfield et al., (2003), a systematic literature review is a key tool in any academic inquiry since it is employed to handle and analyze the diversity of a particular area of knowledge, as well as to provide evidence that is reliable, authoritative and of a high standard.

Decision-makers are increasingly searching for knowledge that is based on evidence that can support solutions to political and social problems, as well as methods for discovering gaps that need to be filled or new issues that might arise. In these situations, systematic reviews can be very effective and supply more valuable information than single case studies (Petticrew; Roberts, 2006; Santos & Cortese, 2022).

The methodology was based on a systematic review of the literature and involved the most appropriate terms for urban vulnerability and the principal measures adopted for hydrometeorological DRR, in light of the extent of the impact of climate change on cities.

The *Science Direct* e *Scielo* database was employed, together with the combination of the term ¨*Urban vulnerability*¨ and the expressions ¨*hydro-meteorological*; *risk disaster*; *sustainable cities*; *climate change*; *nature-based solution*; *social participation*; *decision support*

system; and *multicriteria analysis*¨.

With regard to the inclusion and exclusion criteria, the research was confined to the period from 2011 to 2021 and articles written in English and Portuguese. Articles were selected that included the term "*urban vulnerability*" in the title and/or keywords, or else displayed international agreements and/or included summaries that were thought to be relevant for the review. Articles that focused on the area of health were not taken into account.

Table 1 shows the articles that were selected at this stage:

Table 1

Articles selected for the analysis

Citation	Approach
Krellenberg et al., (2014)	Local adaptation efforts to confront two hazards related to alterations in climate: flooding and heat, combining concepts of socio-environmental fragmentation and vulnerability
Voskamp et al., (2015).	Tool for selecting adaptation measures and seeking collaborative greenish-blue measures
Iwama et al., (2016)	Concepts of risk, vulnerability and climate change
Schmidt & Barbosa (2016)	Application of the *Analytical Hierarchical Ponderation* (AHP) technique
Tapia et al., (2017)	Assessment of urban vulnerability for heatwaves, drought and flooding in 517 European towns and cities
Kita (2017)	Assessment of the vulnerability of cities to floods
Denjean et al., (2017),	Systematizing the means of using nature-based solutions (NBS)
Mitra et al., (2018)	B*ayesian-network models* and multi-criteria analysis and GIS for decision support systems (DSS)
Sala & Yepes (2018)	Review about assessing urban vulnerability
Dhyani et al., (2018)	Review based on eco-systems
Belle et al., (2018)	NBS for mitigating the risks of disaster from drought, fires and floods
Mileu & Queirós, (2018)	Mapping risks for decision-making
Cerreta et al., (2018)	The use of GIS [geographic information systems] to assist the setting up of the municipal DSS
Apreda et al., (2019)	Climate vulnerability and measuring the impact of heatwaves and flooding by means of indicators
Leal Filho et al., (2019)	Analysis of how cities are attempting to adapt to climate change

Citation	Approach
Thaler et al., (2019)	Social transformation, the management of natural hazards and the mitigation of risks
Vasconcelos et al., (2019)	Systematic review of the literature
Weiss et al., (2019)	Environmental vulnerability, making use of GIS tools and multi-criteria analysis
Salimi & Al-Ghamdi (2020).	The main impacts of climate change on urban areas and adaptation strategies for climate change
Shah et al., (2020)	Review of hydro-meteorological risks, vulnerability and the structures and indicators of risk assessment within the context of NBS
Kumar et al., (2020)	Operating and implementing NBS
Kuhl et al., (2020)	Adaptation to coastal areas in developing countries
Kumar et al., (2021)	Application of NBS to natural risks
Malta & Marques (2021)	Impact of socio-environmental vulnerability linked to the risk of environmental degradation

Source: Prepared by the author (2022).

In the second stage a word cloud was created (Figure 1), through electronic pages (www.wordclouds.com), together with the most commonly cited keywords in the articles displayed in Table 1. The evidence provided by the principal words mentioned allow the research to be refined and the most appropriate works in the review to be selected.

The research sought to identify the studies which included urban vulnerability as the main feature. Following this, an assessment was carried out to determine the main measures adopted for mitigating risks of disaster in their different stages, as well as the measures taken for immediate recovery and during the post-disaster response phase. In seeking to find the most effective sustainable solutions, the NBS provided evidence for the research. It should be pointed out that international agreements and publications were resorted to for the purposes of contextualization and the articles cited in the selected works were drawn on for the systematic review.

Figure 1

The cloud of the keywords that was most widely cited in the selected articles

Source: Prepared by the author (2022).

Connection of the international agreements with disaster risk mitigation

Urban vulnerability was assessed by means of the Hyogo Accord (HA) and the Sendai Framework for Disaster Risk Reduction (SFDRR), of the 2030 Agenda through Sustainable Development Goals (MDGs), of the Urban Agenda (UA) and the Paris Accord for Climate Change. This introduced knowledge of disaster risk management and the connected areas of climate change and sustainability within the urban environment (UNDRR, 2021).

The HA was based on the premise that greater resilience by nations and communities faced with hazards, leads them to give priority to DRR, with a strengthened institutional base, as well as making use of knowledge, innovation and education to create a culture of security and resilience at every level (adapted from Marchezini, 2020).

The same author also shows that with AS there is a considerable change from HA, and that this takes place when there is an emphasis on Disaster Risk Management, which not only includes the DRR but also prevents new risks that have not yet arisen. The priorities of AS are as follows: understanding disaster risks, strengthening the governance required for the management of disaster risks; investing in the reduction of disaster risks to achieve resilience; and improving planning strategies for potential disasters so that there can be an effective response with regard to recovery, rehabilitation, and reconstruction by incorporating the ¨build back better¨ system (Kim & Olshansky, 2015).

With regard to what has been examined in this article, ODS-11 – Sustainable Cities

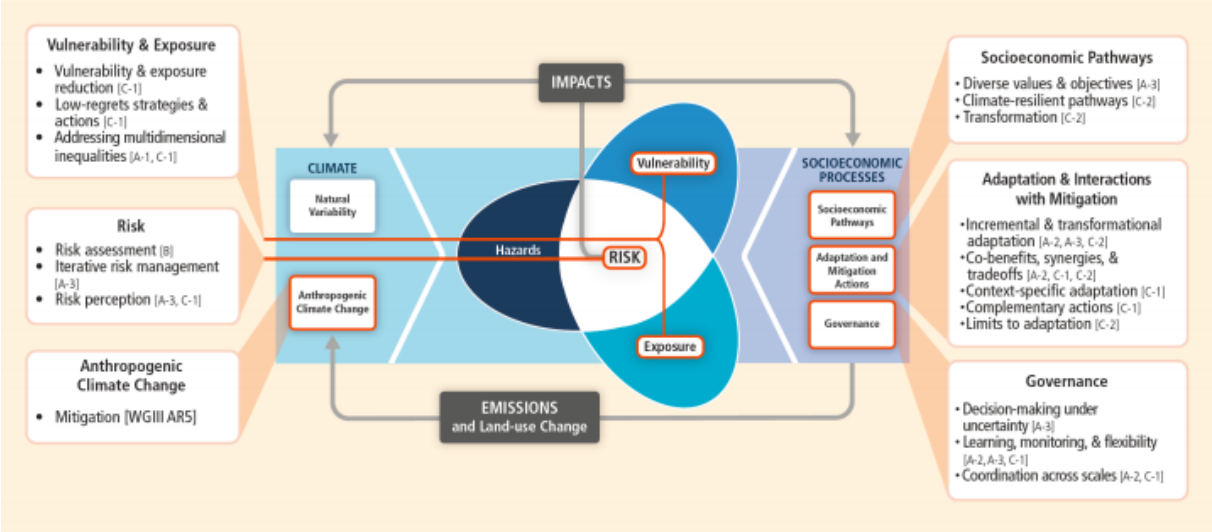
and Communities and ODS-13 – Action against Global Climate Change – these are regarded as most closely aligned to HA and AS, since they involve goals and appropriate action for the mitigation of disaster risks (*United Nations*, 2015).

The AP includes goals for the reduction of greenhouse gas emissions to control the increase of the temperature in the planet by the year 2100 and lay down guidelines for the mitigation of these impacts as well as to enable towns and cities to adapt to climate change (EBC, 2015). Figure 2 connects disaster risk management to climate change, on the basis of the Fifth Assessment Report (AR5), of the International Panel of Climate Change (IPCC), which form the basis of the definitions employed in this review.

In the Third U.N. Conference on Housing and Sustainable Urban Development (2016), there was a definition of the New Urban Agenda which was overseen by the SDG [Sustainable Development Goals]. The AU has a close relationship with the AS and seeks to approve and put into practice disaster risk management policies which can i) reduce vulnerability, ii) increase resilience, iii) extend the capacity to respond to disasters when faced with natural and anthropogenic threats and iv) foster the ability to mitigate and adapt to climate change (SEDEC/MI, 2017). The same author also suggests that the international agreements which provide guidelines for the DRR through its goals and global indicators (and which must be suited to the needs of the local environment), allow the activities to be carried out and monitored.

Figure 2

Strategies for disaster risk management when related to climate change



Source: IPCC (2014).

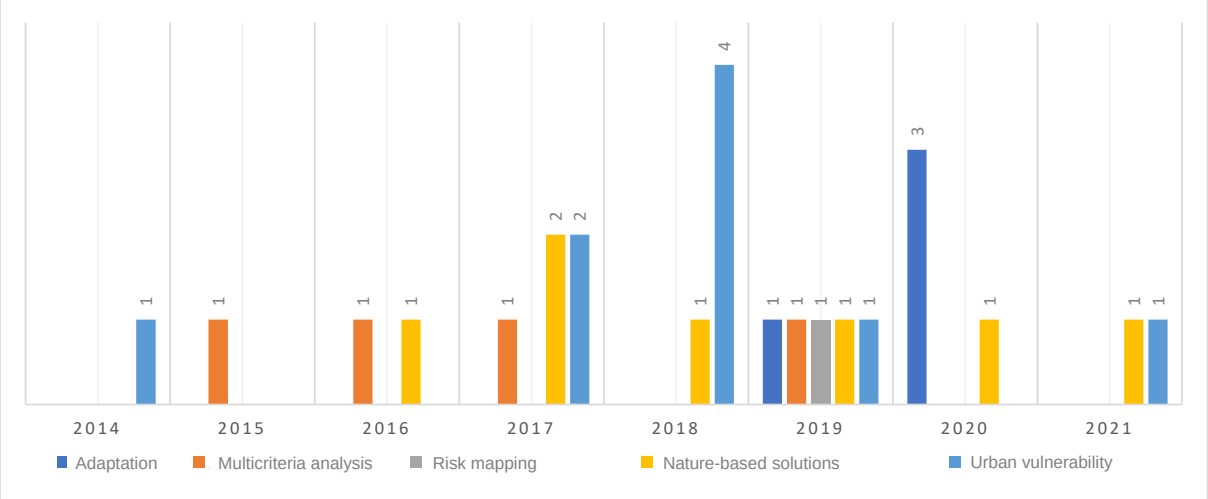
Results

An evolving pattern was noted for the term “urban vulnerability”, when applied to various articles as a key variable in the equation used for the reduction of disaster risks.

The articles selected, (which are shown in Table 1), were published in the years from 2014 to 2021, most of them between 2017 and 2019. The term “nature-based solutions” was found in the articles published after 2016. In 2020, there were signs of an advance in the studies related to urban vulnerability with adjustments to climate, and new ideas for assessing the methods used at the local level (for towns and cities). Figure 3 shows the relationship of the key issues in the works selected with the number of articles corresponding to their year of publication.

Figure 3

Evolving pattern of the central areas of research per year

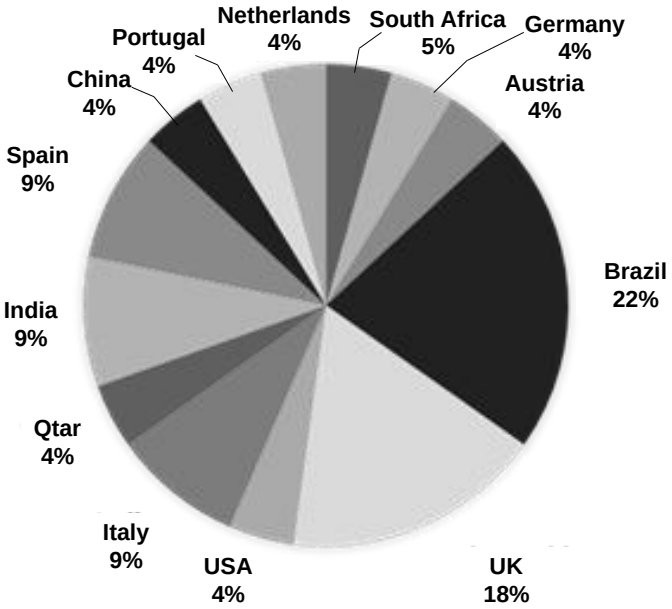


Source: Prepared by the author (2022).

Since the *Scielo* database was employed, there has been a repetition of articles written in Brazil which can explain the nationality of the researchers in the results, as shown in Figure 4.

Figure 4

Origin of the first author in the works selected



Source: Prepared by the author (2022).
[In chart > Holland/South Africa/Germany/Brazil/United Kingdom/US/Italy/Spain

Thus it can be seen that out of the first authors selected, five of them were from Brazil, four from the United Kingdom, two each from Spain, Italy and India, and one article from authors in the US, Holland, Qatar, China, Portugal, Germany and South Africa.

The reviews, together with most of the published articles, were those that addressed the question of the relationship between urban vulnerability, climate change and DRR, and those that were found in the two databases selected for this research, in the defined period. These were "*Science of The Total Environment*" and "*International Journal of Disaster Risk Reduction*", both of which had three articles in this review.

Urban vulnerability and its impacts on the city

Understanding the concept of vulnerability requires a brief analysis of its meaning and the way it has evolved in the established approach to risk reduction. According to AR5, vulnerability is one of the main factors that determine the risks caused by climate, the other two being danger and exposure (IPCC, 2014). As Reckien et al. (2017) have stated, "Climate change is recognized as having been the greatest threat to our society in recent decades" and for this reason, urbanization, sustainable development and climate change are interwoven, and their dimensions coalesce in this global challenge.

In AR5, vulnerability is defined as "a proneness or predisposition to be adversely affected", and this condition encompasses "a wide range of concepts and features, including sensitivity or susceptibility to the effects of damage and a lack of any capacity to adjust to, or

cope with, a difficult situation" (IPCC, 2014, Glossary). The most recent interpretation by the IPCC for vulnerability only recognises two central aspects of vulnerability – sensitivity and the capacity to face a situation (i.e., to be adaptive). Sensitivity can be defined as "the degree to which a system is affected, in either a beneficial or adverse way, by stimuli related to climate". The capacity to confront a situation can be understood as "the capacity of people, organisations and systems to address, handle and overcome adverse circumstances by means of their skills, resources and available opportunities" (IPCC 2012).

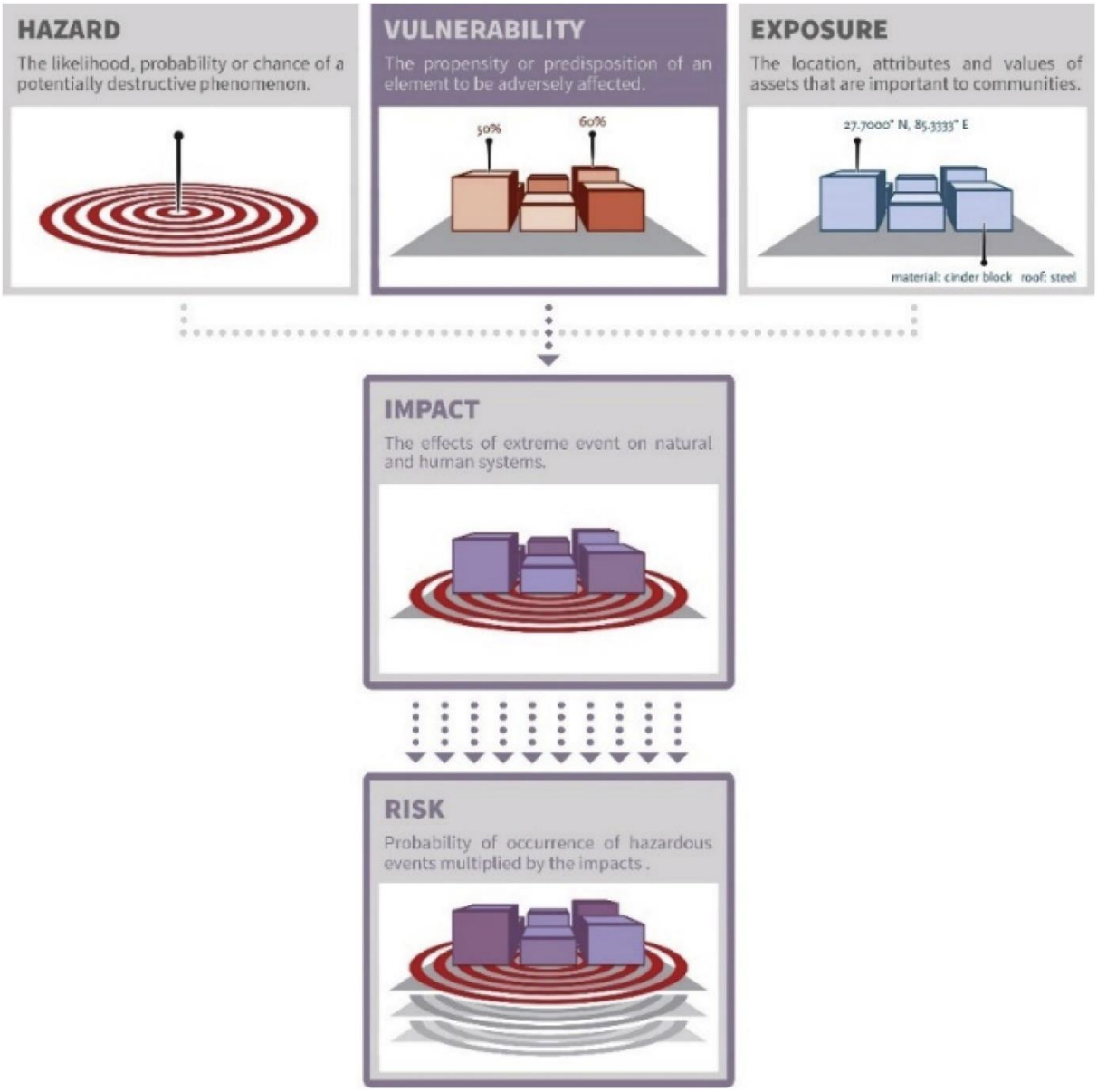
Susceptibility can be understood as the extent to which people, or particular assets, are subject to alterations and changes as a result of exposure to outside pressures. In other words, it is a precondition to suffer damage when there is something hazardous (Kuhlicke et al., 2012), owing to the fragiliy of buildings or other unfavorable conditions such as insufficient infrastructure, loss of physical contact and very limited access to basic services.

Again in AR5, the risk is represented as the "probability of a dangerous incident occurring or trends that are multiplied by repeated events¨. These events or trends "arise from the interaction between danger (triggered by a climate change scenario), vulnerability (susceptibility to suffer from damage) and exposure (people, assets or eco-systems at risk)" (IPCC, 2014).

According to AR5, when dealing with an urban system exposed to a climatic phenomenon, vulnerability represents someone´s proneness or predisposition to be adversely affected and the combination of danger and exposure determines the resulting impact (Figure 5).

Figure 5

The role played by vulnerability in determining the impact



Source: World Bank (2014); Apreda et al., (2019). Adapted.

Interdisciplinary solutions and transdisciplinary approaches are needed (which involve science, politics, professionals and governance) to overcome the obstacles and practices that can be envisaged when confronting the social challenges posed by climate change (Mcphearson et al.,2016), to “form resilience and social preparation” (Biagini et al., 2014), by forming resilient pathways of governance for climate change (Broto & Bulkeley, 2013).

Urban resilience is a general approach to reduce urban vulnerability in the long term and account must be taken of its features during the planning stage of urban projects and not just when disruptions occur (Salimi & Al-Ghamdi, 2020). With regard to urban resilience and climate events, Voskamp et al., (2015) examine two important factors and suggest that the

adjustment measures should be focused on four different capacities of the urban system to reduce its vulnerability (Table 2).

Table 2

Urban Resilience

Features of Resilience	Capacities
Continuous ability to cope with situations that have not been planned for and are disturbing, and to be able to recover from them rapidly	Capacity to confront something - to cope with upsetting situations when they occur, mitigate the damage and economic or social inconvenience
	Capacity to make a recovery - to recover from disturbing situations after they have occurred
Process of adapting – for an improved degree of protection from future events	Limited Capacity - to prevent damage by building up a limited resistance to disturbances
	Adaptive Capacity of the urban system - underlining the fact that the adaptive process must be continuous and long term

Source: Voskamp et al. (2015). Adapted.

The services of the urban eco-system can increase resilience in cities (Gómez-Baggethun & Barton, 2013; Dobbs et al., 2018). In view of this, understanding how the management of the ecosystem services operate, is essential to ensure sustainable urban planning (Luederitz et. al., 2015) and to maintain economic activities (Arku et al., 2017) within the context of climate change.

Sustainable urban drainage provides a valuable service as an eco-system, as well as assisting in mitigating the effects of flooding (Cormier & Pellegrino, 2008; Marques, 2020). Voskamp et al., (2015) recommend combining measures aimed at the drainage system with eco-systemic solutions or in other words, SBN, which not only provides services for managing water resources and the risk of floods but also offers benefits to the environment and human health.

SBN consists of activities designed to protect, restore and handle (in a sustainable way) the natural or modified eco-systems that confront social challenges – such as climate change and the risks of natural hazards. They carry this out in an effective and adaptable manner by being concerned with human welfare and benefiting biodiversity. (UNDRR, 2021). SBN broadens the adaptive capacity of the city in the following ways: i) confronting situations competently, ii) extending the limited capacity of the city; iii) harnessing water to prevent a drought and iv) boosting the city´s capacity for urban recovery by enabling the infiltration of water in soil after a flood (Voskamp et al., 2015).

International context for RRD

As seen earlier, when an attempt is made to obtain a systematic perspective of the cities and DRR, this is proof of the importance of concentrating on vulnerability; this has already been recognised by HA and AS (UN, 2015) because it represents the gateway to measures that can mitigate risk (Schneiderbauer et al., 2017).

The goal of AS lies in the prevention of new risks of disasters and the reduction of those that already exist in a way that can broaden the scope of their attempts to combine social, cultural, educational, environmental, technological, political and legal areas with measures designed to reduce exposure, danger and vulnerability to disasters. Thus it anticipates being able to increase resilience in response to events and is based on the belief that it is the State that is principally responsible for managing the risk of disasters (CRED & UNISDR, 2016).

In the AR5 framework, the vulnerability shown by climate change plays a crucial role in determining the severity of impacts and its assessment involves several features and processes which are often defined and evaluated in different ways in different disciplines (Brooks, 2003; Füssel, 2007; O'brien et al., 2007; Johnson et al., 2013). These viewpoints have influenced the assessment of climate and led to a change in the paradigm of an approach that is geared to the particular science/research area that was common in the 1990s. Moreover, it is focused on quantifying dangers, through an approach that is guided by policies and pays more attention to the features that influence behavior and the response of the systems that are affected.

After a time, the DRR approaches were integrated with the Adjustment to Climate Change: the IPCC is adopting a new terminology, by breaking away from the AR4 and drawing closer to the DRR framework (Fritzsche et al., 2014). As well as this, the evolving concept of vulnerability is centred on making a local assessment with a view to improving our understanding of the factors involved in vulnerability, linked to the losses and damage caused, both during and after the occurrence of climate events. (Posey, 2009; Fazey et al., 2010; Yoo et al., 2011; Ludena & Yoon, 2015).

As a result of this evolutionary trend, there has been a growing interest in the integration of the biophysical and socio-economic features of cities to ensure there can be an assessment of all the urban features involved, together with their mutual relationships. This requires suitable methodologies for assessing vulnerability, owing to their particular attributes and various interactions, accompanied by great spatial heterogeneity and a multiplicity of time scales (Secchi, 2000; Batty, 2009; Alves, 2021).

Assessment of urban vulnerability, tools and indicators

Geographic Information Systems (GIS) which are already widely used by managers and urban planners to estimate the degree of susceptibility and vulnerability to which these localities are exposed, are assisting in encouraging the use of databases for forming future scenarios of change in the use of soil, as well as the effects of alterations in the landscape, when faced with extreme events and climate change (Vasconcelos et al., 2019; Mileu & Queirós, 2018; Malta & Marques, 2021).

The GISs allow a huge volume of data from various formats and sources to be used, as well as making a confrontation and connection with various factors and deterministic variables for physical conditions (Weiss & Pippi, 2018). These include instruments that are indispensable for management planning, as well as city planning (Mileu & Queirós, 2018), and like any data analysis tools, they require the information to be reliable and suited to the analytical task (Schmidt & Barbosa, 2016).

Multi-criteria analysis (MCA) is being used to reduce the errors made by academics and planners within the urban environment (Weiss & Pippi, 2019), and has emerged in urban management to break down complex problems into smaller issues and guide specialists and decision-makers to stress the relative importance of each of the features in the constructed hierarchy (Schmidt & Barbosa, 2016). These judgments are converted into numbers and referred to as `weights`. They are based on the assumption that it is necessary to evaluate the weightings of the specialists by comparing factors or features in a paired manner. This pairing leads on to standardization and combinations, which results in a vector of values that measures the relative importance of each factor when compared with the others. However, this procedure raises some doubts since it fails to take into account the subjective character that is inherent in the assessments of the specialists in their first impressions, which is common in supervised techniques. (Schmidt & Barbosa, 2016).

Apreda et al., (2019) conducted a hierarchical analysis with a quantitative assessment of vulnerability in urban sub-systems. They displayed a spatial analysis which allowed a transition to be made from one level to another and assured the uniformity of the data by making them comparable with each other. In this way, the limits of vulnerability could be determined which was useful for a) the recognition of critical areas, b) the development of adaptive solutions, c) connecting cities, d) climate change, and e) possible disasters. In this study, the maps of vulnerability were displayed which showed the main indicators of this relationship and the development of scenarios that revealed the impacts caused in the city.

With the assistance of GIS, it has been noted that several studies (Weiss & Pippi, 2019), have made advances in the spatialization and/or mapping to determine urban vulnerabilities, aggregate physical and hydro-meteorological data and relate the capacity for

mobilization and adjustment of whole populations to extreme climate events involving the risks and natural susceptibilities of the cities.

There are a number of research studies and methodologies concerned with the drawing up of maps about risk (Weiss & Pippi, 2019), which result from analyses and combinations of numerous variables and involve forging links between tangible and intangible criteria. These are also assisting the authorities and decision-makers to form new strategies of sustainable development to make these spaces more resilient (Oliveira & Silva, 2017; Malta & Marques da Costa, 2021).

In view of this, the indicators are one of the most common tools for operating theoretical concepts, since they are adopted in a different way to provide information about non-measurable states or conditions and summarizing complex situations into a single number (Fritzsche et al., 2014). If they are carried out in accordance with certain criteria (relevance, reliability, trustworthiness, accessibility, precision, importance, utility, viability and validity), the indicators and impact are a reliable tool for decision-making and easily understood by policymakers since they allow a comparison to be made with critical thresholds or previous measurements (Fritzsche et al., 2014).

For several years, the European Environmental Agency (EEA) has supported local governments by putting forward a system for indicators of urban vulnerability to flooding. This contains green spaces, a degree of soil permeability, population density and the socio-economic level of the people (Swart et al., 2012; Timmerman et al., 2017). These and other indicators are being adopted to map the vulnerability to floods in urban areas (Kazmierczak & Cavan, 2011; Kazmierczak & Connelly, 2011; Wolf & Mcgregor, 2013; Bao et al., 2015; Bouwens, 2017).

NBS applied in cities for the DRR and adapted to climate change

The cities are in the front line when it comes to the risks associated with climate change and this makes it imperative to seek for the reduction of hydro-meteorological disaster risks (Boland et al., 2021). With regard to these risks, the adaptation and mitigation are supported by both structural and non-structural measures such as forecasts and advanced warnings (Kumar et al., 2020; 2021).

The structural measures are aimed at withstanding the intensity and frequency of extreme meteorological events but are not flexible, sustainable or resilient to urbanization and climate change (Kumar et al., 2020, 2021). These strategies require considerable financial investment and fail to solve the root of the problem of hydro-meteorological risks and make people, as well as the eco-systems, more vulnerable over a period of time (Kitha & Lyth, 2011; Jones et al., 2012; Depietri & Mcphearson, 2017).

In view of the failings of the traditional measures, there is an awareness that in isolation they are not sufficient to deal with the growing intensity of hydro-meteorological risks. For this reason, NBS is being introduced for planning and implementing more adaptable, economic, resilient and sustainable management measures since it includes innovative systems that are inspired by, or copied from, nature (Kumar et al., 2020, 2021).

NBS is based on "*Low impact development*" techniques which were introduced in the US in the 1990s (OBWB, 2021; UACDC, 2010) and subsequently by the *International Union for Conservation of Nature* (IUCN) and the European Commission (CE) (UNDRR, 2021). The IUCN defines the NBS as comprising actions to protect, manage and restore natural or modified eco-systems in a sustainable way, while addressing and proportionally adapting to the challenges of society effectively and providing benefits to human welfare and biodiversity (Cohen-Shacham et al., 2016; IUCN, 2016). In addition, the CE defines NBS as involving activities that are inspired, supported or borrowed from nature. In other words, it employs the resources and complex processes of nature such as its ability to store carbon and regulate water flows to attain desired results, such as mitigating the risk of disasters in a particular environment (EC, 2015). The NBS can be understood as the adoption of strategies for tackling current socio-environmental problems through nature by benefiting from the intrinsic complexity of eco-systems. Moreover, it is linked to determined policies, acts of legislation and global agendas in this article, such as the Paris Accord, SDG [Sustainable Development Goals] and Sendai (UNISDR, 2015), which underline the importance of these agreements for incorporating a systematic approach to DRR.

The IUCN sets out eight principles which must be taken into account for the development of NBS on a global scale (Cohen-Shacham et al., 2016) (Table 3). The principles not only recognise the value of the biological factors in the solutions but also take account of the complexity of socio-enviromental questions.

Table 3

Principles of NBS

Principles	Description
1.	It adopts norms for the protection of nature
2.	It can be either implemented alone or combined with other solutions to meet social challenges
3.	It should be determined by the natural and cultural contexts of the locality, which includes traditional and scientific knowledge
4.	It should provide social benefits in a just and equitable manner and act transparently, with full participation of the community
5.	It helps to maintain biological and cultural diversity and the capacity of eco-systems to evolve in the course of time
6.	It should be applied on a landscape scale
7.	It recognises and addresses the question of a trade-off between the achievement of certain immediate economic gains and future choices for offering a wide range of services in the eco-system
8.	It should combine the general design of policies with actions required to face a particular challenge

Source: Adapted from Cohen-Shacham et al., (2016).

The term NBS is an umbrella term which encompasses particular approaches related to the eco-system such as, for example, Ecosystem-based adaptation (EBA), DRR-based ecosystems, and Ecosystem-based mitigation (EBM) (Cohen-Shacham et al., 2016).

EBA involves the use of biodiversity and ecosystem services as a part of a strategy for assisting people to become adapted to the adverse effects of climate change or in other words, it is a strategy adapted to the adverse effects of climate change (CBD, 2009; Dhyani et al., 2018).

Eco-DRR is a sustainable management strategy for a) the protection and restoration of ecosystems b) mitigating disaster risks and c) achieving sustainable and resilient development (Estrella & Saalismaa, 2013). Eco-DRR is also known as a set of "no regrets strategies" and is the outcome of a long history of environmental management for adapting to variations in climate and to DRR (Dhyani et al., 2018).

With regard to EBM, it seeks to reduce greenhouse gas emissions by confining and storing them in ecosystems by means of protection, restoration and management strategies (UNDRR, 2021).

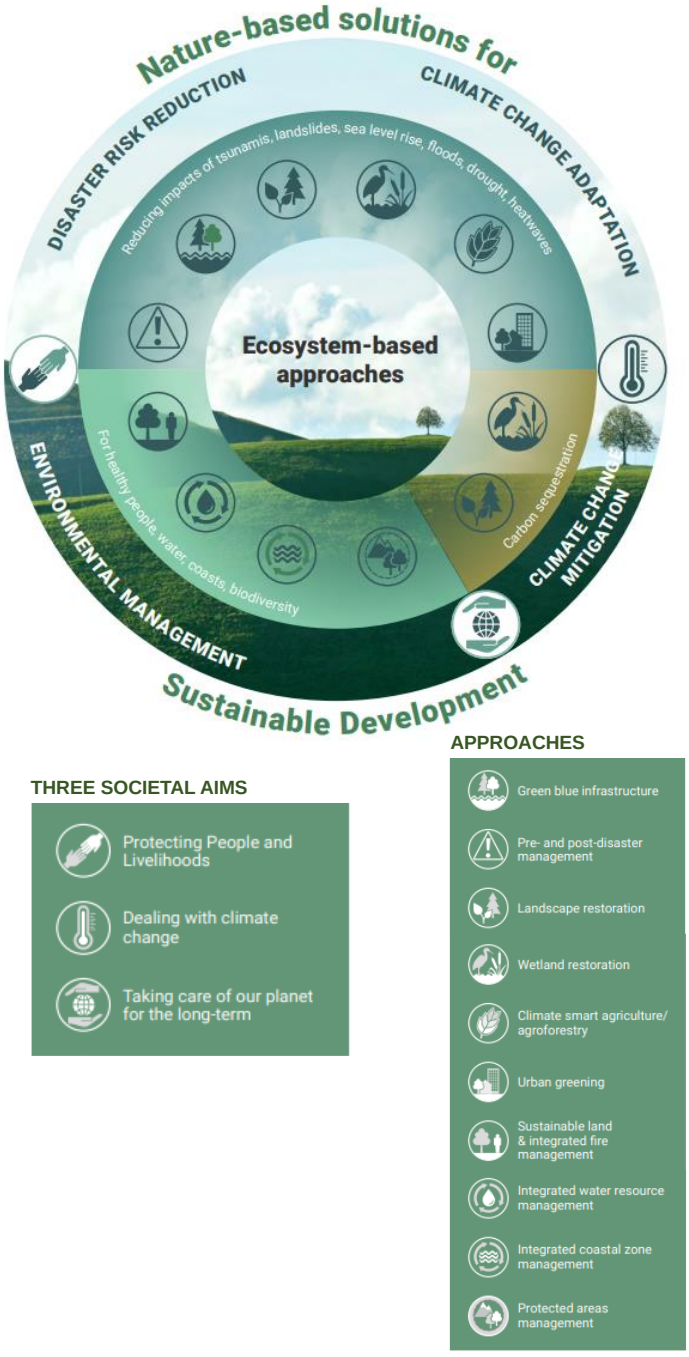
The Eco-DRR and EBA approaches concern the mitigation of large-scale disasters such as tsunamis and landslides (by being adapted to different climatic conditions) (UNDRR, 2021). However, there are a few differences between these terms - EBA only addresses risks related to climate whereas Eco-DRR encompasses both climate and non-climate events (Dhyani et al., 2018).

NBS seeks to encourage conservation and sustainable use in a holistic and equitable

manner, to meet its objectives which are: i) to protect people and their livelihood; ii) to cope with climate change; and iii) to take care of our planet (UNDRR, 2021). Moreover, according to the authors, these strategies, which are based on ecosystems, not only involve concepts of disaster risk reduction, adaptation and the mitigation of climate change, but also environmental management which combines natural resources and solutions that are essential to attain the ODS (UNDRR (2021) (Figure 6).

Figure 6

NBS for sustainable development



Source: Adapted from UNDRR (2021).

In the following section, there is an examination of the main discoveries obtained from the literature review with regard to the NBS used in cities for the DRR and adaptation to climate change, while taking account of urban vulnerability.

The authors, Kumar et al. (2020), investigate the adoption of NBS for natural risks and discuss the process of operating and implementing NBS. The research looks at projects which address the question of hydro-meteorological risks through NBS in Europe. These projects were built on the principles of sustainable development and set targets for improving human welfare and the performance of the eco-system that can act against hydro-meteorological risks in the urban environment (Table 4).

Table 4

Projects which address the question of meteorological risks (Europe)

Name	Description of the project
TURAS - *Transitioning towards urban resilience and sustainability*	Improvement of urban sustainability (green enclosures at an accessible price).
Expansion of green Spaces	Making connections between green areas by adopting a multi-purpose green approach and involving the local citizens in urban planning.
Opening	Urban planning integrated with NBS for an efficient regulation of water flow, together with an improvement of biodiversity, health and the natural habitat.
Operations	Combination of NBS with traditional measures for optimizing the benefits of the ecosystem and strengthening the coastal defenses against the rising level of the sea.
Connecting with nature	Expansion of commercial and social undertakings in the production and implementation of NBS on a large scale in the urban environment, with a view to measuring the impact made by adapting to climate change and encouraging sustainable economic development.
Grow Green	Investment in BBS to foster climate and hydrological resilience.
UNALAB-*Urban Nature Labs*	Reference to the benefits, cost-effectiveness, financial viability and replicability of BBS, by encouraging urban communities to be intelligent, inclusive, resilient, and sustainable though the co-creation of a system to face climate and hydrological challenges.
Urban GreenUp	Mitigation of the effects of climate change with the aim of improving air quality and the management of water, as well as increasing the sustainability of cities by means of NBS.
NATURVATION	Assessing the achievements of NBS in the cities, examining their innovative practices and working with communities and stakeholders to develop tools for recognizing the potential of NBS.
Cities of Nature	Creation of a platform for NBS, that can offer technical solutions, methods and tools for urban planning.
The Naiade water meter	Evaluation of the ecosystem services, contestant involving the main insurance brokers and local authorities.

Source: Adapted from Kumar et al., (2020).

Dhyani et al., (2018) analyzed the feasibility and suitability of Eco-DRR for the Indian city of Nagpur with a view to reducing the losses caused by disasters and addressing the

hazards and vulnerability of the urban population. The study carried out a diagnosis of the situation and assessed how solutions can assist in improving the quality of the environment in densely populated urban areas. The researchers confirmed the importance of using ecosystem services in urban areas, and included: i) the possibility of treating residual water with NBS (which involves a variety of plants in prepared wetlands); ii) the need for the rejuvenation of rivers and protection of river banks; iii) the implementation of new green roadways to combat air pollution; iv) forestation, and the restoration or conservation of biodiversity through green roofs; v) plantations beside the curbs and the development of vertical gardens with active communication and the participation of the local community.

Kumar et al., (2021) address the importance of assessing NBS to mitigate vulnerabilities, such as the need to monitor the efficiency of these operations. As the authors make clear, this assessment will encourage the community to be involved in the implementation and monitoring of the NBS, by assisting in decision-making Moreover, they underline the fact that there is a lack of strategies and standards for this monitoring that are accepted worldwide.

Denjean et al., (2017) put forward a structural framework for systematizing the use of NBS, by integrating its potential for resilience. The authors support a shift in paradigm away from reducing disaster risks to improving resistance to disasters, or in other words, there is a need to overcome the belief that we can prevent or eliminate every kind of risk and instead rely on a paradigm, where we know this is impossible and hence should seek to strike an ideal balance between prevention and preparation.

Kuhl et al., (2018) analyzed and summarized both current and traditional approaches for creating projects concerned with coastal adaptation to climate change in developing countries, which have regions that are extremely vulnerable to the impacts of weather. The authors confirmed that their strategies would become more complex over a period of time since they had to combine a wide range of approaches. It was noted that there is a growing interest in NBS for climate change which suggests that there will be an increase in adaptation strategies based on the eco-system in the future, particularly in coastal zones.

Belle et al., (2018) investigated the knowledge and practices of NBS for reducing the disaster risks of drought and flooding in the east of the Free State in South Africa, which will be a Water Management Area for mitigating the impact of hydrological disasters and adapting to alterations in the climate. The authors confirmed that there would be several obstacles to an effective implementation of this type of NBS in the locality. There are gaps in environmental education and thus a need to formulate and implement public policies for the conservation, protection and rational use of wetland areas. The implementation of NBS in the region is also hampered by problems related to the question of regularizing land ownership, which is inequitable and complicated since it has its roots in the discriminatory practices of the era of

apartheid.

As has been seen, there is a growing pressure for the implementation and improvement of NBS for handling hydro-meteorological risks and an understanding that that this measure will be increasingly adopted. NBS emerged in Europe in the mid-2000s and has begun to be implemented throughout the world. There are countries in various stages of implementation which are facing different circumstance and undertaking a wide range of activities. This is particularly the case with the principles of NBS, since it is stressed that these should be determined in natural settings and the particular cultural background of the localities where they are implemented through a widespread social involvement. This makes these activities unique since they are not pre-determined solutions but are carried out in a particular territory with features that are suited to the locality and the people involved, in addition, they are accompanied by other measures in a context that combines the activities of hydrometeorological DRR with adaptation to climate change.

Final Considerations

This article seeks to systematize studies on the question of the vulnerability of cities by examining the evolutionary pattern of the term “urban vulnerability” with the key concepts involved, the methodology employed for their determination and the actions recommended by researchers and policymakers. The purpose of this is to make the urban Spaces more resilient to the risk of hydro-meteorological disasters or in other words to examine which measures have been adopted in big cities for the reduction of hydro-meteorological risks and for adapting to climate change.

When faced with climate change, the DRR has now become an emergency service that seeks to protect human lives and material goods, because many of our cities are expanding and thus include areas susceptible to extreme events, which means they are in a potential condition to experience climate change. In light of this, urban vulnerability has become a key factor in the current assessment of climate change and there is a need to strengthen studies concerned with this question.

It is of great importance to establish a coherent theoretical framework that can offer guidelines for the formation/adaptation of indicators, assist planning and carry out activities in urban spaces. This is because, as has been noted in the databases used for this research project, there has been an increase in the number of publications related to the following areas: i) DRR, ii) adaptation to climate change and its mitigation iii) systems for supporting decision-making and iv) in recent years, SBN. This shows the value of these approaches for confronting the contemporary urban challenges caused by climate change.

This review reveals some of the limitations that arise from the keywords, because urban vulnerability can be linked to other terms such as social and/or climatic vulnerability and thus

it is recommended that new combinations are formed with the aim of exhausting the references. In addition, only two databases were used although, as it is a current and growing problem, it is recommended that the research should be extended to other databases.

Finally, this review demonstrates that there is a need for a greater effort to be made to create a systematic method on how to reduce hydro-meteorological risks and hence, assist decision-makers to make adaptations to climate change. It is hoped that this will foster new measures that give priority to eco-systematic solutions, as well as research studies that make use of the international global agreements and targets by ensuring that they are converted into local goals at the level of towns and cities and have a focus on hydrographic basins.

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