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Nature-based Solutions for climate-resilient cities: A proposal of a model for successful implementation

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Abstract

Nature-based Solutions (NbS) were introduced by the IUCN for the first time, but today have different definitions in the literature. NbS are deemed the key to urban sustainability and aim to enhance the built environment through ecological and environmental interventions to support the built environment for future extremes of climate change and related hazards. NbS include blue and green infrastructures, ecological engineering, ecosystem services and ecosystem-based adaptation. Various frameworks defined different key considerations and the literature suggests plenty of frameworks towards successful NbS applications. Current debates critique the extent to which innovative and adaptive the solutions are, whether they are implemented by considering social values and social equity, and the financial burden they often bring which strengthens the disparities between the world cities. Uncontrolled urbanization often causes cities to become an environmental problem. This paper conducts a literature review to lay out the current debates and to highlight the multidimensionality of NbS. It focuses on the potential of NbS in disaster risk reduction and so the paper draws a framework to successfully implement and provide improvements for NbS based on the theoretical ground. NbS are investments in the life quality of the residents and preventive tools in the risk management of cities. The paper attempted to frame the NbS clearer for scholars interested in the subject.

Keywords: nature-based solutions, resilient cities, urban sustainability, urban water, eco-sensitive city, climate change adaptation

1. Introduction

We are in an era under pressure from the environmental crisis induced by climate change. With the COVID-19 pandemic, all experienced how nature recovers its fresh air quality when all air pollutants (mainly cars and plants) are disrupted for a while. Our daily-life routine harms nature and this creates an environmental crisis in turn. The way we consume environmental resources and build our cities puts pressure on nature and narrow green spaces. A study by Mohommad and Pugacheva (2022) revealed that the pandemic made people realize the significance of a healthy nature and the need for green recovery since a study by Castellar et al. (2021) uncovered that nature is interpreted by people as a green factor and defined with the presence of vegetation. Lately, the approach to restoring and increase the quality and the number of green spaces and the classical perception of the water–urban ecosystem interaction in urban areas changed to Nature-based Solutions (NbS), which was first used by the International Union for Conservation of Nature (IUCN) in the early 2000s (Mell et al., 2022; OECD, 2020; Krauze & Wagner, 2019). NbS have

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different definitions in the literature. Mell et al. (2022) defined NbS as a set of aid tools to cities in terms of preventing and reducing the biophysical environment problems including climate change effects, ecological losses, risk of flooding and air quality. Frantzeskaki et al. (2017) defined NbS as transition initiatives with solutions to restore nature, imitate nature and build upon nature to address place-specific environmental problems. OECD (2020) defined NbS as an umbrella concept for other environmental approaches including ecosystem-based adaptation (EbA), eco-disaster risk reduction (eco-DRR), green infrastructure (GI) and natural climate solutions (NCS). Depietri and McPhearson (2017) defined NbS as a combined 'hybrid' strategy that is based on ecosystem functions and engineering implementations in urban areas. NbS studies cover a wide range of research disciplines including ecosystem services and agriculture, eco-hydrology and climate change, wetlands, water quality, ecological engineering, green infrastructure and urban sustainability, remote sensing and geographical information systems (Bunclark & Hernandez, 2022).

Although most of the literature framed the vision of NbS within the ecological and biophysical environment, NbS also has strands contributing to the socio-economic values including the better spatial use of green spaces in cities and peripheries, decreasing crime numbers, increasing the well-being of residents and eventually rising the estate prices and contributing to the authority planning process in developing projects and policies (Mell et al., 2022). Simply, creating parks and green spaces can reduce urban floods, help to balance urban heat and provide recreational opportunities attracting communities and contribute to the human-nature relationship (OECD, 2020). Green walls, roof gardens and vegetated infiltration help to manage wastewater treatment and stormwater. This way, green infrastructure and imitation of green services are becoming part of the natural treatment process to reduce water pollution and surface run-off stormwater, particularly in Asian cities (Kooy et al., 2017). A well-planned recycling of greywater can decrease the demand for freshwater by up to 60 % and reduce the consumption of natural sources (Oral et al., 2020). Fuldauer et al. (2022) found that utility sectors covering electricity, transport and water infrastructure have a direct influence on 17% of SDG. Manufacturing, mining, and construction services influence 8% of SDG. Increasing the urban green space and enabling easy access to it enhances the livability of a city. For example, converting abandoned land into a community garden or other green-social forms enhances social cohesion and values disadvantaged urban areas. Restoring a polluted river passing by an urban area, which affects the neighbours negatively, can help to increase urban water quality as well as the value of nearby properties (ICLEI, 2017). NbS adoption can support balancing the pressing issues regarding poorly managed rapid urbanization, particularly in low and middle-income countries in Asia (Lechner et al., 2022). These examples point at how multi-dimensional NbS are and require a well-thought pathway to implement and to address the problems as mentioned above. This study conducts a literature review in line with that and aims to answer the questions as follows:

- What are the dimensions of NbS?
- What is the controversy between the positive and negative impacts of NbS?
- How possibly NbS contribute to disaster risk management considering climate change?
- How possible to address the issues through step-by-step process models?

2. Research Methods

To answer the research questions above, it is required to conduct a comprehensive examination of NbS research. Accordingly, a search on the ScienceDirect database with the keyword "nature-based solutions" was conducted. To understand NbS in the urban context, papers falling within the interest of hard science subjects including materials science, chemical engineering, biological sciences and so on were excluded from the literature review. Rather, papers discussing the NbS-related topics with the aim of framing the multi-dimensional features of NbS were mainly selected to include in the paper to better understand how differently NbS contribute to the environment and society. This inclusion strategy also helped to draw a model to achieve the standards defined by the literature review.

2.1. A review of the NbS framework

Global Standard of IUCN for NbS aims to ensure the NbS implementations are credible, tracked and measured for adaptive management. The standard consists of eight criteria which encompass societal challenges, design at scale, biodiversity net gain, economic feasibility, inclusive governance, balance trade-offs, adaptive management, mainstreaming and sustainability (IUCN, 2020). Depietri and McPhearson (2017) stressed a threefold integrated approach to NbS by establishing social-ecological interactions, ecological-technological interactions, and social-technological interactions. Voskamp et al. (2021) identified four key principles to implement and achieve successful NbS projects. They are institutional settings, availability of financial resources, level of expertise and know-how, and collaborative work for planning with governance.

Calliari et al. (2019) draw an adaptive management cycle for NbS which assesses the direct benefits vs. costs and co-benefits vs. costs of NbS implemented. They highlighted the explicit multi-stakeholder engagement, multi-functionality rather than single functioning, and targeting simultaneous delivery of economic, social and environmental benefits. The cycle they suggest includes a backcasting stage which means identifying a set of actions to realize the desired environmental situations. The actions should be reviewed and assessed before and after implementing. This requires several feedback loops at different stages to evaluate, to review and to adjust according to the potential needs and to avoid potential unintended consequences. Conti et al. (2021) also draw a feedback loop between healthy city outcomes and nature-based ecosystem endowment. A feedback loop is a self-reinforcing cycle according to their point of view. Davies and Lafortezza (2018) suggest a transitional path to the adoption of NbS and favor the balanced use of grey, green and hybrid infrastructure. The path begins with the education of existing and future infrastructure professionals. It continues with the reform of institutions and their cultures. The path considers the strategy of community-empowered place-making combined with 'ecosystem literacy' and, finally it develops a new approach to public and private sector procurement. Wickerberg et al. (2021) draw a framework that is shaped around a list of 'how' questions towards a promising NbS implementation, as follows:

- How the process will be?
- How are the NbS principles translated into local process?
- How the collaboration is initiated and organized?
- How to facilitate change by co-creation of knowledge?
- How to integrate NbS at the right scale?
- How to meet experimentation and formal planning processes as the implementation pathways?

Accordingly, as the review thus far emphasised, a framework for a successful NbS implementation entails five components as below:

- Social awareness and participatory process,
- Technical knowledge and expert consultation,
- Communication between stakeholders including the public and private sector and residents and (if there are) NGOs,
- Legal establishment (policies, laws, codes, and regulations),
- Post-implementation evaluation (likewise post-occupancy evaluation, end-user and long-term impact should be kept monitored routinely for a while).

2.2. A review of the controversies in NbS

The majority of NbS studies outline the positive impacts. Despite this fact, there are certain hesitations and barriers against the NbS adoptions. Mell et al. (2022) examined the barriers to successful NbS and they highlighted the factors regarding governance, finance, program and delivery. By focusing on the NbS implementations in Liverpool, UK, they defined eight indicators as below:

- Climate mitigation and adaptation,
- Water management,
- Green space management and air quality,
- Socio-cultural indicators,
- Participatory planning and governance,
- Social justice and social cohesion,
- Public health and well-being, and
- The potential of economic opportunities and green jobs.

Moreno et al. (2022) identified 23 barriers. Communication between stakeholders in terms of organizational barriers was highlighted by Croeser et al. (2021). They also underlined the importance of diagnosing the problems and obstacles specific to the local bodies in the way of delivering NbS implementations and taking actions against the persistence of the problems. The literature uncovers the controversy and disparity between the regions in terms of comparing the difference between their approach, perception and adoption of NbS. For example, Lechner et al. (2022) emphasized that the adoption of NbS remained more limited in Southeast Asia than in Europe. Different challenging conditions across the regions affect the decision and possibility of NbS adoption. The overarching reasons include the scale and area of polluted water, land and air, the pressure of rapid population in urban settlements, more complex hydro-meteorological event patterns and rapid deforestation which threatens the water, soil and air quality of the environment and the quality of residents' life. Lechner et al. (2022), thus, identified the challenges in five groups encountered in Southeast Asia against the adoption of NbS as below:

- Characteristics of urbanization
- Biophysical environmental and climatic context;
- Environmental risks and challenges for restoration;
- Human nature relationships and conflicts; and
- Policy and governance context.

Another argument between the South and North, the East and West appears from the epistemological approach. Mabon et al. (2022) argue that from the understanding of NbS, an epistemic injustice emerges. They underlined the exclusion vs. the dominance as embodying testimonial injustice (when someone or group's knowledge is viewed as less significant) and hermeneutical injustice (when someone or group's experience is viewed as less significant to what dominant is).

3. Multiple dimensions of Nature-based Solutions

The literature review sufficiently points out four dimensions that need to be considered holistically: social, economic, environmental and policy perspectives. The problems and NbS to be adopted address one of them or more than one (i.e. socio-economic, socio-environmental etc.).

3.1. Social perspective

In terms of acting solid, wide public support is crucial "towards implementing climate mitigation policies and achieving decarbonization" (Mohommad & Pugacheva, 2022). NbS are not only engineering and design-based interventions but also require social inclusion as NbS often target to strengthen the social-ecological settings (Frantzeskaki et al., 2017). A certain level of 'green knowledge' of residents is necessary to conduct a participatory process (Voskamp et al., 2021), but at the same time, social disinterest in the environmental problems is a handicap as well (Moreno et al., 2022). A study (Nóblega-Carriquiry et al., 2022) surveyed the social perspective of the residents of the NbS in the Tordera delta in Spain and concluded that understanding nature had two standpoints. For some, it was only good to maintain the original and to help re-naturalization of the delta area, whereas for some it would be good to adapt nature to socio-economic opportunities for the locals. For the latter, a further analysis uncovered the perception of nature and human activities. For some, nature was under stress of unsustainable economic activities by the locals, and for some their socio-economic activities in the delta area were suffering from frequent floods, which needed to be prevented.

Raymond et al. (2017) underlined that NBS should develop synergy between ecosystem services and the manmade environment. Kabisch et al. (2022) highlighted that NbS should be driven by mutual learning and should bring sustainable transitions in cities. However, 'lack of public awareness and support' is one of the barriers listed by Sarabi et al. (2020). Frantzeskaki (2019) emphasized that NbS needs to fit into the urban mosaic and aesthetically appealing to residents to have them appreciated and cared for. A participatory approach is a key to socially acceptable urban design. Raymond et al. (2017) stated ensuring citizen involvement in governance and monitoring is one of the success keys to effective NbS. To say, NbS helps to improve the sense of place and the feeling of belonging to a place among the residents as long as it is developed taking into account the local communities (Alva, 2022).

The majority of NbS research concerns environmental urban context, but contrary, only a little shed some light on land use concerns (Hanson et al., 2020). For a just NbS, intentionally developed urban land use and accessibility of resources should be targetted to eliminate the drivers of socio-economic inequalities. The clearest inequalities are seen in race and income classes. Capital circulation ignores disadvantaged groups including minorities and low-income residents. In simple terms, greening NbS projects should address this contestation and bring solutions to achieve environmental justice (Cousins, 2021). However, greening projects often reward capitalist values and welcome higher-income groups, mostly replacing lower-income groups. Social justice, in/equalities and affordability are among the least focused and evaluated in the studies reviewed by Hanson et al. (2020). Pathak et al. (2022) also emphasized the equity implications in the design and application of NbS among their seven key principles to address when planning NbS. Overlapping with these arguments, 'property ownership complexities' and 'space constraints' are among the barriers listed by Sarabi et al. (2020).

3.2. Economic perspective

NbS projects hitherto are realized mostly by local or national authorities and sponsored with public finances. To say, private investors are not very much into involving the NbS implementations as they deem it less marketable and high risk with low reward (profits) in turn. Hence, authorities with limited access to financial sources encounter major barriers to sponsoring the realization of NbS projects (OECD, 2020). Thinking of how developing business models for NbS is more than necessary to establish partnerships between the private sector and local authorities to form an investment pool (Frantzeskaki et al., 2020). In May 2021, the European Commission (EC) shared a document to highlight the potential NbS holds for the environment and climate change mitigation. Alva (2022) criticized this EC document as having been written from a strong financial perspective to charm companies and investors, who were also responsible for causing the climate change crisis.

Green infrastructure for flood risk reduction is a well-known NbS component. However, similar to the argument above, it is lately deemed as neoliberal urban governance. To give an example, it was very arguable when the city council of Houston, USA, proposed a plan to relocate 400 low-income households and to rehabilitate the area as floodable green space for the city. This raised dispute because the climate change discourse was forcefully used to evict mostly black and brown low-income residents out to the peripheries of the city. In this way, creating green infrastructure as one of NbS components intentionally or unintentionally contributes to the socio-economic disparities as wealthier groups can afford to pay for valuable estates benefitting green areas, whereas disadvantaged groups cannot afford and are eventually excluded (Shi, 2020). This shows how social and economic perspectives are bound together. In their assessment guide for NbS implementations, Raymond et al. (2017) placed a monitoring phase to evaluate the outcomes and uncover the barriers to achieving the long-term goals. It is evident that the financial contribution of NbS should consider different spatial and temporal intervals to fully understand the socio-economic benefits.

It would be wrong to assess NbS projects solely based on the financial scheme. This would diminish their rationale as the costs would go head-to-head with traditional engineering solutions. One must see NbS as living solutions as their effectiveness is mostly measured by the environmental capacity empowerment to respond to climate change pressure on the environment (Calliari et al., 2019). O'Leary et al. (2023) emphasized that NbS can lead to a sustainable blue economy by improving marine and coastal ecosystem services. Bockarjova et al. (2022) researched to reveal the dimension of the value transfer between the social benefits and the financial investment into NbS. They estimated that 85 NbS interventions in 13 EU countries delivered an aggregate social value of US$ 800 million per year to residents. Per hectare of urban space, these NBS deliver an average of US$ 96,285 worth of yearly benefits to residents (median US$ 48,981). They estimated that in 65% of the 60 NbS projects they reviewed, the added value to residents surpassed the total financial cost. The NbS projects they reviewed have the financial load varied between $110.000 and $1.75 billion, with a separately estimated maintenance cost ranging from $1 million to 14.7 million per year.

3.3. Environmental perspective

Urban development has been viewed from an economic perspective without considering to what extent natural resources have been harmfully consumed. Particularly, water management and waste management in cities are problematic. For urban areas, no arguably water is the main factor with its accessibility and serviceability to direct urbanization (Krauze and Wagner, 2019). The management applications were mostly developed in the early 1960s and by then engineers and authorities were only aiming at a single purpose for projects, i.e. for the sake of urban infrastructure, without considering environmental destruction and degradation (Matthews and Cruz, 2022). In North America, approaches considering the low impact on the environment were first adopted in the 1990s and the movement was named Low Impact Development (Alemaw et al., 2020). Drinking water supply and sanitation were mostly provided through grey infrastructure. Unlike the earlier viewpoint, stormwater and wastewater are no longer seen as disposable and harmful. As the perception of sustainability increase and become widespread, they are seen as the most valuable and 'cheap' resource to recycle. Considering many Asian cities and suburbs with high populations and with lacking grid infrastructure systems, this approach helps to secure and protect the continuity of water sources (Kooy et al., 2020). Moving from the low-impact development to NbS provided an ecological transition to mitigate urban water challenges and to transform conventional cities to water sensitive cities. Improving the efficiency of water use techniques and reducing the freshwater demand through recycling, filtrations and better land use planning can solve the primary water-related problems in cities. A holistic approach considering environmental, economic, social, technical and political aspects is called Integrated Urban Water Management, which takes one step further than conventional urban water management (Oral et al., 2020).

Depietri and McPhearson (2017) emphasize that grey infrastructure is only a prevention system and is insufficient which requires a huge amount of investment and a continuous budget to maintain, which can structurally fail in extreme cases. Krauze and Wagner (2019) emphasized that NbS may include a novel grey structure, but this approach should remain as auxiliary to the development of blue-green infrastructure. They suggest the 'mimicking nature' approach for the development of NbS to recover the urban ecosystem. Moreno et al. (2022) indicated that more cost-benefit analyses must be studied to reveal green infrastructure versus grey infrastructure solutions, particularly in coastal risk management. NbS, whether green or grey or hybrid, requires investment not only in the construction phase but also in monitoring and maintenance. NbS are a sign of the reorientation from grey infrastructure to green infrastructure (Matthews and Cruz, 2022), in this regard.

Frantzeskaki et al. (2017) pointed out the transformative effect of NbS on urban sustainability in terms of enhancing the conditions of balance, resilience and socio-environmental relations without damaging or exceeding the capacity of the surrounding ecosystem. The scale of NbS is also critical to replicate the implementation in the same city or another one. Each NbS project needs localization for the application, even for green roofs, green walls, and green courtyards (Frantzeskaki, 2019). Kabisch et al. (2022) emphasized the local context among their five key NbS challenges. Sowińska-Świerkosz and Garcia (2022) draw a SMART approach to NbS regarding this 'localisation' factor (Figure 1) considering specific, measurable, attainable, realistic and timely targets.

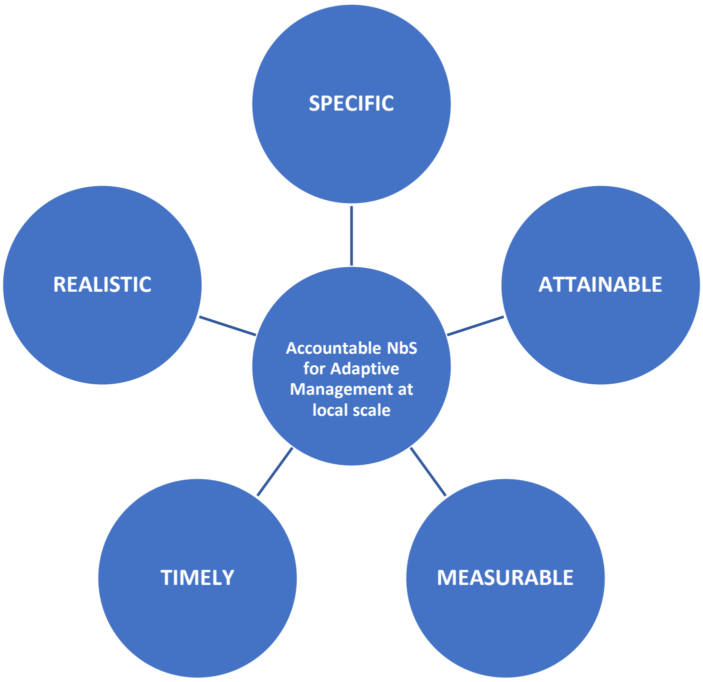

Figure 1 The elements of the SMART approach defined by Sowińska-Świerkosz and Garcia (2022).

Localization is significant for bringing solutions to specific problems. For example, Bahrain aims for mangrove transplantation to rehabilitate degraded coastal areas. Vietnam aims to manage sustainable forests and enhance carbon sequestration. Morocco aims to protect "its natural heritage, biodiversity, forestry and fishery resources (Seddon et al., 2020). IUCN (2020) stated that NbS help to stabilise global warming to below 2 degrees by 2030 and could provide cost-effective mitigation against the adverse impacts of climate change on biodiversity. Climate change's effect on the rapid extinction of biodiversity can be reduced and slowed down by well-considered NbS projects, as Pathak et al. (2022) pointed out as one of their seven key principles for NbS. Climate change can reveal how harmful we use natural sources. The Marmara Sea in Turkey suffered from the bio-chemical formation of mucilage as the Sea was used for the discharge of urban wastewater with no or low level of treatment. This affected the tourism and fishing industry in Istanbul (Tuğaç, 2023). Kabisch et al. (2022) highlight that NbS should ensure multiple benefits for human as well as non-human. Pineda-Pinto et al. (2022) argue that the environmental perspective is only human-centred. Biodiversity conservation and public health are the following concerns (Hanson et al., 2020) if multi-target NbS is attempted. Therefore, Pineda-Pinto et al. (2022) introduce the concept of ecologically just cities. This includes human focus and non-human nature focus, which underlines that non-human nature is symbiotically linked with human nature.

3.4. Policy perspective

Although NbS planning is a highly technical process including multiple expertise of engineers, architects, planners, landscape designers and other disciplines, the projects need to be framed within an appropriate policy environment as well. This should cover land-use regulation and zoning, permitting, safety and performance codes and standards, procurement policies, land rights and environmental protection regulation (OECD, 2020).

Institutional settings and the willingness of authorities are the key factors and at the same time barriers in the realization of NbS. Local officers often encounter difficulties in convincing politicians about how NbS are needed and its potential benefits for the area in hand (Voskamp et al., 2021). Sarabi et al. (2020) identified 'Lack of political will and long-term commitment' , 'Lack of sense of urgency among policymakers', and 'Lack of supportive policy and legal frameworks ' as three of the barriers to the NbS adoption. Regarding the multi-stakeholder nature of NbS, a collaborative approach is required between municipal staff and other urban actors, such as civil society, NGOs and residents (Frantzeskaki, 2019). Frantzeskaki et al. (2020) define 'policy need' as the bridge (a strategic solution) between the opportunity (the current status) and the objective (the desired status). Dumitru et al. (2020) suggest that providing systematic evidence from NbS case studies at a smaller scale can be useful for an in-depth understanding of the outcomes. This could guide better for an impact evaluation so that the policy-makers understand the influences over specific objectives.

NbS implementations are manmade interventions in the end and they are often limitedly applied to a degraded environment (Krauze and Wagner, 2019). An argument (Mell et al., 2022) is that the public reactions affect the NbS projects to invest by the local authorities since the more visible the project is, the more positive reactions would be gained from the public, which is linked to green and blue infrastructure, such as green walls, green parks and riverbed rehabilitation. Nóblega-Carriquiry et al. (2022) emphasize that local communities aspire for an NbS-based future, but a participatory process needs to be conducted to result in appropriate land use policies while achieving flood prevention and environmental protection.

It is also about the differences between the culture of collaboration and hierarchy in the European and the Asian systems that affect the adoption of NbS (Morita and Matsumoto, 2021). Although, the tertiary public administration directly influences 50% of SDG targets through the governance services it provides (Fuldauer et al., 2022), excessive imposing of the positive impacts of NbS to urban politicians and authorities may result in reduced inspiration and handicaps in catalyzing the change. The pressure on the urban resilience policy need may turn into marginal voices that are being disregarded (Shamsuddin, 2020). At this point, it is overlapping that 'functionality and performance uncertainties' and 'misalignments between short-term plans and long-term goals' are two barriers identified by Sarabi et al. (2020).

4. Nature-based Solutions for disaster risk management

As the literature review thus far elaborated how multi-dimensional NbS is and also is an addressing tool to combat the climate change effects in the natural and built environment, it is now more relatable to discover how NbS can be utilised for disaster risk management. High-density urban settlements with land use planning mostly covering housing are highly vulnerable to disasters. The risk of urban settlements keeps increasing with the intense pattern of land use and unplanned growth despite the climate change effects becoming more observable (Sagala et al., 2022). Sendai Framework for Disaster Risk Reduction, the 2030 Agenda for Sustainable Development Goals, the Paris Agreement and the New Urban Agenda by the United Nations are the international policies adopted for disaster risk reduction (DRR) and climate change adaptation (CCA). They point to the importance of NbS to achieve sustainable development. The policies abovementioned focus on the restoration and preservation of ecosystems (Da Silva et al., 2022). The New Urban Agenda was adopted on 20 October 2016 and was one of the earliest policies to refer to NbS and ecosystem-based solutions (The New Urban Agenda, 2017). Following this, The World Bank NbS Program was established in 2017.

The most obvious impact of climate change is the volatile rainfall patterns that cities across the world are hit by in increasing numbers and most of which drainage systems fail against the frequent overloading and suffer from surface runoff water due to the large impervious areas (Oral et al., 2020). From the perspective of CCA, NbS are increasingly becoming the key tools. NbS suggest environmentally friendly implementations for water-related risks such as ecosystem degradation (e.g. rapid decrease in groundwater), coastal storms, riverine floods, and urban floods on one hand, and on the other hand intensive and spreading droughts in different world geographies (OECD, 2020). To give an example, rehabilitated floodplains and wetlands are examples of NbS that can prevent floods by increasing water retention and can save communities and contribute to their well-being by adding recreational value to the surrounding area (OECD, 2020). Some countries are highly vulnerable to climate change and suffer hydro-meteorological disasters frequently. Turkey is one of them and climatically extreme events change year by year. In 2020 and 2021 water reservoirs supplying freshwater to cities including Istanbul and Bursa reached critique levels due to seasonal drought with no rainfall event. In the same years, few cities were hit by heavy rainfalls, which caused urban floods with deadly results (Tuğaç, 2023). In terms of urban water-food-energy cycle and security, NbS are still at the preliminary stage, but surely the implementations can help to balance evapotranspiration and by that, the seasonal rainfalls are kept in the normal spectrum rather than going extremes in between floods and droughts (Oral et al., 2020).

Re-naturalization of the urban environment in an era of environmental crisis is a promising roadmap to achieve urban resilience (Dumitru et al., 2020). Cities located in valleys, on hillsides or in coastal areas are better protected by planning with and for nature (ICLEI, 2017). However, Seddon et al. (2020) revealed that only 30 countries out of 104 provided measurable targets to realize NbS. In most cases, NbS are implemented to increase water quality and quantity in terms of environmental management and to reduce flood risk (OECD, 2020). Unlike blue and green infrastructures, which are protective and restore natural sources, grey infrastructure refers to building structures such as dams, dikes, channels and storm surge defences to reduce disaster risks (OECD, 2020).

Nehren et al. (2023) categorized the approaches towards NbS for DRR into five groups. The first one includes the ecosystem-based DRR approaches. These approaches target the CCA and mitigation, ecological restoration and sectoral restoration, such as soil bioengineering and climate adaptive agriculture. The second group attributes to landscape units and related hazards, such as mountainous and coastal areas as well as wetlands and drylands. Urban forests and landscapes are also part of this group's target. The third group targets the climate extremities and different climatic conditions, from tropical and subtropical climates to semiarid and dry climates. The fourth group includes the approaches for biophysical services and ecological services. The last group is formed to understand the measures and techniques in NbS for DRR. To explore the potential of NbS for DRR, Tyllianakis et al. (2022) analyzed countries depending on capability drivers and necessity drivers. They included the percentage of the forest area a country has, the percentage of GDP generated from agricultural, forestry and fishery activities, and the percentage of country area that is assigned as to be protected among the capability drivers. Necessity drivers include parameters to reveal the proneness to disasters, such as the average rate of CO_2 emission, the percentage of the population living in urban centres, the percentage of country land at the risk of inundation, and the average yearly economic cost of climate change impact.

Enhancing resilience only in one system may result in further negative impacts in other systems. Therefore, resilience and NbS need to be taken into account together from the wider window of urban planning (Bush & Doyon, 2019). Kabisch et al. (2022) underlined that NbS should be integrated and based upon a systems approach, rather than one system approach, and should appreciate long-term benefits. To see how NbS for DRR works, particularly for stormwater and urban water management, it is essential to create an objective resilience assessment framework, as one that Beceiro et al. (2022) provided. They draw a two-dimensional framework to assess the integration of NbS in the city and to assess the extent of the operation services of NbS. The latter dimension includes spatial planning (hazard and exposure planning, land use and NbS inclusion), service management (resources availability and adequacy, service management and planning), resilience-engaged service (reliable service, flexible service and scenarios relevant for disaster response), infrastructure safety and robustness, infrastructure preparedness, and infrastructure dependence and autonomy.

5. Potential model for development of Nature-based Solutions

Regarding the social, economic, environmental and policy perspectives as discussed and the capacity to improve the disaster risk management as highlighted in this paper, it is now more evident that the implementation of NbS requires a well-established roadmap prior to development. To fulfil the needs, to evaluate the NbS responses and to improve, if necessary, an inclusive framework should be utilised. While many researchers emphasized the issues related to NbS and developed various frameworks to improve the implementation process of NbS in the literature review, this paper also attempts to suggest a model to address the issues through a step-by-step process model. In this regard, a well-known strategy is emphasized, which is Plan-Do-Check-Act and is adopted in many disciplines from industrial engineering to business management and education (Loyd and Gholston, 2016). The plan stage includes all about the planning process, setting the project objectives and deliverables, defining who the stakeholders are, setting a timeline and clarifying the projects risks and constraints. The do stage simply implies the implementation. The check stage points at the review of the implementation to make sure whether the implementation is ongoing as planned. This stage is the critical one in the cycle because it helps to define the mistakes or unintentionally wrongly going components. It allows fixing the mistakes or improving the status with further actions within the plan. This is also the stage that is pointed out by many researchers as a feedback loop. The act stage is the last one on the cycle in which the decisions taken at the previous stage turns into the real act and adjustments made in the plan. Hence, the PDCA cycle is a tool for continuous improvement as the literature review articulates in this paper. In Japan, it has long been a risk management tool for disaster mitigation. Okada (2004) mentioned that the PDCA cycle can be useful for both pre-disaster and post-disaster stages. Yamada et al. (2011) utilized the PDCA cycle for community-based flood risk mitigation to ensure the participatory approaches (Figure 2).

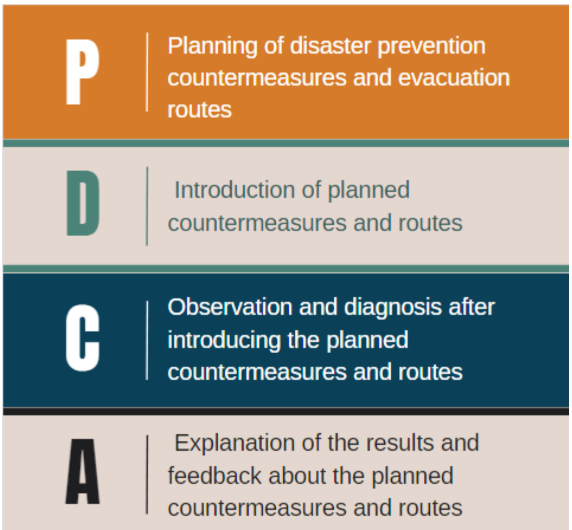

Figure 2 The PDCA cycle application for flood risk mitigation by Yamada et al. (2011).

Since the cycle has four stages, one can find it similar to another well-established approach, the disaster management cycle, which has Response, Recovery, Mitigation and Preparation. Unlike the conventional cycle, the matching of the stages can be interpreted as Mitigation/Plan, Recovery/Do, Response/Check and Preparation/Act. To define better, the plan stage concerns the questions of how to mitigate, the do stage concerns how well implemented for recovery, the check stage concerns how successful the response was, and the act stage concerns the lacking parts that cause failure in the preparation planning. Thinking from this angle, the two cycles match efficiently.

NbS require a serious amount of time and financial investment. The implementation of NbS is not an issue for countries with high GDPs but is a big concern for countries with considerably low GDPs. Because we are living in an information and technology era, technological developments should be adopted and adjusted according to the needs for better planning and implementation. In this regard, a contemporary approach can be helpful, which is Digital Twin Construction (DTC). Sacks et al. (2020) provide a convincing argument for how DTC is applicable within the PDCA cycle and also the other way. They matched the Plan/Model, the Do/Build, the Check/Monitor and interpret, and the Act/Evaluate and improve. If NbS aim to bring solutions to the needs from a multi-dimensional approach for a better urban environment and urban system than the previous status, then the testing from a replicated model becomes more critical than ever. Digital modelling, digital monitoring and evaluating to improve the solutions surely save time and money not only from the side of the authorities but also for the urban residents, who are the taxpayers. Delgado and Oyedele (2021) also point out the benefits of DTC, how the conceptual planning turns into a model to process and test so more than one scenario can be seen with the estimated results. To give a preliminary example, Pillai et al. (2022) applied DTC modelling to simulate their NbS proposals and to find an optimal seagrass for the coastal zone of Emilia-Romagna, which area is vulnerable to coastal erosion and storm surges. While the DTC approach is at a rudimentary stage, it is for sure in future it will be more utilized by designers, investors and authorities.

6. Conclusion

For the past few decades, the discussion of the human impact on the environment has been circling the theme of 'sustainability'. Lately, the argument has changed to 'Nature-based Solutions'. This time the argument considers the natural environment as much as the built environment. Today, world populations and leaders are convinced by the fact that climate change affects our natural environment and more seriously, it threatens our built environment with the increasing frequency of disasters occurring. Accordingly, the sustainability approach moved from being human-centred to ecosystem-centred as the approach began to take into account more extensively the recovery and restoration of the natural environment than the question of how we build with less impact on nature. NbS have several successful examples around the world cities and the evaluations revealed promising outcomes. As the literature articulates the positive consequences of NbS interventions; it seems the most suitable approach to balance the human impact on the natural environment.

However, it should be emphasized that NbS are beyond simple infrastructure projects and cannot be diminished to the question of how to design green spaces randomly over a city without thinking more complex as this paper discussed the multi-dimensionality of NbS. None of the arguments (the principles of NbS and barriers to NbS) rose is less important than the others or vice versa. The implementations should not be viewed as a financial burden. In some cases, NbS can be considered a more cost-effective approach than building grey infrastructure. They are investments in the life quality of the residents and preventive tools in the risk management of cities. As the number of NbS implementations increases in the world, researchers need to evaluate and identify the outcomes objectively so that further examples will not repeat the same mistakes but will improve the replications.

The paper attempted to frame the NbS clearer for scholars interested in the subject. The literature review provided a comprehensive discussion regarding the issues in NbS approaches and implementations from different angles. It should be kept in mind that NbS implementations are not magical tools that result in the short term. Long-term visions should be targeted and post-implementation evaluations are necessary to understand how the human and non-human nature co-benefit from the interventions. It is recommended that future scholars to research on NbS case studies to reveal the impacts and outcomes based on the arguments provided in this paper.

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Resume

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