Review

Not peer-reviewed version

A Review: Nature-Based Solutions

Chinomnso ONWUBIKO * and Dennis Worlanyo *

Posted Date: 20 September 2024

doi: 10.20944/preprints202409.1583.v1

Keywords: nature-based solutions; climate change; coastal ecosystems; ecosystem-based adaptation

Review

A Review: Nature-Based Solutions

Chinomnso C. Onwubiko [1,*] and Denis Worlanyo Aheto [2]

[1] Department of Fisheries and Aquatic Sciences, School of Biological Sciences, College of Agriculture and Natural Sciences, University of Cape Coast, Cape Coast, Ghana
[2] Africa Centre of Excellence in Coastal Resilience (ACECoR), Centre for Coastal Management, University of Cape Coast, Cape Coast, Ghana
* Correspondence: chinomnso.onwubiko@stu.ucc.edu.gh

Abstract: Coastal zones, although vital for human livelihoods and environmental services, are increasingly vulnerable to climate change, especially communities dependent on marine ecosystems. These areas face significant threats from urbanization, population growth, and climate impacts, leading to biodiversity loss and ecosystem degradation. Recognizing these challenges, the United Nations declared 2021--2030 the Decade for Ecosystem Restoration, led by the UNEP and FAO, with the aim of restoring degraded ecosystems to achieve sustainable development goals (SDGs). The link between healthy ecosystems and disaster risk reduction (DRR) has gained global prominence, especially through the Sendai Framework for Disaster Risk Reduction (SFDRR), which emphasizes the importance of ecosystems in mitigating risks. Despite this, many tools for assessing risks in different ecosystem scenarios remain inaccessible to key stakeholders in disaster management. Advances in spatial modelling have supported ecosystem management, policy-making, and ecosystem health assessment, particularly following the Millennium Ecosystem Assessment. These models have been applied in regions such as the Great Bahamas, Haiti, and the Republic of Congo, helping shape ecosystem-based approaches to development. Moving forward, improving access to spatial tools and models is crucial to enabling effective ecosystem-based DRR and climate adaptation strategies.

Keywords: nature-based solutions; climate change; coastal ecosystems; ecosystem-based adaptation

Introduction

Coastal zones are the most populated areas on earth, although they are increasingly vulnerable to climate change (Turner et al., 2016). These impacts are experienced more by those who are dependent on marine and coastal ecosystems for their livelihood (Savo et al., 2016). Communities that rely on these ecosystems for food, economic development, shoreline security, and recreation are negatively impacted (Thomas et al., 2018). The threats to ecosystems are projected to accelerate in the future with a growing population and urbanization, in addition to climate change (Seto et al., 2011). The resulting effects include the loss of biodiversity and ecosystem services (Artmann & Breuste, 2015).

The UN (United Nations) has pronounced the decade (2021-2030) as the ocean decade for Ecosystem Restoration. This movement is led by the United Nations Environment Programme (UNEP) and the Food and Agriculture Organization (FAO) of the United Nations to build a broad and globally based movement to champ the restoration of ecosystems, thereby putting the planet on track for a sustainable future. Additionally, there is a call for the preservation and restoration of ecosystems throughout the world for the good of society and the environment, with the goal of halting ecosystem degradation and restoring it to achieve the United Nation's Sustainable Development Goals (UN SDGs). However, these goals can be accomplished only with a healthy ecosystem (Mills et al., 2020).

Coastal ecosystems are crucial for disaster risk reduction (DRR). This relationship has gained increased global attention. The global guideline for disaster risk reduction (DRR) strategies from 2015-- 2030, the Sendai Framework for Disaster Risk Reduction (SFDRR), recognizes Ecosystem-based Disaster Risk Reduction (Eco-DRR) as a crucial strategy for risk reduction and increasing resilience (UNISDR, 2015). This has made significant progress since the Hyogo Framework for Action (HFA) was proposed (UNISDR, 2005). This recognition of the importance of ecosystems in risk assessments is another significant progress under the Sendai Framework for Disaster Risk Reduction (SFDRR) priority 1. This allows stakeholders to visualize the connection between ecosystem conditions and disaster risk (Estrella et al., 2016). The increasing global perception notwithstanding, the tools required to visualize risks under different ecosystem scenarios remain inaccessible to stakeholders in disaster risk reduction and climate change adaptation (Ferrario et al. 2014). This has led to an increase in the number of integrated spatial models (McCallum et al., 2016).

Additionally, spatial models have been widely used to assess ecosystem management (Yang et al., 2011) and ecosystem health (DeFries & Pagiola, 2005). The development of spatial tools and models for evaluating ecosystem benefits and their use in development plans was facilitated by the 2005 Millennium Ecosystem Assessment (MEA) (Assessment, 2005; Guerry et al., 2012; Mooney, 2011). This has been used to facilitate policies and decisions in Great Bahamas, Haiti, and the Republic of Congo (EME, 2011; Watson et al., 2011).

Background to the Study

Recently, the repercussions of ignoring the protective role that natural ecosystems provide against flooding, particularly as changes in land use and climate result in increased flood risk, have been alarming. Floods are the most prevalent and devastating of all disasters globally, especially in coastal areas. Flooding accounted for approximately 43% of the number of recorded natural disasters between 1994 and 2013, which affected nearly 2.5 billion people (UNISDR, 2015); however, there were few exceptions in 1998 and 2010, where the total losses exceeded $40 billion. As the population grows, climate changes, and urbanization increases, coastal flooding is expected to worsen (Allan, 2021). Sustainable and effective flood risk management is critical to safeguard the public and their livelihoods from future losses from flooding.

Nature-Based Solutions: A Sustainable Approach

The concept of NbS originated from the IUCN during the 2009 COP (Conference of the Parties) by the United Nations Framework Convention on Climate Change (UNFCCC). In 2013, the International Union for Conservation of Nature (IUCN) included nature-based solutions (NbS) as one of the three pillars of its global program. A systematic understanding of how nature and society are interconnected forms the foundation of the NbS concept.

Therefore, any practice that opposes biodiversity and natural processes does not qualify as an NbS practice.

Presently, the importance of NbS as a long-term, resilient approach to reducing disaster risk has become widely recognized (World Bank, 2017). Initiatives have been set up around the world to aid communities in adjusting to and reducing the impacts of climate change (Chausson et al., 2020; Kabisch et al., 2017; Kalantari et al., 2018). The use of NbS is one strategy. Ecosystem-based strategies such as ecological restoration, ecosystem-based adaptation, green infrastructure, ecosystem-based management, ecosystem-based disaster risk reduction and ecological engineering are all included under the term NbS (Cohen-Shacham et al., 2016). These approaches are referred to as NbS because they leverage biodiversity and ecosystem services to address climate-related societal challenges. The capacity of NbS to address flood risk has received increased attention (World Bank, 2017). Until recently, flood risk management involved only conventional engineering measures, also known as hard engineering or gray measures. The NbS concept has evolved as a sustainable alternative to traditional gray approaches. These interventions can be green measures or hybrid measures. These approaches alleviate drought, flood, and erosion, thereby reducing vulnerability while also providing several benefits to people and the environment. EbA approaches have been marked as an area of priority for investment in global funds (the Green Climate Fund). However, there are still gray areas in its comprehensive assessment, implementation, and standardized methodology. As a result, it is important to establish guidance and standards for NbS. These resources can assist in the design of projects, support implementers and attract funders involved in the development of successful NbS projects. Moreover, the guidance helps in establishing a shared understanding of the anticipated effectiveness and outcomes in reducing risks.

A study by Seddon et al. (2021) highlighted the consent and full engagement of indigenous people and local communities as one of the guiding principles of NbS. This notwithstanding, they are frequently disregarded when making decisions regarding the use of land related to the management and protection of ecosystems, leading to the neglect of human rights (Bayrak & Marafa, 2016). This results in a weak framework and misappropriation of natural resources (Vidal, 2008), thereby displacing and marginalizing vulnerable communities (Scheidel & Work, 2018; Veldman et al., 2019). Only by complying with these principles can NbS become resilient and sustainable, thereby addressing issues of climate change and biodiversity loss, both now and in the future (Seddon et al., 2021). The effectiveness of engagement with stakeholders has been highlighted (Kabish et al., 2016; Seddon et al., 2020). Stakeholder engagement in NbS is not a new concept and has significantly progressed in recent years (Mabelis & Maksymiuk, 2009). Stakeholder involvement in NbS has become increasingly important in recent years. This allows for a holistic and more effective approach to improve the resilience of socioecological systems. Recent studies have recommended the incorporation of indigenous and local knowledge in the design and application of solutions (Kabisch et al., 2016; Raymond et al., 2017). However, indigenous stakeholders are still not included in these decisions. This is mainly because some believe that involving many stakeholders slows down policy and planning due to differing viewpoints (Raymond et al., 2017).

Climate change is attributed to human activities that disrupt the Earth's atmosphere and cause long-term variations (Albrecht & Arts, 2005). Studies have shown changes in temperature and patterns of rainfall and wind as a result of climate variability, and these changes are predicted to continue (Sharma & Ravindranath, 2019). These changes impact ecosystems and the benefits derived from them. These increased adverse impacts exert pressure on human populations and natural systems, which has in turn aggravated existing environmental threats, posing new threats and hindering our ability to fully achieve sustainable development goals (SDGs). Nature-inspired solutions are put in place worldwide to reduce the impacts of climate change. Research has indicated that Africa will directly experience the effects of climate change on weather patterns and agricultural productivity, with variations across different regions of the continent (Collier et al., 2008). Varying weather observations have recently been made in Nigeria (Elisha et al., 2017). As rainfall durations increase, flooding and run-offs have resulted in many states in Nigeria (Enete., 2014), more so in coastal areas. Some parts of the country are expected to experience increased rainfall, i.e., the southern part, which will cause flooding and submersion of coastal lands (Akande et al., 2017). There have also been reports of persistent drought in northern Nigeria caused by reduced rainfall and higher temperatures, resulting in a significant decrease in the volume of Lake Chad and other lakes in the country (Amanchukwu et al., 2015; Dioha & Emodi, 2018).

Changes in land use/land cover and climate change impact ecosystem health (Mantyka-Pringle et al., 2015). As the impacts of climate change are projected to increase, ecosystems and ecosystem services will be negatively impacted (Bellard et al., 2012; Hulme et al., 2001; Knutson et al. 2010; Midgley & Bond, 2015; Sala et al., 2000; Sintayehu, 2018; Webster, 2005). However, progress has been made as a result of the increased awareness of the role of nature. Stiff and fixed coastal ecosystems such as mangroves provide coastal resilience against floods. With approximately 40% of the human population living along coastlines (CIESIN, 2007), coastal dwellers are at risk of flood and storm surges. As engineered infrastructures become outdated, there is a need for more sustainable measures (Turner et al., 1996).

As the recognition of the sustainability of nature-based solutions (NbS) for mitigating and adapting to societal challenges such as flooding, drought, and storm surges continues to increase (Anderson and Renaud, 2021), the importance of public acceptance in reducing disaster risk is being acknowledged in hazard reduction policies (Sarzynski & Cavaliere, 2018). The United Nation's global framework for disaster reduction (2015--2030) promotes inclusivity through engagement and participation (UNISDR, 2015), whereas the European Union Water Framework Directive emphasizes public participation as a requirement in addressing flooding issues (European Commission, 2000).

The 2004 Indian Ocean incident brought about a change in perspective regarding the role of natural ecosystems, emphasizing the importance of coexisting with nature rather than manipulating it (de Groot, 2012; Anderson and Renaud, 2021). This shift led to the recognition of harnessing the services provided by these ecosystems (Renaud et al., 2016). According to the IUCN, nature-based solutions are actions that safeguard, responsibly oversee, and revive natural or altered ecosystems to effectively address societal issues while benefiting both human well-being and biodiversity. The Convention on Biological Diversity (CBD, 2009) defines NbS as the utilization of biodiversity and ecosystem services as a component of a comprehensive strategy to help people adapt to the adverse effects of climate change.

Floods account for approximately 86% of the disasters of the last decade; however, historical and accurate data prior to 1985 are lacking. A study by Nkwunonwo (2016) highlighted a lack of historical and accurate data on flood events prior to 1985. Several influences, such as increasing urbanization, SLR and climate change, have recently increased concerns about flooding (Peduzzi et al., 2011; Raaijmakers et al., 2008). Over the last twenty years, flood reports have been substantial, causing billions of dollars in damage (Guha-Sapir et al., 2013). The EM-DAT database has recorded over 3700 flood disasters spanning a period of 1985--2014 (Shen & Hwang, 2019). These events were responsible for several death records in Asia while rendering many homeless (Tapsell & Tunstall, 2008). In Nigeria, flooding is a critical issue (Obeta, 2014) and therefore should receive the utmost attention. The prevalent flood cases and potential solutions to related challenges have received considerable attention. However, deliberations are focused on geopolitical regions, communities and states (Adedeji et al., 2012; Aderogba et al., 2012; Aderogba, 2012a; Agbonkhese et al., 2014; Obeta, 2014; Terungwa & Torkwase, 2013). In addition to the causes of this menace, poor environmental management, a lack of proper urban planning and changes in climate are other possible factors (Aderogba et al., 2012). Despite the overwhelming paucity of concrete measures and ability to address hazards fully in the country, there have been extensive considerations for coordinated efforts. They include enhanced public enlightenment programmes, social responses, policy directives, environmental and infrastructural planning, and physical intervention (Agbola et al., 2012). Additional approaches explored include community-level early warning signals, humanitarian aid from private and government sectors, and increased preparedness through capacity building (Adedeji et al., 2012; Agbonkhese et al., 2014). A study by Terungwa and Torkwase (2013) highlighted the need for technology and science to be included in environmental education in school curricula. Additionally, flood hazard mapping and assessments of the vulnerability of people and property play crucial roles in fostering community resilience to floods (Ajibade et al., 2013). It is crucial to increase the current strength and capabilities of local communities in Nigeria to address flood risk scenarios (Obeta, 2014). The increased frequency has been credited to climate change and poor urban planning. Between 1985 and 2014, approximately 11 million lives were affected by flooding in Nigeria, resulting in approximately 1100 deaths and property losses amounting to US$17 billion (Nkwunonwo, 2016). However, Rivers State, like the other Niger Delta States, have more records of flooding.

The Role of Natural Ecosystems in Climate Change Adaptation and Disaster Risk Reduction

The role of ecosystem services in adapting to climate change and reducing disaster risk has received increased attention (CBD, 2009; Munang et al., 2013; Renaud et al., 2013). The discussions on climate change adaptation and disaster risk reduction hinged on ecosystems and their services, which are also included in policy documents (CBD, 2009). These services are the benefits derived from natural ecosystems (MA, 2005). Studies have shown the role of natural ecosystems in reducing disaster risk (Badola & Hussain, 2005; Renaud et al., 2013); however, these ecosystems have not been exempted from degradation and losses (MA, 2005), thereby reducing their capacity to protect. Therefore, there is a need to strategically manage ecosystems to ensure that they provide the maximum number of services that are needed in society in the face of disasters and a changing climate. However, it is vital to realize that these limits solely depend on ecosystem-based solutions (Doswald & Osti, 2013; Renaud et al., 2013.

 doi:10.20944/preprints202409.1583.v1

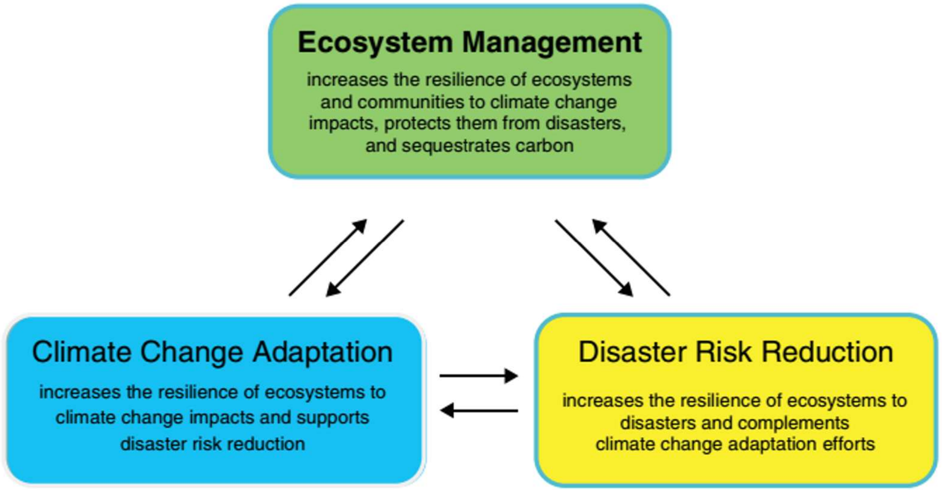


Figure 1. The role of natural ecosystems in climate change adaptation and disaster risk reduction (adapted from Munang et al., 2013).

As the global awareness of climate change impacts increases, i.e., floods, there is, therefore, a need to apply an integrated approach in combating this threat. The novelty of this study lies in its novelty. The integrated approach to flood risk management involves the use of quantitative and qualitative methods by involving relevant stakeholders, identifying gaps in the framework of stakeholders in disaster risk reduction and climate change adaptation, mapping the land use/land cover of the study area and modelling the protective role of mangroves in the study area.

Literature Review

This chapter contains a review of the literature on assessing flood risk in coastal communities via quantitative and qualitative methods. Concepts such as nature-based solutions, the linkages between ecosystem conditions and disaster risk reduction and United Nations SGDs are explored.

Flooding is the second most common disaster and accounts for approximately 40% of all natural disasters worldwide (Noji, 1991; Ohl & Tapsell, 2000). It also accounts for most of the challenges faced by communities worldwide, as frequent and intense flooding events continue to threaten human settlements and infrastructure. In recent decades, there has been a growing recognition that traditional engineering approaches alone are insufficient to mitigate flood risk sustainably. This literature review aims to explore the use of nature-based solutions for managing flood risk and assess their effectiveness in preserving ecosystem services while enhancing resilience. To establish a common ground, it is paramount to define the key terms prevailing throughout this review. “Flood risk” refers to the potential adverse consequences resulting from flooding, including damage to structures, loss of life, environmental degradation, and economic impacts. “Nature-based solutions” encompass strategies that utilize or mimic natural processes to address societal challenges, such as flood management, while simultaneously offering additional benefits such as biodiversity conservation, carbon sequestration, and recreational opportunities.

Understanding the factors leading to floods is essential for effective disaster preparedness and planning. The primary causes can be categorized into climatic, hydrologic, and anthropogenic factors. Climatically, sea level rise and extreme precipitation events such as heavy rainfall play critical roles in triggering floods. Hydrologically, the floodplain topography, river discharge, and water retention capacity significantly impact flood intensity. Anthropogenic influences include land-use changes, deforestation, urbanization, and inadequate drainage systems. Analysing these causes provides insights into addressing root issues to prevent or minimize flood occurrence.

The impacts of floods extend beyond immediate damage and trigger long-term social, economic, and environmental consequences. Loss of life, property, infrastructure, displacement and

 doi:10.20944/preprints202409.1583.v1

psychological trauma are some of the primary societal effects. Economically, direct losses include damage to property, agriculture, business interruption, and increased demands on emergency services. Moreover, indirect costs arise through postdisaster recovery efforts. Ecologically, floods alter ecosystems, causing habitat degradation, biodiversity loss, and pollution due to sedimentation, increasing vulnerability for flora and fauna. Climate change exacerbates the frequency and intensity of floods due to increased sea level rise, altered precipitation patterns, and increased temperature.

An integrated approach encompassing both structural and nonstructural strategies ensures a comprehensive framework for effective flood risk management. It is vital to employ a multifaceted approach that combines structural and nonstructural measures. Structural measures involve constructing reservoirs, diversion channels, flood embankments, and wetland restoration, whereas nonstructural measures include flood forecasting, early warning systems, land-use zoning, establishment of rescue teams, evacuation planning, and community-based initiatives.

The role of healthy and functional natural ecosystems in reducing flood risk has gained global recognition. Extensive studies have demonstrated that wetlands and forested watersheds act as natural buffers or sponges, absorbing excess water during rainfall events and efficiently attenuating peak flow intensity, thus minimizing downstream flood hazards (Vallecillo et al., 2020; Fu et al., 2013; Mitsch et al., 2001; Kundzewicz & Menzel, 2005; Renaud et al., 2013; Iacob et al., 2014; Rojas et al., 2022; Brouwer & Van, 2004; Narayan et al., 2017; Millennium Ecosystem Assessment, M. E. A. 2005; Sutton-Grier et al., 2015; Busayo et al., 2022; Leal Filho et al., 2021; Ntajal et al., 2017; Belle et al., 2018). Some examples include the ability of green spaces to reduce temperatures (Maimaitiyiming et al., 2014) and the role of mangroves in reducing the impacts of sea level rise and storm surge. NbS has gained popularity as an umbrella concept that integrates nature-based approaches such as ecosystem-based disaster risk reduction (Eco-DRR) and ecosystem-based management (EbM) to address the impacts of climate change (Dorst et al., 2019) and the loss of biodiversity and human well-being. The benefits of NbS have been acknowledged by the scientific community, with the Sixth Assessment Report of the IPCC acknowledging the effectiveness of NbS in reducing a range of climate change risks to ecosystems, biodiversity, and people with several cobenefits (IPCC, 2022).

Understanding How Effective Nature-Based Solutions Address the Impacts of Climate Change

Globally, climate change and biodiversity loss are the two enormous challenges of the 21st century (Johnson et al., 2022; Key et al., 2022). Climate change has led to increased sea-level rise, increased climate variability and intense floods (IPCC, 2018). This has led to severe social and economic consequences in middle-income countries, thereby increasing their vulnerability to the impacts of climate change (WEF, 2020). These challenges cannot be solved autonomously as a result of their interdependent relationships. For example, a loss in biodiversity can result in deforestation and the release of greenhouse gases, which cause global warming, whereas increased urbanization can result in exposure to the harsh impacts of climate change (IPCC, 2022; Hamilton & Friess, 2018; Johnson et al., 2021). Recently, the dominant approaches for addressing the impacts of climate change on people and infrastructure have relied on hard-engineered solutions (Jones et al., 2012), such as the use of sea walls to reduce the impacts of sea level rise and storm surges (Enríquez-de-Salamanca et al., 2017), which have been unsustainable. However, there is a growing recognition of the sustainable role of NbS in rescuing the impacts of climate change (Hobbie & Grimm, 2020). Nature-based solutions (NbS) harness the benefits provided by different types of ecosystems to increase human well-being while preserving biodiversity (Munang et al., 2013). Therefore, NbS is suitable for addressing both climate change and biodiversity loss.

Nature-based solutions are approaches that are used to address societal challenges (Seddon et al., 2019). They involve a range of actions that protect ecosystems, thereby providing benefits to people (Cohen-Shacham et al., 2016). NbS includes established approaches such as ecosystem-based adaptation, ecosystem-based disaster risk reduction, natural climate solutions, green and blue infrastructure, and landscape restoration (Cohen-Shacham et al., 2016; 2019; Griscom et al., 2017). These services utilize a range of ecosystem services from healthy and resilient natural ecosystems. One of the benefits of NbS is the ability to address multiple SDGs simultaneously. The role of NbS in

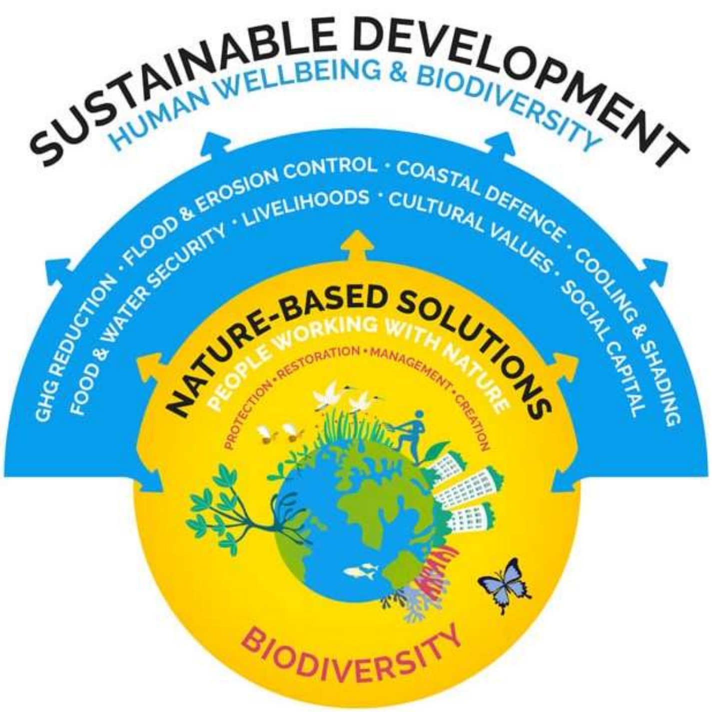
 doi:10.20944/preprints202409.1583.v1

climate change adaptation has increased, leading to recognition by the IPCC (2019) and the IPBES (2019), which have been endorsed by the World Economic Forum (WEF, 2020). The United Nations Framework Convention on Climate Change (UNFCCC) also emphasizes NbS, and the Paris Agreement of UNFCCC (2015), where parties are requested to acknowledge the importance of conservation and enhancement, as suitable sinks and reservoirs for greenhouse gases," plus it is crucial to emphasize the importance of safeguarding the integrity of all ecosystems. The outcome was the inclusion of NbS in the nationally determined contributions by approximately 66% of the Paris Agreement signatories (Seddon et al., 2020). However, the execution of these actions varies as a result of the level of economic development.

Currently, evidence of NbS is spread across various fields, hindering the synthesis of its effectiveness in climate change adaptation. However, some studies have focused on compiling this evidence (Bonnesoeur et al., 2019; Dadson et al., 2017; Filoso et al., 2017; Morris et al., 2018; Rowiński et al., 2018). Stakeholders are encouraged to consider the synergies and trade-offs associated with NbS to maximize its benefits. A study by Seddon et al. (2020) outlined 4 guiding principles of NbS: (1) it is not an alternative to fossil fuels; (2) it involves ecosystems in the ocean and on land; (3) indigenous people and local communities must be consulted; and (4) it must offer tangible benefits for biodiversity. Only then can we create NbS that is strong and resilient, addressing the persistent issues of climate change and loss of biodiversity while also sustaining man and nature (Seddon et al., 2021). This review considered coastal ecosystems in Nigeria, Africa, and globally.

Conceptual Framework of the Research

This research work was guided by an integrated approach to address flood risk in coastal communities. Figure 2 demonstrates how nature can be valuable in combating climate change. As the evidence base for the degradation of ecosystems has developed (IPCC, 2018), a more sustainable alternative is needed. NbS are actions used to address societal challenges that involve working with nature (Seddon et al., 2020) while also supporting a wide range of SDGs (Maes et al., 2019). NbS actions are categorized under the protection, restoration, and management of ecosystems. Studies have shown that NbS is key to the achievement of the majority of the SDGs (Chausson et al., 2020; Hanson et al., 2020; Seddon et al., 2020). The SDGs addressed include Goal 13-Climate Action, specifically Target 2 (strengthening the resilience and adaptive capacity to climate-related disasters), and Goal 15-Protecting biodiversity.



 doi:10.20944/preprints202409.1583.v1

Figure 2. Nature as an ally in fight against climate change (Seddon et al., 2021).

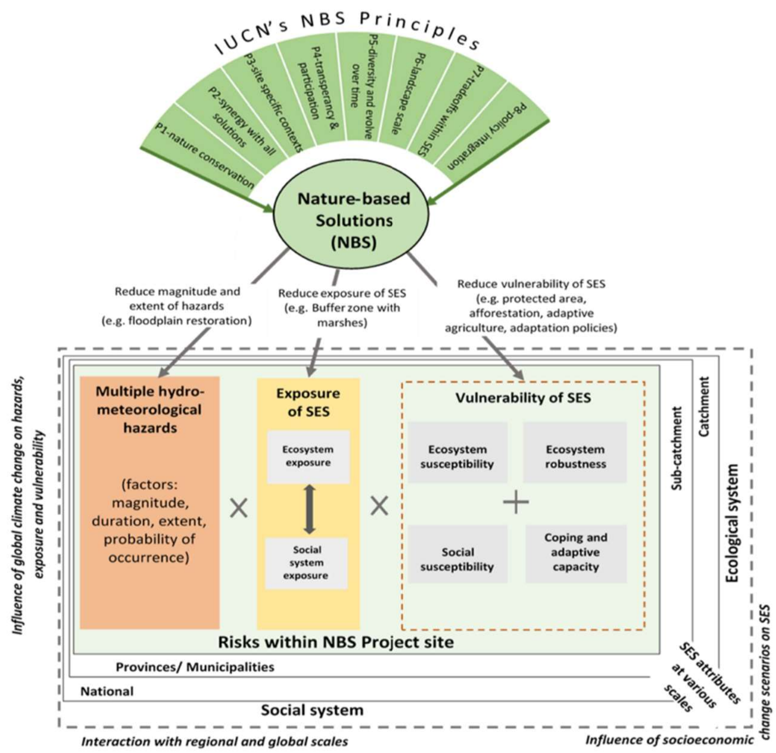


Figure 3. Conceptual framework for vulnerability and risk assessment in the context of nature-based solutions (adapted from Shah et al., 2020).

Different frameworks have been developed to assess the vulnerability and risk of social-ecological systems (SES) to hazards, taking into account different scenarios. However, no frameworks have been specifically designed to implement NbS for hydrometeorological concerns. Given the importance of balancing the ecological and social benefits of NbS, risk and vulnerability assessments should equally consider ecological and social aspects in the implementation area. This conceptual framework was created primarily with the main elements of the delta-SES risk assessment framework in mind, as well as other frameworks of a similar nature that have been suggested in recent studies and the proposed NbS guidelines endorsed by the IUCN. The framework's main elements, according to Shah et al. (2020), are as follows: (i) the vulnerability of social-ecological systems (SES) to different hydrometeorological hazards (such as floods and droughts); (ii) the vulnerability of SES, which comprises ecosystem robustness, social susceptibility, ecosystem susceptibility, and the coping and adaptive capacity of the social system; (iii) the risks at the NbS project site are determined by how exposure, vulnerability, and hazard interact; and (iv) the impacts of hydrometeorological hazards on the SES near or on the project site for NbS. While the NbS project site with particular SES characteristics would constitute the basic space for risk assessment, this framework also shows the interactions between social and ecosystem systems as well as the impacts of numerous risks and hazards from the local to the global level. The framework also takes into account system sustainability with the intervention of NbS and other strategies for risk reduction, as well as changes that reflect the progress of the ecological components of NbS. To operationalize the concept, a risk assessment method based on indicators might be applied.

Origin of Nature-Based Solutions

The framing of NbS has evolved over time (Seddon et al., 2021). Studies have documented evidence that local communities working with nature adapt to the impacts of disaster risk and climate change. A previous study by Kairo et al. (2001) documented examples of strategies such as the reforestation and afforestation of mangroves to provide flood protection. In 2008, the World Bank released a publication on NbS, describing the various benefits it derives from investing in climate change adaptation measures that encourage the conservation of biodiversity (Mackinnon et al., 2019). Furthermore, in the event of the United Nations' 15th Conference of the Parties, the IUCN defined NbS as measures to reduce poverty; secure water, food, and energy sources; address climate change impacts; and foster economic development. The IUCN's 2013--2016 Program promoted NbS as a major pillar (IUCN, 2012). According to the European Commission (2015), the European Union (EU) implemented NbS with a special emphasis on green infrastructure (GI). The IUCN defines NbS in terms of measures that promote human well-being and biodiversity, whereas the EC highlights innovation and economic cost-effectiveness with a view to using nature's potential to address social concerns (European Commission, 2000). NbS consists of green infrastructure (GI), ecosystem-based disaster risk reduction (Eco-DRR), agroecology, ecological restoration (ER), EbA, REDD+ and ecological engineering (EE).

Biodiversity and People at the Foundation of Nature-Based Solutions

NbS offers a variety of advantages for both biodiversity and human well-being. This is in line with its Global Standard and IUCN framing (Cohen-Shacham et al., 2019; IUCN, 2020), which also plainly differentiates NbS from activities that manipulate nature and destroy biodiversity. However, activities that conserve biodiversity also support societal benefits by increasing the distribution of several ecosystem services in the short term while also supporting the resilience and health of ecosystems in the long term. For the sustainable and successful implementation of NbS, the consent of indigenous people must be consulted in a way that respects their culture. This also guarantees its effectiveness and resilience as well as the involvement of all relevant stakeholders and local communities. This helps foster ownership and empowerment in local communities.

Effectiveness of Nature-Based Solutions

There is increased awareness of engaging in nature-based solutions to alleviate flood challenges globally, as well as in Africa (Kalantari et al., 2018; Seddon et al., 2020). Previous studies have shown that forests and natural wetlands can be used to change the hydrological cycle (Dadson et al., 2017, Filoso et al., 2017) and that site-based interventions such as constructed wetlands can be useful for treating wastewater in developing nations. Additionally, studies have reported increased focus on curbing water insecurity (Acreman et al., 2021), drought and flood risk mitigation (Kalantari et al., 2018), and climate change on the continent. Although NbS was featured in the National Climate Change Adaptation Policies (Seddon et al., 2020), there is still not enough scientific proof of its effectiveness (FAO, 2015). This has led to unpopular narratives that are inconsistent with science (European Commission, 2000). A review by Acreman et al. (2021) revealed that approximately 75% of deforestation case studies revealed an increase in downstream flood peak flow, which was based on the example of a study by Mumeka (1986), whereas approximately 25% showed no effect (Mwendera, 1994). A study by Nyika and Dinka (2022) reported that approximately 38.2% of total searched outputs on NbS are related to institutions in South Africa with interest in ecology and environmental sciences (see Figure 4).

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 20 September 2024 doi:10.20944/preprints202409.1583.v1

Figure 4. Countries leading in nature-based solution research in Africa and globally (Nyika & Dinka, 2022).

Specific Applications of Nature-Based Solutions

Nature-based strategies are employed in solving societal challenges (IUCN, 2020), such as climate change and disaster risk. This study evaluated how NbS can contribute to addressing adaptation to climate change and minimizing disaster risk.

Nature-Based Solutions for Climate Change Adaptation

NbS is an umbrella term that includes all ecosystem-based approaches, which include green infrastructure (GI), ecosystem-based adaptation (EbA), ecological restoration (ER), ecological engineering (EE) and blue infrastructure (BI). These approaches are increasingly used in adapting to climate change impacts.

Nature-Based Solutions for Disaster Risk Reduction

Over the last decade, approximately 50% of the population has been affected by flood events (IUCN, 2017s). As climate change accelerates, these disasters are projected to increase. Nature plays a role in reducing disaster risk. A study by the IUCN (2017) reported the role that parks and marshes in the United States played in preventing the prolonged damage caused by Hurricane Katrina (IUCN, 2017). Furthermore, Renaud and Murti (2013) reported that the coastal forests of Sanriku Fukko in Japan reduced the impact of the tsunami in 2011. Approximately 20 million tons of damage in US dollars were saved during the periodic hurricanes in Barbados (Mueller & Bresch, 2014). Furthermore, a study by Duncan et al. (2014) revealed that the proximity of mangrove forests to rice farms in India accelerated the recovery of crops from salt intrusion by three times compared with areas without mangroves. In the coastal city of Leyte, some indigenous residents were unharmed by Typhoon Haiyan, which was attributed to the mangrove forests that acted as a shield against the hazard (IUCN, 2017).

References

1. Acreman, M., Smith, A., Charters, L., Tickner, D., Opperman, J., Acreman, S., ... & Chivava, F. (2021). Evidence for the effectiveness of nature-based solutions to water issues in Africa. Environmental Research Letters, 16(6), 063007.

2. Adedeji, O. H., Odufuwa, B. O., & Adebayo, O. H. (2012). Building capabilities for flood disaster and hazard preparedness and risk reduction in Nigeria: need for spatial planning and land management. *Journal of Sustainable Development in Africa*, *14*(1), 45-58.
3. Adedeji, O. H., Odufuwa, B. O., & Adebayo, O. H. (2012). Building capabilities for flood disaster and hazard preparedness and risk reduction in Nigeria: need for spatial planning and land management. *Journal of Sustainable Development in Africa*, *14*(1), 45-58.
4. Adegbola, A. A., & Jolayemi, J. K. (2012). Historical rainfall-runoff modelling of river Ogunpa, Ibadan, Nigeria. Indian Journal of Science and Technology, 5(5), 2725-2728.
5. Aderogba, K. A. (2012). Qualitative studies of recent floods and sustainable growth and development of cities and towns in Nigeria. International Journal of Academic Research in Economics and Management Sciences, 1(3), 1-25.
6. Aderogba, K. A. (2012a). Qualitative studies of recent flood and sustainable growth and development of cities and towns in Nigeria. International Journal of academic research in Economics and management science, 1(3), 1-25.
7. Agbonkhese, O., Agbonkhese, E. G., Aka, E. O., Joe-Abaya, J., Ocholi, M., & Adekunle, A. (2014). Flood Menace in Nigeria: impacts, remedial and management strategies. Civil and Environmental Research, 6(4),32-40.
8. Agbonkhese, O., Agbonkhese, E. G., Aka, E. O., Joe-Abaya, J., Ocholi, M., & Adekunle, A. (2014). Flood Menace in Nigeria: impacts, remedial and management strategies. Civil and Environmental Research, 6(4),32-40.
9. Ajibade, I., McBean, G. and Bezner-Kerr, R. (2013). Urban flooding in Lagos, Nigeria: Patterns of vulnerability and resilience among women. Global Environmental Change, 23,1714-1725.
10. Akande, A., Costa, A. C., Mateu, J., & Henriques, R. (2017). Geospatial analysis of extreme weather events in Nigeria (1985–2015) using self-organizing maps. *Advances in Meteorology*, *2017*.
11. Albrecht, J., & Arts, B. (2005). Climate policy convergence in Europe: an assessment based on National Communications to the UNFCCC. *Journal of European Public Policy*, *12*(5), 885-902.
12. Allan, R. P., Hawkins, E., Bellouin, N., & Collins, B. (2021). IPCC, 2021: summary for Policymakers.
13. Amanchukwu, R. N., Stanley, G. J., & Ololube, N. P. (2015). A review of leadership theories, principles and styles and their relevance to educational management. *Management*, *5*(1), 6-14.
14. Anderson, C. C., & Renaud, F. G. (2021). A review of public acceptance of nature-based solutions: The 'why', 'when', and 'how 'of success for disaster risk reduction measures. *Ambio*, *50*(8), 1552-1573.
15. Anderson, C. C., & Renaud, F. G. (2021). A review of public acceptance of nature-based solutions: The 'why', 'when', and 'how 'of success for disaster risk reduction measures. *Ambio*, *50*(8), 1552-1573.
16. Artmann, M., & Breuste, J. (2015). Cities built for and by residents: soil sealing management in the eyes of urban dwellers in Germany. Journal of Urban Planning and Development, 141(3), A5014004.
17. Assessment, M. E. (2005). Ecosystems and human well-being: current state and trends.
18. Bayrak, M. M., & Marafa, L. M. (2016). Ten years of REDD+: A critical review of the impact of REDD+ on forest-dependent communities. Sustainability, 8(7), 620.
19. Bellard, C., Bertelsmeier, C., Leadley, P., Thuiller, W., & Courchamp, F. (2012). Impacts of climate change on the future of biodiversity. Ecology letters, 15(4), 365-377.
20. Belle, J. A., Jordaan, A., & Collins, N. (2018). Managing wetlands for disaster risk reduction: A case study of the eastern Free State, South Africa. *Jàmbá: Journal of Disaster Risk Studies*, *10*(1), 1-10.
21. Bonnesoeur, V., Locatelli, B., Guariguata, M. R., Ochoa-Tocachi, B. F., Vanacker, V., Mao, Z., … Mathez-Stiefel, S.-L. (2019). Impacts of forests and forestation on hydrological services in the Andes: A systematic review. Forest Ecology and Management, 433, 569–584. https://doi.org/10.1016/j.foreco.2018.11.033
22. Brouwer, R., & Van Ek, R. (2004). Integrated ecological, economic and social impact assessment of alternative flood control policies in the Netherlands. *Ecological economics*, *50*(1-2), 1-21.
23. Busayo, E. T., Kalumba, A. M., Afuye, G. A., Olusola, A. O., Ololade, O. O., & Orimoloye, I. R. (2022). Rediscovering South Africa: Flood disaster risk management through ecosystem-based adaptation. *Environmental and Sustainability Indicators*, *14*, 100175.
24. CBD, (2019). Voluntary guidelines for the design and effective implementation of EbA to climate change adaptation and disaster risk reduction and supplementary information. In: CBD Technical Series No. 93. Secretariat of the Convention on Biological Diversity (93). https://www.cbd.int/doc/publications/cbd-ts-93-en.pdf.
25. Center for International Earth Science Information Network (CIESIN), Columbia University; and Centro International de Agricultura Tropical (CIAT) (2005). Gridded Population of the World Version 3 (GPWv3). Palisades, NY: Socioeconomic Data and Applications Center (SEDAC), Columbia University.
26. Chausson, A., Turner, B., Seddon, D., Chabaneix, N., Girardin, C. A., Kapos, V., ... & Seddon, N. (2020). Mapping the effectiveness of nature-based solutions for climate change adaptation. Global Change Biology, 26(11), 6134-6155.

27. Chausson, A., Turner, B., Seddon, D., Chabaneix, N., Girardin, C. A., Kapos, V., ... & Seddon, N. (2020). Mapping the effectiveness of nature-based solutions for climate change adaptation. Global Change Biology, 26(11), 6134-6155.
28. Cohen-Shacham, E., Andrade, A., Dalton, J., Dudley, N., Jones, M., Kumar, C., ... & Walters, G. (2019). Core principles for successfully implementing and upscaling Nature-based Solutions. Environmental Science & Policy, 98, 20-29.
29. Cohen-Shacham, E., Andrade, A., Dalton, J., Dudley, N., Jones, M., Kumar, C., ... & Walters, G. (2019). Core principles for successfully implementing and upscaling Nature-based Solutions. Environmental Science & Policy, 98, 20-29.
30. Cohen-Shacham, E., Walters, G., Janzen, C., & Maginnis, S. (2016). Nature-based solutions to address global societal challenges. IUCN: Gland, Switzerland, 97, 2016-2036.
31. Cohen-Shacham, E., Walters, G., Janzen, C., & Maginnis, S. (2016). Nature-based solutions to address global societal challenges. IUCN: Gland, Switzerland, 97, 2016-2036.
32. Collier, P., Conway, G., & Venables, T. (2008). Climate change and Africa. *Oxford review of economic policy*, *24*(2), 337-353.
33. Dadson, S. J., Hall, J. W., Murgatroyd, A., Acreman, M., Bates, P., Beven, K., … Wilby, R. (2017). A restatement of the natural science evidence concerning catchment-based 'natural' flood management in the UK. Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences, 473(2199), 20160706. https://doi.org/10.1098/rspa.2016.0706
34. Dadson, S. J., Hall, J. W., Murgatroyd, A., Acreman, M., Bates, P., Beven, K., … Wilby, R. (2017). A restatement of the natural science evidence concerning catchment-based 'natural' flood management in the UK. Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences, 473(2199), 20160706. https://doi.org/10.1098/rspa.2016.0706
35. De Groot, R., Brander, L., Van Der Ploeg, S., Costanza, R., Bernard, F., Braat, L., ... & Van Beukering, P. (2012). Global estimates of the value of ecosystems and their services in monetary units. *Ecosystem services*, *1*(1), 50-61.
36. DeFries, R., Pagiola, S., Adamowicz, W. L., Akcakaya, H. R., Arcenas, A., Babu, S., ... & Thönell, J. (2005). Analytical approaches for assessing ecosystem condition and human well-being. Ecosystems and human well-being: current state and trends, 1, 37-71.
37. Dioha, M. O., & Emodi, N. V. (2018). Energy-climate dilemma in Nigeria: Options for the future. In *IAEE Energy Forum* (Vol. 2, pp. 29-32).
38. Dorst, H., Van der Jagt, A., Raven, R., & Runhaar, H. (2019). Urban greening through nature-based solutions–Key characteristics of an emerging concept. *Sustainable Cities and Society*, *49*, 101620.
39. Elisha, I., Sawa, B. A., & Ejeh, U. L. (2017). Evidence of climate change and adaptation strategies among grain farmers in Sokoto State, Nigeria. *IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT)*, *11*(3), 1-7.
40. EME [Evaluacio'n de los Ecosistemas del Milenio de Espa~na] (2011) Sı´ntesis de resultados. Fundacio´n Biodiversidad. Ministerio de Medio Ambiente, y Medio Rural y Marino. Madrid: Spain.
41. Enete, I. C. (2014). Impacts of climate change on agricultural production in Enugu State, Nigeria. *Journal of Earth Science & Climatic Change*, *5*(9), 234.
42. Enríquez-de-Salamanca, Á., Díaz-Sierra, R., Martín-Aranda, R. M., & Santos, M. J. (2017). Environmental impacts of climate change adaptation. Environmental Impact Assessment Review, 64, 87–96. https://doi.org/10.1016/j.eiar.2017.03.005
43. Estrella, M., Renaud, F. G., Sudmeier-Rieux, K., & Nehren, U. (2016). Defining new pathways for ecosystem-based disaster risk reduction and adaptation in the post-2015 sustainable development agenda. Ecosystem-based disaster risk reduction and adaptation in practice, 553-591.
44. European Commission, (2000). Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for community action in the field of water policy. Official Journal of the European Communities L 327: 1–72.
45. European Commission, (2000). Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for community action in the field of water policy. Official Journal of the European Communities L 327: 1–72.
46. European Commission, (2000). Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for community action in the field of water policy. Official Journal of the European Communities L 327: 1–72.
47. FAO, (2015). Towards effective national forest funds FAO Forestry Paper No. 174. Rome, Italy Authored by Matta R (available at: www.fao.org/3/a-i4359e.pdf)
48. Ferrario, F., Beck, M. W., Storlazzi, C. D., Micheli, F., Shepard, C. C., & Airoldi, L. (2014). The effectiveness of coral reefs for coastal hazard risk reduction and adaptation. Nature communications, 5(1), 1-9.
49. Filoso, S., Bezerra, M. O., Weiss, K. C., & Palmer, M. A. (2017). Impacts of forest restoration on water yield: A systematic review. PLoS One, 12(8). https://doi.org/10.1371/journal.pone.0183210

50. Fu, B., Wang, Y. K., Xu, P., & Yan, K. (2013). Mapping the flood mitigation services of ecosystems–A case study in the Upper Yangtze River Basin. *Ecological Engineering*, *52*, 238-246.
51. Griscom, B. W., Adams, J., Ellis, P. W., Houghton, R. A., Lomax, G., Miteva, D. A., … Fargione, J. (2017). Natural climate solutions. Proceedings of the National Academy of Sciences of the United States of America, 114(44), 11645–11650. https://doi.org/10.1073/pnas.1710465114
52. Guerry, A. D., Ruckelshaus, M. H., Arkema, K. K., Bernhardt, J. R., Guannel, G., Kim, C. K., ... & Spencer, J. (2012). Modelling benefits from nature: using ecosystem services to inform coastal and marine spatial planning. International Journal of Biodiversity Science, Ecosystem Services & Management, 8(1-2), 107-121.
53. Guha-Sapir, D., Hoyois. P.H., Below, R. (2013). Annual Disaster Statistical Review 2012: The Numbers and Trends. Brussels: CRED; 2013.
54. Hamilton, S.E. & Friess, D.A. (2018). Global carbon stocks and potential emissions due to mangrove deforestation from 2000 to 2012, Nature Climate Change 8 (3) 240–244, https://doi.org/10.1038/s41558-018-0090-4.
55. Hanson, H. I., Wickenberg, B., & Olsson, J. A. (2020). Working on the boundaries—How do science use and interpret the nature-based solution concept?. *Land use policy*, *90*, 104302.
56. Hulme, M., Doherty, R., Ngara, T., New, M., & Lister, D. (2001). African climate change: 1900-2100. Climate research, 17(2), 145-168.
57. Iacob, O., Rowan, J. S., Brown, I., & Ellis, C. (2014). Evaluating wider benefits of natural flood management strategies: An ecosystem-based adaptation perspective. Hydrology Research, 45(6), 774–787. https://doi.org/10.2166/nh.2014.184
58. IPBES. (2019). Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science Policy Platform on Biodiversity and Ecosystem Services. In S. Díaz, J. Settele, E. S. Brondízio, H. T. Ngo, M. Guèze, J. Agard, A. Arneth, P. Balvanera, K. A. Brauman, S. H. M. Butchart, K. M. A. Chan, L. A. Garibaldi, K. Ichii, J. Liu, S. M. Subramanian, G. F. Midgley, P. Miloslavich, Z. Molnár, D. Obura, A. Pfaff, S. Polasky, A. Purvis, J. Razzaque, B. Reyers, R. Roy Chowdhury, Y. J. Shin, I. J. VisserenHamakers, K. J. Willis, & C. N. Zayas (Eds.). Bonn, Germany: IPBES Secretariat, 56 pp.
59. IPCC, Climate change 2022: impacts, adaptation, and vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, 2022.
60. IPCC, Climate change 2022: impacts, adaptation, and vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, 2022.
61. IPCC. (2018). Global warming of 1.5°C. An IPCC special report on the impacts of global warming of 1.5°C above preindustrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. In V. Masson-Delmotte, P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P. R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J. B. R. Matthews, Y. Chen, X. Zhou, M. I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, & T. Waterfield (Eds.). Geneva, Switzerland: Intergovernmental Panel on Climate Change.
62. IPCC. (2018). Global warming of 1.5°C. An IPCC special report on the impacts of global warming of 1.5°C above preindustrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. In V. Masson-Delmotte, P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P. R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J. B. R. Matthews, Y. Chen, X. Zhou, M. I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, & T. Waterfield (Eds.). Geneva, Switzerland: Intergovernmental Panel on Climate Change.
63. IPCC. (2019). Climate change and land: An IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems [P. R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Pörtner, D. C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, & J. Malley (Eds.)]. Geneva, Switzerland: Intergovernmental Panel on Climate Change.
64. IUCN. (2012). The IUCN programme 2013–2016.
65. IUCN. (2020). Global Standard for Nature-Based Solutions. A User-Friendly Framework for the Verification, Design and Scaling up of NbS.
66. IUCN. (2020). Global Standard for Nature-Based Solutions. A User-Friendly Framework for the Verification, Design and Scaling up of NbS.
67. Johnson, B. A., Kumar, P., Okano, N., Dasgupta, R., & Shivakoti, B. R. (2022). Nature-based solutions for climate change adaptation: A systematic review of systematic reviews. *Nature-Based Solutions*, 100042.

68. Jones, H. P., Hole, D. G., & Zavaleta, E. S. (2012). Harnessing nature to help people adapt to climate change. Nature climate change, 2(7), 504-509.
69. Kabisch, N., Frantzeskaki, N., Pauleit, S., Naumann, S., Davis, M., Artmann, M., ... & Bonn, A. (2016). Nature-based solutions to climate change mitigation and adaptation in urban areas: perspectives on indicators, knowledge gaps, barriers, and opportunities for action. *Ecology and society*, *21*(2).
70. Kabisch, N., Korn, H., Stadler, J., & Bonn, A. (2017). *Nature-based solutions to climate change adaptation in urban areas: Linkages between science, policy and practice*. Springer Nature.
71. Kalantari, F., Tahir, O. M., Joni, R. A., & Fatemi, E. (2018). Opportunities and challenges in sustainability of vertical farming: A review. *Journal of Landscape Ecology*, *11*(1), 35-60.
72. Kalantari, F., Tahir, O. M., Joni, R. A., & Fatemi, E. (2018). Opportunities and challenges in sustainability of vertical farming: A review. *Journal of Landscape Ecology*, *11*(1), 35-60.
73. Kalantari, F., Tahir, O. M., Joni, R. A., & Fatemi, E. (2018). Opportunities and challenges in sustainability of vertical farming: A review. *Journal of Landscape Ecology*, *11*(1), 35-60.
74. Key, I. B., Smith, A. C., Turner, B., Chausson, A., Girardin, C. A., Macgillivray, M., & Seddon, N. (2022). Biodiversity outcomes of nature-based solutions for climate change adaptation: characterizing the evidence base. *Frontiers in Environmental Science*, *10*.
75. Knutson, T. R., McBride, J. L., Chan, J., Emanuel, K., Holland, G., Landsea, C., ... & Sugi, M. (2010). Tropical cyclones and climate change. Nature geoscience, 3(3), 157-163.
76. Kundzewicz, Z. W., & Menzel, L. (2005). Natural flood reduction strategies–a challenge. *International Journal of River Basin Management*, *3*(2), 125-131.
77. Leal Filho, W., Azeiteiro, U. M., Balogun, A. L., Setti, A. F. F., Mucova, S. A., Ayal, D., ... & Oguge, N. O. (2021). The influence of ecosystems services depletion to climate change adaptation efforts in Africa. *Science of The Total Environment*, *779*, 146414.
78. Mabelis, A.A.; Maksymiuk, G. Public participation in green urban policy: Two strategies compared. Int. J. Biodivers. Sci. Manag. 2009, 5, 63–75.
79. MacKinnon, K., van Ham, C., Reilly, K., & Hopkins, J. (2019). Nature-based solutions and protected areas to improve urban biodiversity and health. Biodiversity and health in the face of climate change, 363-380.
80. Maes, M. J., Jones, K. E., Toledano, M. B., & Milligan, B. (2019). Mapping synergies and trade-offs between urban ecosystems and the sustainable development goals. Environmental science & policy, 93, 181-188.
81. Maimaitiyiming, M., Ghulam, A., Tiyip, T., Pla, F., Latorre-Carmona, P., Halik, Ü., ... & Caetano, M. (2014). Effects of green space spatial pattern on land surface temperature: Implications for sustainable urban planning and climate change adaptation. *ISPRS Journal of Photogrammetry and Remote Sensing*, *89*, 59-66.
82. Mantyka-Pringle, C. S., Visconti, P., Di Marco, M., Martin, T. G., Rondinini, C., & Rhodes, J. R. (2015). Climate change modifies risk of global biodiversity loss due to land-cover change. Biological Conservation, 187, 103-111.
83. McCallum, I., Liu, W., See, L., Mechler, R., Keating, A., Hochrainer-Stigler, S., ... & Moorthy, I. (2016). Technologies to support community flood disaster risk reduction. International Journal of Disaster Risk Science, 7, 198-204.
84. Midgley, G. F., & Bond, W. J. (2015). Future of African terrestrial biodiversity and ecosystems under anthropogenic climate change. Nature Climate Change, 5(9), 823-829.
85. Millennium ecosystem assessment, M. E. A. (2005). *Ecosystems and human well-being* (Vol. 5, p. 563). Washington, DC: Island press.
86. Mills, A., Christophersen, T., Wilkie, M. L., & Mansur, E. (2020). The United Nations Decade on ecosystem restoration: catalyzing a global movement. *Unasylva*, *252*, 119-126.
87. Mitsch, W. J., Day, J. W., Gilliam, J. W., Groffman, P. M., Hey, D. L., Randall, G. W., & Wang, N. (2001). Reducing Nitrogen Loading to the Gulf of Mexico from the Mississippi River Basin: Strategies to Counter a Persistent Ecological Problem: Ecotechnology—the use of natural ecosystems to solve environmental problems—should be a part of efforts to shrink the zone of hypoxia in the Gulf of Mexico. *BioScience*, *51*(5), 373-388.
88. Mooney H (2011) Getting there. In: Kareiva P, Tallis H, Ricketts TH, Daily GC, Polasky S (eds) Natural capital: theory and practice of mapping ecosystem services. Oxford University Press, Oxford. Kindle Edition
89. Morris, R. L., Konlechner, T. M., Ghisalberti, M., & Swearer, S. E. (2018). From grey to green: Efficacy of eco-engineering solutions for nature-based coastal defense. Global Change Biology, 24(5), 1827–1842. https://doi.org/10.1111/gcb.14063
90. Munang, R., Thiaw, I., Alverson, K., Mumba, M., Liu, J., & Rivington, M. (2013). Climate change and Ecosystem-based Adaptation: a new pragmatic approach to buffering climate change impacts. *Current Opinion in Environmental Sustainability*, *5*(1), 67-71.
91. Munang, R., Thiaw, I., Alverson, K., Mumba, M., Liu, J., & Rivington, M. (2013). Climate change and Ecosystem-based Adaptation: a new pragmatic approach to buffering climate change impacts. *Current Opinion in Environmental Sustainability*, *5*(1), 67-71.

92. Munang, R., Thiaw, I., Alverson, K., Mumba, M., Liu, J., & Rivington, M. (2013). Climate change and Ecosystem-based Adaptation: a new pragmatic approach to buffering climate change impacts. *Current Opinion in Environmental Sustainability*, *5*(1), 67-71.
93. Narayan, S., Beck, M. W., Wilson, P., Thomas, C. J., Guerrero, A., Shepard, C. C., ... & Trespalacios, D. (2017). The value of coastal wetlands for flood damage reduction in the northeastern USA. *Scientific reports*, *7*(1), 9463.
94. Nkwunonwo, U. C. (2016). A review of flooding and flood risk reduction in Nigeria. *Global Journal of Human-Social Science B: Geography, Geo-Sciences, Environmental Science and Disaster Management*, *16*(2), 22-42.
95. Nkwunonwo, U. C. (2016). A review of flooding and flood risk reduction in Nigeria. *Global Journal of Human-Social Science B: Geography, Geo-Sciences, Environmental Science and Disaster Management*, *16*(2), 22-42.
96. Noji, E. K. (1991). Natural disasters. *Critical care clinics*, *7*(2), 271-292.
97. Ntajal, J., Lamptey, B. L., Mahamadou, I. B., & Nyarko, B. K. (2017). Flood disaster risk mapping in the lower Mono river basin in Togo, West Africa. *International journal of disaster risk reduction*, *23*, 93-103.
98. Obeta, M. C. (2014). Institutional approach to flood disaster management in Nigeria: need for a preparedness plan. British Journal of Applied Science & Technology, 4(33), 4575-4590.
99. Ohl, C. A., & Tapsell, S. (2000). Flooding and human health: the dangers posed are not always obvious. *Bmj*, *321*(7270), 1167-1168.
100. Peduzzi, P., Velegrakis, A., Estrella, M., & Chatenoux, B. (2013). Integrating the role of ecosystems in disaster risk and vulnerability assessments: Lessons from the Risk and Vulnerability Assessment Methodology Development Project (RiVAMP) in Negril, Jamaica. The role of ecosystems in disaster risk reduction, 109-139.
101. Raaijmakers, R., Krywkow, J., & van der Veen, A. (2008). Flood risk perceptions and spatial multicriteria analysis: exploratory research for hazard mitigation. Natural hazards, 46, 307-322.
102. Raymond, C. M., Frantzeskaki, N., Kabisch, N., Berry, P., Breil, M., & Nita, M. R. (2017). A Framework for Assessing and Implementing the Cobenefits of Nature-Based Solutions in Urban Areas. Environmental Science Pollution. 77, 15–24. doi: 10.1016/j.envsci.2017.07.008
103. Renaud, F. G., Sudmeier-Rieux, K., & Estrella, M. (Eds.). (2013). *The role of ecosystems in disaster risk reduction*. United Nations University Press.
104. Renaud, F. G., Sudmeier-Rieux, K., & Estrella, M. (Eds.). (2013). The role of ecosystems in disaster risk reduction. United Nations University Press.
105. Renaud, F. G., Sudmeier-Rieux, K., Estrella, M., & Nehren, U. (Eds.). (2016). *Ecosystem-based disaster risk reduction and adaptation in practice* (Vol. 42). Cham: Springer International Publishing.
106. Renaud, F.G., Sudmeier-Rieux, K., & Estrella, M. (Eds.), (2013). The Role of Ecosystems in Disaster Risk Reduction. United Nations University Press, Tokyo.
107. Rojas, O., Soto, E., Rojas, C., & López, J. J. (2022). Assessment of the flood mitigation ecosystem service in a coastal wetland and potential impact of future urban development in Chile. *Habitat International*, *123*, 102554.
108. Rowiński, P. M., Västilä, K., Aberle, J., Järvelä, J., & Kalinowska, M. B. (2018). How vegetation can aid in coping with river management challenges: A brief review. Ecohydrology & Hydrobiology, 18(4), 345– 354. https://doi.org/10.1016/j.ecohyd.2018.07.003
109. Sala, O. E., Stuart Chapin, F. I. I. I., Armesto, J. J., Berlow, E., Bloomfield, J., Dirzo, R., ... & Wall, D. H. (2000). Global biodiversity scenarios for the year 2100. science, 287(5459), 1770-1774.
110. Sarzynski, A., & Cavaliere, P. (2018). Public participation in planning for community management of natural hazards. In *Oxford Research Encyclopedia of Natural Hazard Science*.
111. Savo, V., Lepofsky, D., Benner, J. P., Kohfeld, K. E., Bailey, J., & Lertzman, K. (2016). Observations of climate change among subsistence-oriented communities around the world. Nature Climate Change, 6(5), 462-473.
112. Scheidel, A., & Work, C. (2018). Forest plantations and climate change discourses: new powers of 'green' grabbing in Cambodia. Land use policy, 77, 9-18.
113. Seddon, N., Chausson, A., Berry, P., Girardin, C. A. J., Smith, A., & Turner, B. (2020). Understanding the Value and Limits of Nature-Based Solutions to Climate Change and Other Global Challenges. Phil. Trans. R. Soc. B. 375 (1794), 20190120. doi:10.1098/rstb.2019.0120
114. Seddon, N., Chausson, A., Berry, P., Girardin, C. A. J., Smith, A., & Turner, B. (2020). Understanding the Value and Limits of Nature-Based Solutions to Climate Change and Other Global Challenges. Phil. Trans. R. Soc. B. 375 (1794), 20190120. doi:10.1098/rstb.2019.0120
115. Seddon, N., Chausson, A., Berry, P., Girardin, C. A., Smith, A., & Turner, B. (2020). Understanding the value and limits of nature-based solutions to climate change and other global challenges. Philosophical Transactions of the Royal Society B, 375(1794), 20190120.
116. Seddon, N., Daniels, E., Davis, R., Chausson, A., Harris, R., Hou-Jones, X., … Wicander, S. (2020). Global recognition of the importance of nature-based solutions to the impacts of climate change. Global Sustainability, 3. https://doi.org/10.1017/sus.2020.8

 doi:10.20944/preprints202409.1583.v1

117. Seddon, N., Daniels, E., Davis, R., Chausson, A., Harris, R., Hou-Jones, X., … Wicander, S. (2020). Global recognition of the importance of nature-based solutions to the impacts of climate change. Global Sustainability, 3. https://doi.org/10.1017/sus.2020.8
118. Seddon, N., Daniels, E., Davis, R., Harris, R., Hou-Jones, X., Huq, S., ... & Wicander, S. (2019). Global recognition of the importance of nature-based solutions to climate change impacts.
119. Seddon, N., Smith, A., Smith, P., Key, I., Chausson, A., Girardin, C., ... & Turner, B. (2021). Getting the message right on nature-based solutions to climate change. Global change biology, 27(8), 1518-1546.
120. Seddon, N., Smith, A., Smith, P., Key, I., Chausson, A., Girardin, C., ... & Turner, B. (2021). Getting the message right on nature-based solutions to climate change. Global change biology, 27(8), 1518-1546.
121. Seddon, N., Smith, A., Smith, P., Key, I., Chausson, A., Girardin, C., ... & Turner, B. (2021). Getting the message right on nature-based solutions to climate change. Global change biology, 27(8), 1518-1546.
122. Seddon, N., Smith, A., Smith, P., Key, I., Chausson, A., Girardin, C., ... & Turner, B. (2021). Getting the message right on nature-based solutions to climate change. Global change biology, 27(8), 1518-1546.
123. Seto, K. C., Fragkias, M., Güneralp, B., & Reilly, M. K. (2011). A meta-analysis of global urban land expansion. PloS one, 6(8), e23777.
124. Shah, M. A. R., Renaud, F. G., Anderson, C. C., Wild, A., Domeneghetti, A., Polderman, A., ... & Zixuan, W. (2020). A review of hydrometeorological hazard, vulnerability, and risk assessment frameworks and indicators in the context of nature-based solutions. *International journal of disaster risk reduction*, *50*, 101728.
125. Sharma, J., & Ravindranath, N. H. (2019). Applying IPCC 2014 framework for hazard-specific vulnerability assessment under climate change. *Environmental Research Communications*, *1*(5), 051004.
126. Shen, G., & Hwang, S. N. (2019). Spatial–Temporal snapshots of global natural disaster impacts Revealed from EM-DAT for 1900-2015. *Geomatics, Natural Hazards and Risk*.
127. Sintayehu, D. W. (2018). Impact of climate change on biodiversity and associated key ecosystem services in Africa: a systematic review. Ecosystem health and sustainability, 4(9), 225-239.
128. Sutton-Grier, A. E., Wowk, K., & Bamford, H. (2015). Future of our coasts: The potential for natural and hybrid infrastructure to enhance the resilience of our coastal communities, economies and ecosystems. *Environmental Science & Policy*, *51*, 137-148.
129. Tapsell, S. M., & Tunstall, S. M. (2008). "I wish I'd never heard of Banbury": the relationship between 'place' and the health impacts from flooding. *Health & place*, *14*(2), 133-154.
130. Terungwa, U. C., & Torkwase, I.C. (2013). Current issues in flood disaster: challenges and implications for science and technology to enhance environmental education. Academic Journal of Interdisciplinary Studies, 2(6), 61-65.
131. Thomas, A. S., Mangubhai, S., Vandervord, C., Fox, M. & Nand, Y. (2018). Impact of tropical cyclone Winston on women mud crab fishers in Fiji. Climate and Development 11, 699–709. doi:10.1080/17565529.2018.1547677
132. Turner, I. L., Harley, M. D., & Drummond, C. D. (2016). UAVs for coastal surveying. Coastal Engineering, 114, 19-24.
133. Turner, I. L., Harley, M. D., & Drummond, C. D. (2016). UAVs for coastal surveying. Coastal Engineering, 114, 19-24.
134. UNISDR, C. (2015). The human cost of natural disasters: A global perspective.
135. UNISDR, C. (2015). The human cost of natural disasters: A global perspective.
136. United Nations International Strategy for Disaster Reduction (UNISDR). 2015. Sendai Framework for Disaster Risk Reduction 2015-2030. http://www.unisdr.org/files/43291_sendaiframeworkfordrren.pdf.
137. Vallecillo, S., Kakoulaki, G., La Notte, A., Feyen, L., Dottori, F., & Maes, J. (2020). Accounting for changes in flood control delivered by ecosystems at the EU level. *Ecosystem Services*, *44*, 101142.
138. Veldman, J. W., Aleman, J. C., Alvarado, S. T., Anderson, T. M., Archibald, S., Bond, W. J., ... & Zaloumis, N. P. (2019). Comment on "The global tree restoration potential". *Science*, *366*(6463), eaay7976.
139. Vidal, G. (2008). Class of quantum many-body states that can be efficiently simulated. Physical review letters, 101(11), 110501.
140. Watson, R., Albon, S., Aspinall, R., Austen, M., Bardgett, B., Bateman, I., ... & Winter, M. (2011). UK National Ecosystem Assessment: understanding nature's value to society. Synthesis of key findings.
141. Webster, P. J., Holland, G. J., Curry, J. A., & Chang, H. R. (2005). Changes in tropical cyclone number, duration, and intensity in a warming environment. Science, 309(5742), 1844-1846.
142. WEF. (2020). Nature risk rising: Why the crisis engulfing nature matters for business and the economy. Geneva, Switzerland: World Economic Forum.
143. World Bank. (2017). Implementing Nature Based Flood Protection: Principles and Implementation Guidance.
144. World Bank. (2017). Implementing Nature Based Flood Protection: Principles and Implementation Guidance.

 doi:10.20944/preprints202409.1583.v1

145. Yang, M. G. M., Hong, P., & Modi, S. B. (2011). Impact of lean manufacturing and environmental management on business performance: An empirical study of manufacturing firms. International Journal of production economics, 129(2), 251-261.