

## REVIEW

# Nature-based Natural-hazard Preparedness: A Cross Section of Categorized Examples

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## ABSTRACT

Despite prevailing interests, no rigorous research has been conducted to examine the role of nature in natural-hazard preparedness. This systematic review aimed to describe how nature can reduce the impacts of natural hazards during the preparedness stage. The study focuses on the land, water, and air systems and on three types of stakeholders: international organizations, developed countries, and developing countries. Further, it provides supplementary strategies, such as immediate actions, local engagement, and research and development, that the stakeholders should apply to enhance their nature-based natural-hazard preparedness. We suggest integrating costs and benefits analysis, local culture, societal challenges, and environmental justice into the implementation of nature-based solutions. Finally, this review outlines the framework of nature-based natural-hazard preparedness by discussing the relationship between nature and society.

**Keywords:** Nature-based solutions; Costs and benefits; Land; Integration; Society

## 1. Introduction

Human beings have continuously deteriorated the quality of land, water, and air resources. Over 75% of the world's lands have been considerably altered by human activities. Consequently, more than two-thirds of all wildlife have been dramatically affect-

ed by environmental crises since the beginning of the 1970s. Approximately two-thirds of salt waters and over 85% of wetlands have also been polluted. Additionally, air pollution has contributed to approximately 11.65% of human deaths as well as the extinction of many biotic vectors <sup>[1]</sup>.

Regardless of national boundaries, human-in-

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duced activities have aggravated the impacts of natural hazards <sup>[2]</sup>. Recent examples include the building collapse during the Türkiye and Syria earthquakes in 2023, long-lasting droughts in California, flooding in Afghanistan and Pakistan in 2022, and outbreaks of infectious diseases. The occurrence of natural hazards has resulted in several visible and invisible impacts, including ecological disturbances, human deaths, risks to basic human needs, and social inequalities.

Nonetheless, understanding the costs and benefits of nature or the application of nature-based solutions may allow multiple nations to prepare for the occurrence of dire natural hazards <sup>[3]</sup>. Nature-based solutions, such as the use of natural-hazard-resistant species like the Ghaf trees, seagrasses, and steppe-land birds against drought, storm surges, and air pollution, respectively, can help in taking measures against natural-hazard impacts in advance, leading to the restoration of nature and resolution of societal challenges. In addition, various species can be utilized as natural-hazard indicators (e.g., using tree nuts and medicinal herbs; leaf loss in plants; rats, snakes, and weasels; and birds and fish as indicators of droughts, food insecurity, earthquakes, and tsunamis, respectively).

As nature-based solutions enhance natural conditions and contribute to natural-hazard preparedness in each nation, they benefit both the natural environment and human beings <sup>[4]</sup>. In this context, we should ask ourselves “How have major stakeholders in different regions addressed the role of nature (i.e., land, water, and air) in natural-hazard preparedness?” The goal of this review was to study this role of nature, considering natural-hazard preparedness as the final goal. The findings of this review are expected to help reduce the human loss, economic damages, and social inequalities resulting from natural disasters.

To frame supplementary strategies, this study initially examined nature-based solutions for natural-hazard preparedness based on three factors: land, water, and air. These three factors were further analyzed through the lens of three types of stakeholders: international organizations, developed nations, and

developing nations. Since the stakeholders try to improve the current status of their nature-based natural-hazard preparedness with supplementary strategies, they have to address factors such as the local culture, participation, integration, societal challenges, emergency training, and environmental justice.

## 2. Literature review

Nature-based solutions (also known as nature-based approaches or ecological engineering) use nature as a tool to productively transform unsustainable human activities <sup>[5]</sup>. “Nature-based solutions” is an umbrella term referring to aspects such as biodiversity, ecosystem services, lessons learned from nature, and nature-focused interventions. However, the main focus of the present study is the application of nature-based solutions for natural-hazard management.

Natural hazards are naturally occurring phenomena such as hurricanes accompanied by floods, earthquakes and tsunamis, snowstorms, sandstorms, droughts, sinkholes, and landslides. They also include quasi-natural hazards such as climate change, desertification, and the spread of coronavirus disease 2019 (COVID-19). The disaster-management cycle includes the phases of natural-hazard prevention/mitigation, preparedness, response, and recovery. The preparedness phase involves preparing for emergencies before, during, and after the occurrence of natural hazards <sup>[6]</sup>; it lasts for the entirety of the disaster-management cycle.

There are approximately 18 kinds of natural hazards, which are characterized by the scale of their occurrence <sup>[7]</sup>. Irrespective of an individual’s place of residence, natural hazards may impact their lives, regardless of regional boundaries and personal desires. The occurrence of natural hazards is beyond human control on countless occasions, necessitating the adoption of preventive measures.

Despite its progressive approach, nature-based solutions have remained a divisive and contentious strategy <sup>[8]</sup>. While being used for climate change mitigation, the term “nature-based solutions” has contributed to a lack of informed consent, an inability to

access natural resources, privatization of an intrinsic nature, and the violation of human rights. Further, due to the ambiguous scope of nature-based solutions, the term has been frequently interpreted for various individual and institutional interests, thereby leading to its inconsistent application.

Involvement of a high extent of risks has been reported for certain applications of nature-based solutions<sup>[9]</sup>. Some politicians and businessmen have maintained that nature-based solutions would help regional economies to move away from a fossil-fuel economy. However, activities such as tree planting in large areas for carbon sequestration could have serious consequences if the stakeholders entirely supplanted the native trees with non-native species. Similarly, the production of bioethanol from corn grains could dramatically increase the use of pesticides.

Thus, nature-based solutions have both benefits and associated costs<sup>[10]</sup>. However, nature-based solutions have proved to be a more sustainable approach against natural hazards than the establishment of built infrastructure (or hard-engineering approach), since they promote preparedness capacity and emergency resilience. As an added investment for nature, restored natural habitats may boost biodiversity, green job creation, and economic performance, and offer other benefits under appropriate cultural contexts. Thus, nature-based solutions promote well-being and regeneration in human society.

A universal formula cannot be applied to nature-based solutions since related contexts, including the changing intensity of natural hazards, politics, and social inequalities, also need to be considered in the approach. However, this has not been the case in most of its applications<sup>[11]</sup>. Moreover, the successful implementation of nature-based solutions for natural-hazard preparedness is not possible without the investment of an appropriate amount of funds.

Since the first introduction of the term “nature-based solutions” by the international community (through its inclusion in the title of the annual report of the World Bank in 2008), researchers have focused increasingly on related topics such as climate

change<sup>[12,13]</sup>. These studies have directly or indirectly involved several disciplines, including climatology, ecology, economics, agriculture, pisciculture, ornithology, medical sciences, natural resource management, legislation, and public policy.

However, not many have studies focused on nature-based solutions for disaster management<sup>[14]</sup>. Although some researchers and policymakers have mentioned nature-based solutions in their domains, no rigorous study has been attempted in relation to natural-hazard preparedness. Moreover, the relationships between nature and society and the collaboration among stakeholders have not been thoroughly examined in the field of natural-hazard preparedness.

Despite the lack of sufficient research, Keesstra et al. (2018) highlighted the importance of the concept of connectivity in nature-based solutions<sup>[15]</sup>. Although natural hazards were not discussed in detail, they strongly indicated that systems thinking would be useful to visualize how nature-based solutions will improve the environment. Connectivity includes multiple lives, processes, and feedback to outline the mainstream of ecology under a complicated environment.

In 2020, the International Union for Conservation of Nature (IUCN) proposed an international standard for nature-based solutions<sup>[16]</sup>. The IUCN highlighted the necessity of a global standard to solve the challenges of nature-based solutions, including those of biodiversity, ecosystem, and economic aspects. Without a global standard, the outcome of nature-based solutions would be unreliable. However, though the IUCN proposed a global standard as a framework for nature-based solutions, it only briefly discussed the issue of natural hazards in its theoretical process.

When the Federal Emergency Management Agency (FEMA) published a book on guidelines for nature-based solutions in 2021, it entirely focused on the impacts of climate change in local regions<sup>[17]</sup>. FEMA assumed that climate change was a big barrier in local communities, which would build their resilience and adaptation to climate change by weaving characteristics of nature into their built environment. The FEMA further maintained that corresponding

implementation strategies would differ among individual communities.

Reflecting the East Asian saying “Humans shall play nature (i.e., land, water, and air) off against nature (the occurrence of natural hazards)”, this study directly examines natural-hazard preparedness employing nature-based solutions. In doing so, this research aims to provide a holistic framework for natural-hazard preparedness by comprehensively addressing all natural hazards, the inconsistent application of nature-based solutions, related risks, and benefits and costs of nature-based solutions, among others. Based on multidisciplinary studies, this review focuses on the relationship between nature and society and includes stakeholders.

### 3. Methods

The systematic literature review in this paper focused on a holistic framework for natural-hazard preparedness and consisted of four steps: (1) formulating a research question, (2) identifying relevant texts, (3) analyzing the texts, and (4) summarizing the obtained evidence [18]. Namely, the PRISMA checklist, which includes numerous items such as the justification for the literature review, the selection procedure, text extraction, and text synthesis among

many, was specifically the primary source of information used in this section [19].

After proposing a single research question regarding the role of nature in natural-hazard preparedness (following the analytical framework in **Figure 1**), the appropriate text data was identified. The criterion of inclusion was that the texts had to be related to nature-based solutions, the occurrence of natural hazards, and the phase of natural-hazard preparedness. To this end, several keywords were inputted into the search engines, including “nature-based solutions”, “natural hazards and risks”, and “natural disaster management”.

This review created its own units of analysis. As the Earth is the geographical scope of this research, all stakeholders were comprehensively categorized into analytical units such as international organizations, developed nations, and developing nations [20]. While the international organizations (e.g., the United Nations and international non-governmental organizations) were considered to deal with international affairs, all countries, both developed and developing nations, were considered to manage their own regional affairs.

The four spheres of the Earth are defined as the geosphere, hydrosphere, atmosphere, and biosphere. Thus, there are three space systems (i.e., geosphere,

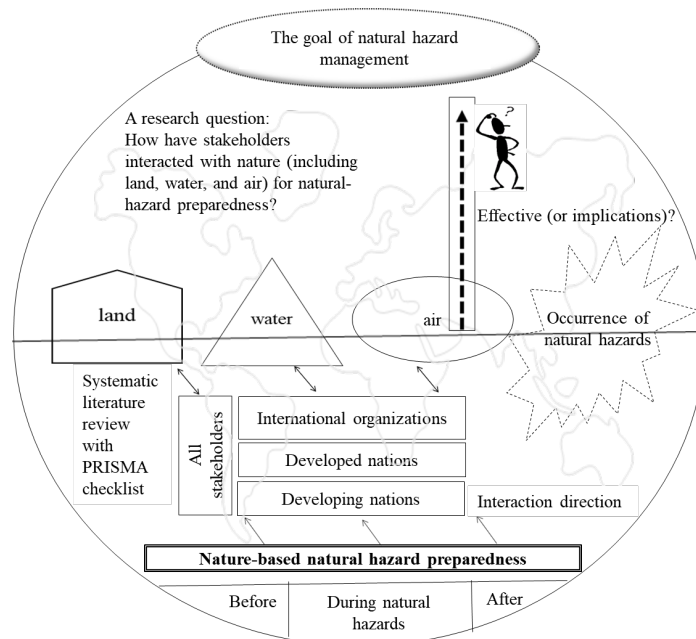


Figure 1. Analytical framework.

hydrosphere, and atmosphere) where life (i.e., biosphere) can exist <sup>[21]</sup>. They are generally termed as land, water, and air. In the present review, three analytical categories were used: land (forests, peat bogs, swamps, etc.), water (whales, salt marshes, seagrass beds, various fish, etc.), and air (various birds, insects, biotic vectors, etc.).

To summarize the evidence, appropriate texts were coded by interpreting and recording them <sup>[22]</sup>. Three units of analysis were repeatedly and flexibly classified into three analytical categories to monitor the effectiveness of the current application of nature-based solutions. In addition, supplementary strategies for nature-based solutions and their meaningful implications were provided, when applicable. This step was implemented to answer the research question.

## **4. Current state of nature-based natural-hazard preparedness**

### **4.1 Land**

The United Nations Environment Programme (UNEP) considers climate change to be an emergency and maintains the significance of implementing both tree planting and climate-smart agriculture. It has been difficult for the UNEP to achieve a full mitigation of climate change because of the slow pace of efforts of multiple nations <sup>[23]</sup>. The World Bank has attempted to mitigate the impacts of certain natural hazards, such as mudslides and floods, by promoting cost-effective strategies. Despite their economic efficiency, planting non-native trees in a region could pose serious threats (or be toxic) to local species.

Even though many European countries have supported nature-based solutions, European soil has become impermeable (also known as soil sealing) owing to urbanization, leading to an increase in heat and floods <sup>[24]</sup>. The United Arab Emirates (UAE) has planted Ghaf trees as a national initiative because they are drought-resistant and help prevent desertification. However, an increase in land pollution and the immigrant population has decreased the number of Ghaf trees.

Harbin City in China has implemented a Sponge

City program to promote biodiversity and urban wells; they absorb rainwater from the ground to mitigate floods. However, the associated cost of building the urban infrastructure is not sustainable. Many nations in Africa have planned to establish forests and wetlands to decrease droughts and water shortages in their region. However, context-specific traditional knowledge has not been well integrated into these endeavors.

### **4.2 Water**

Considering the role of whales in carbon dioxide (CO<sub>2</sub>) sequestration (via their faeces, phytoplankton, carbon sinks, and the carbon cycle), the International Monetary Fund estimated the value of the financial benefits of whales at about 2 million US dollars per individual, in 2019 <sup>[25]</sup>. Therefore, whales are much more efficient in absorbing CO<sub>2</sub> than small fish and other marine organisms. Nonetheless, the number of whales in the ocean is decreasing, and policymakers are not sufficiently aware of the value of whales in terms of natural-hazard preparedness.

Australia has attempted to protect its seagrasses, mangroves, tidal marshes, commercial fish, and other species to prepare for the impacts of storm surges through international partnerships with neighboring countries. However, the involved parties have shown a lack of appropriate theoretical backgrounds. Similarly, Canada has implemented plans to protect approximately 30% of its seas until 2030, for natural-hazard preparedness <sup>[26]</sup>. Moreover, storing huge amounts of CO<sub>2</sub> in the ocean successfully will require further involvement of the local communities.

Even though Bangladesh has continuously implemented nature-based solutions, such as various-term actions and instruments, the country has faced considerable challenges related to coastal afforestation. Moreover, their efforts have been mostly managed in a scattered way <sup>[27]</sup>. While the Pacific islands such as Samoa, Kiribati, and Vanuatu have actively utilized their indigenous ecological knowledge, such as the reliance on bio-indicators as early warning systems, these countries have not fully implemented coastal planning against natural hazards.

### 4.3 Air

After officially adopting nature-based solutions in the 21st century, the IUCN has made partial efforts to stabilize the concentrations of greenhouse gases in the atmosphere. Further, it has continued to reduce the impacts of natural hazards via the Global Standard and other guidelines. Nonetheless, its policies related to the air systems still lack information on targeted customers. The Red Cross has prioritized making partnerships with environmental organizations for natural-hazard preparedness <sup>[28]</sup>, but it has mainly focused on land and water, without equally supporting the air systems.

Authorities of Andalusia in Spain have tried to protect the steppe-land birds in their region by improving the air quality and replacing traditional fence marks with plastic ones. Despite an increase in the number of birds, Andalusia still requires both interoperability among communication channels and relevant training programs. In addition, the number of bees, butterflies, and moths has greatly decreased in many developed nations because of their poor air quality. An insufficient number of pollinators will lead to disruptions in the ecosystems, food security, and natural-hazard preparedness.

Even though the African nations have tried to improve their air quality, key sources of air pollution have not been well managed. The lenient regulations for vehicle air filters, use of solid fuels during cooking, and burning of private waste are some examples of this mismanagement <sup>[29]</sup>. These issues are complicated owing to their interconnections with regional conflicts. Additionally, many birds in South America have been killed by lead contamination. However, negligible information is available on the relationship between lead contamination and the bird population.

## 5. Implications

Nature-based solutions will expedite the decrease of the Earth's temperature if all stakeholders (i.e., international organizations, developed nations, and developing nations) systematically take appropriate

actions <sup>[30]</sup>. For example, forests in the United States have absorbed about 10% of the country's gas emissions; however, nature-based solutions would compensate for approximately 30% of the climate change impacts in the future <sup>[31]</sup>. In essence, nature-based solutions derived from nature will contribute to lessening the impacts of natural hazards, while maintaining protection against them when they arise.

Comparatively speaking, hard solutions, also known as engineered solutions, are effective at handling high-frequency events, while nature-based solutions will be better at handling low-frequency ones <sup>[32,33]</sup>. As a result, nature-based solutions—like conversation projects—are self-sustaining, but hard solutions still need significant financial outlays for associated costs. If attempts are made to substantially work on the major aspects of nature, climate change, biodiversity loss, and natural-hazard preparedness will be widely improved in multiple regions. Therefore, nature-based solutions should be planned and implemented on a long-term basis.

Nature-based solutions may help prepare against various dire risks, arising as consequences of the natural-hazard occurrence <sup>[34]</sup>. The solutions involve preparing for events such as high temperatures, rising sea levels, melting glaciers, extreme weather events, disruptions to human livelihoods, and the spread of infectious diseases. Tree planting, coastal ecosystem improvement, the recovery of biotic vectors, and other actions are essential to mitigate the intensity of frequent natural hazards. By applying these measures, the consequent human loss, financial instability, infrastructure failure, and psychological impact on individuals will be reduced.

At the national level, major stakeholders should integrate nature-based solutions with the phase of natural-hazard preparedness <sup>[35]</sup>. Nature-based solutions are a long-standing alternative for the whole field of emergency preparedness. From a strategic viewpoint, nature-based solutions should be adapted for each nation during policy design and implemented based on the information given in **Table 1**. Even though natural hazards can occur anywhere, the national organizations and their policies are more

**Table 1.** Supplementary strategies for nature-based natural-hazard preparedness.

Units	Alternatives
5.1 Land	<p>The UNEP must provide practical goals for climate change by further encouraging various nations' quick actions. The World Bank should consider not only financial benefits but also evidence-based science.</p> <p>European countries must improve stakeholder engagement against low soil permeability. In addition, the UAE needs to strongly prohibit the illegal uprooting of Ghaf trees or other species.</p> <p>Chinese local governments should solve the economic challenge of building Sponge Cities with potential changes in financial regulation. The African nations need to systematically document local knowledge.</p>
5.2 Water	<p>Policymakers need to study the role of whales in decreasing the amount of greenhouse gas emissions and consider policies to increase their numbers.</p> <p>Australia should develop and provide appropriate theoretical education for those who are working on coastal ecosystems. Similarly, Canada needs to involve local communities to achieve CO<sub>2</sub> storage in the ocean.</p> <p>Bangladesh requires high-level organized efforts for its nature-based solution, and the Pacific islands need to embrace coastal planning.</p>
5.3 Air	<p>The IUCN should include birds, insects, and other endangered species as well as air pollution sources for targeted customers, and the Red Cross should expand its partnerships with organizations working on air systems.</p> <p>After facilitating technological improvement and policy change for interoperability, Spain should provide appropriate training to stakeholders. All developed nations should increase the number of pollinators by avoiding the use of chemicals, attracting biotic vectors, decreasing outdoor lighting during the night, and applying other environmental strategies.</p> <p>While dealing with regional conflicts, the African nations need to discuss air-related issues in their formal agenda. Researchers in South America need to study the exact impacts of lead poisoning on bird species and other wildlife.</p>

proficient at coordinating various efforts than the stakeholders at other levels.

Nature-based solutions have been regarded as a powerful tool for natural-hazard preparedness but the corresponding supplementary strategies must be implemented to ensure effectiveness<sup>[36]</sup>. Implementation should not be based on a lesson observed but on a lesson learned. The stakeholders need to adopt further actions such as identifying, analyzing, evaluating, and prioritizing human and material resources, while equally considering the positive factors and vulnerabilities in the region. In doing so, the practical implementation of each supplementary strategy will be established.

The implications of the supplementary strategies are firmly based on the local culture<sup>[37]</sup>. Nature is interconnected with the local culture via human interaction and the local environment. The phase of natural-hazard preparedness is also influenced by local culture. Indigenous people have accumulated traditional knowledge from their ancestors, which is based on their perception of land, water, and air as a part of the local culture. Similarly, their methods of emergency preparedness depend on their local

culture; in a sense, natural-hazard preparedness has always been an important part of the local culture.

Participation must be fully acknowledged while implementing supplementary strategies<sup>[38]</sup>. The three stakeholders mentioned in this study must willingly participate in the management of all aspects of their nature-based solutions. Otherwise, the desired effects cannot be achieved in the expected time, particularly considering that the land, water, and air systems are interconnected with each other. Professionals from various fields, including decision-makers, technical specialists, emergency responders, and residents, should also be allowed to work for natural-hazard preparedness.

An integrated emergency management system must be further expanded in multiple regions. The three stakeholders must initiate extensive international networks among themselves, with a global goal in mind. The national integration of governments, industries, voluntary organizations, mass media, academic researchers, and other local communities should be attempted. Integration based on consensus building should be embodied at various levels, such as internal, external, horizontal, vertical, and diago-

nal levels<sup>[39]</sup>.

Assuming that all three stakeholders are involved in delivering the supplementary strategies, they will accordingly act on the societal challenges surrounding the land, water, and air systems<sup>[40]</sup>. Subsequently, natural-hazard preparedness will consider the major societal barriers such as politics, governance issues, economic costs and benefits, social inequalities, and multiple environmental factors. Since these societal challenges are differently situated in many local communities, strategic interests and accumulated capacities will continue to be required.

Key stakeholders will need to enhance their implementation of the supplementary strategies<sup>[41]</sup>. While the potential of including benefits and costs in nature-based solutions has not been substantially recognized in some regions yet, major stakeholders will integrate nature and natural hazards with political alliances, multilateral funding, research and development, and other factors. Further measures should be adopted to fully embody the extent of supplementary strategies around natural-hazard preparedness. For example, stakeholders need to include nature-based solutions in emergency training and exercises related to natural hazards. Even though nature-based solutions have begun to be included in the academic curricula, emergency training and exercises have been rarely mentioned. While raising the extent of public awareness regarding supplementary strategies, detailed concepts, related benefits and costs, and other techniques should be provided for the diverse trainees.

Supplementary strategies will achieve a certain level of environmental justice in relation to natural hazards<sup>[42]</sup>. Environmental justice involves equally distributing environmental benefits and costs to various regions, while ensuring that all the stakeholders are involved in decision making. In further preparations for natural hazards, all stakeholders should enhance their disaster-response capabilities. Further, disadvantaged populations should be ensured social justice through policies such as non-discrimination and inclusion<sup>[43]</sup>.

Nature-based solutions with supplementary strat-

egies will eventually keep pace with the concept of systems thinking in the field<sup>[44]</sup>. Recalling that supplementary strategies involve numerous components and their interactions (e.g., interactions among land, water, and air, dynamic relationships among international organizations, developed nations, and developing nations, and so forth), systems thinking may apply to hierarchical structure, feedback loops, and other synergies in addition to those variables and interconnectedness. It will be easier to get ready for the occurrence of different natural hazards if the system is observed and then improved overall.

## 6. Conclusions

The main goal of this research was to investigate the role of nature in natural-hazard preparedness. This review has discussed previous studies, barriers, and other implications. The goal of this study was achieved by elucidating that the subject has been rigorously studied, in terms of land, water, and air systems, by international organizations, developed countries, and developing countries.

A major theme of this review has been that the three stakeholders will advance the current status of nature-based natural-hazard preparedness by referring to supplementary strategies. In doing so, each stakeholder implements assigned roles at the national level such as further studies on whales' contribution to carbon sequestration, actions for the increase in the number of pollinators, and other organized efforts. Simultaneously, the stakeholders also need to address the effects of nature-based solutions, the local culture, active participation, complete integration, societal barriers, emergency training, and environmental justice.

This review has provided a comprehensive framework of the relationships between nature and society via nature-based natural-hazard preparedness. This framework may be utilized as a theoretical reference by various stakeholders during the preparations for natural hazards, while including all players, all risks, and the costs and benefits of nature-based solutions. On the other hand, limitations in the timely future implementation of nature-based natural-hazard pre-



paredness by the international community are only partially discussed in this paper. This limitation arises because of the existence of many disagreements and challenges around the land, water, and air systems. Without taking necessary action, the effects of nature-based natural-hazard preparedness will not be rapidly established.

Researchers should study nature-based solutions in other phases of the natural-hazard management cycle such as natural-hazard prevention/mitigation, response, and recovery in the future. They may refer to the framework of the nature-based natural-hazard preparedness provided in this paper. To address the limitations of this research, the ways to efficiently implement the suggested nature-based natural-hazard preparedness in affected nations or local communities should be further studied. Such efforts may help reduce not only the physical impacts but also the social impacts of natural hazards in multiple regions.

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## Conflict of Interest

The author declares that he has no financial or non-financial conflicts of interest with this manuscript.

## Availability of Data and Materials

The author confirms that the data supporting the findings of this study are available within the article.

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