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Review

Effectiveness of Nature-Based Solutions in Natural Disaster Events

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Abstract: Nature-Based Solutions (NBSs) are tools that promote risk prevention and impact mitigation and recovery from disturbances by placing nature at the centre. In recent years, NBSs have been increasingly used to prevent extreme natural events, such as forest fires and hydrological or geomorphological processes, that pose risks. In this sense, the implementation of these measures allows for the sustainable management of the natural environment. Choosing one management approach over another requires consideration of the available natural resources, as well as the effectiveness and sustainability of each option. In the context of global change, NBSs can play a key role in enabling ecosystems to adapt naturally to the disturbances expected in the coming decades.

Keywords: wildfire; forest management; hydrological processes; geomorphological risk; global change

1. Introduction

Nature-Based Solutions (NBSs in advanced) are approaches that harness natural processes and ecosystems to address social and environmental challenges, such as climate change, water and food security, and disaster management. The concept of using nature to solve societal problems has deep historical roots, with early examples found in ancient agricultural and water management practices. The modern term "Nature-Based Solutions" gained prominence in the early 2000s, championed by organizations like the World Bank and the International Union for Conservation of Nature (IUCN (Grand, Switzerland)). This formalized a growing recognition of ecosystem services as crucial for human well-being and resilience. The approach was presented as a sustainable way to address challenges like climate change and food security. It marked a significant shift from purely engineered solutions to more integrated, holistic approaches. The relevance of NBS is such that, in March 2022, at the fifth United Nations Environment Assembly (UNEA 5), the United Nations adopted a resolution on this matter, which closely aligns with the definition proposed by the European Commission. Scientific evidence of these multiple benefits and practical knowledge is rapidly expanding in Europe, supported by research projects funded under Horizon 2020 and Horizon Europe. These solutions include forest restoration and sustainable landscape management, which promote benefits for both biodiversity and human well-being [1]. Despite good intentions at the international level, there are unintended adverse effects, insufficient private funding, and the risk that NBS will be used to mask systemic inaction. The report itself points to the significant disparity between investment in NBS ($154 billion) and spending on activities harmful to nature (nearly $7 trillion in 2023), such as fossil fuels and agriculture, which undermines the benefits of investing in NBS. Standing out as 'no-regret' strategies for climate adaptation, NBSs generate benefits and also enhance the resilience of ecosystems to better withstand future disturbances. The difficulty of anticipating and managing extreme events calls for the immediate implementation of adaptation strategies to mitigate their potential negative impacts and unexpected losses in advance [2]. Although NBS can significantly reduce flood risks, their effectiveness diminishes or may be overwhelmed during extremely intense and prolonged rainfall events. In these situations, traditional grey infrastructure (drains, walls) may still be necessary as a complement, so a combination of both methods and techniques may be most appropriate. Over the past five years, the global surge in high-intensity wildfires, floods, and hillslope processes has inflicted staggering economic and environmental damage. Nature-based solutions (NBS) are not a universal solution and their effectiveness depends on the local context and may be limited in the face of extreme weather events. There are concerns about funding disparities, the risk of 'greenwashing', and challenges in long-term evaluation and monitoring. Direct global economic losses from natural disasters have consistently surpassed hundreds of billions of dollars annually, with a significant portion attributed to these hydro-meteorological and geological events; for instance, the total economic cost of natural perils in 2024 alone was estimated at over $400 billion and unquantifiable environmental biodiversity losses that produced diminished agricultural productivity, and substantial degradation of ecosystem services, including water purification and carbon sequestration [3,4]. Nevertheless, certain limitations must be acknowledged, such as large-scale implementation, the lack of standardized evaluation frameworks, financial constraints, biodiversity loss, and complexities in governance and context-specific effectiveness. In response, Nature-Based Solutions (NBS) present a paradigm shift in mitigating these impacts. Furthermore, tensions between traditional finance and nature-based solutions (NbS) could be revealed. Challenges include the insurance sector's difficulty in quantifying the long-term benefits of NbS for risk modelling and the limited insurability of NbS assets compared to conventional infrastructure. NBS are essential in mitigating natural disasters, since recent scientific evidence supports that this type of intervention is considerably cost-effective and as effective as engineering solutions in reducing risks [5]. Furthermore, there is a risk of 'greenwashing' if insurers promote NbS while continuing to insure activities that contribute to disasters. Therefore, having this type of solution as an alternative or complement is not only necessary to strengthen the scope and effectiveness of disaster control and reduction, but is also of utmost importance to improve management capacities in the face of events of this nature.

In the context of post-fire forest management, NBSs have been applied to restore damaged ecosystems, improve landscape resilience and prevent future fires by enhancing the ecosystem services provided as a benefit to humans and their needs [6]. Despite the profitability noted by the authors, there are some limitations and contradictions, such as the inclusion of biased economic assessments that often underestimate long-term benefits, an excessive emphasis on certain well-documented types of NBS, and a dependence on public funding that hinders scaling up, resulting in limited effectiveness against extreme events, biodiversity risks from poorly planned projects, and negative social impacts. In addition, practices such as the creation of erosion barriers using burned logs to slow erosion can help the re-establishment of vegetation [7]. Other practices, such as the use of controlled grazing, can reduce the accumulation of forest fuel, reducing the risk of severe fires in the future. Despite being a very localized solution that is difficult to replicate in large areas due to the cost involved, before carrying out any intervention, it is necessary to assess which are the most appropriate and where these applications should be prioritized. These strategies integrate traditional and scientific knowledge, highlighting the importance of collaboration between local communities, scientists and environmental managers to achieve the sustainable and adaptive recovery of affected ecosystems [8]. The NBSs most used in post-fire forest management include log and slash erosion barriers, mulching, salvage logging and livestock grazing [9–12]. There are some factors that could jeopardize the viability of NBSs and their effectiveness, such as political fragmentation, insufficient attention to prevention rather than extinction, challenges posed by the implementation and scalability of NBSs, and the possibility of "greenwashing" if the underlying causes of increased fire risk are not addressed. Also, NBSs have emerged as highly promising alternatives to traditional flood management strategies due to their potential for greater efficiency, cost-effectiveness and environmental sustainability [13]. For instance, civilizations have long utilized natural wetlands for water purification and flood control. These interventions range from localized, small-scale applications, such as green rooves and vegetated building facades [14], to broader territorial strategies, including the integration of ponds, swales or green rain gardens in urban environments [15]. Although the term 'NBS' is not explicitly included in the European Floods Directive (2007/60/EC) because the concept had not been widely introduced at that point, its implementation has increasingly incorporated references to, and encouragement of, nature-based measures as viable tools for enhancing flood risk management [16]. In many cases, international reports produced by entities such as the European Commission remain mere outlines of intentions that stand out for their conceptual ambiguity, insufficient private funding, and dependence on the local context, in addition to the negative side effects of poor implementation, political barriers, and a potentially overly optimistic view of the reports. In sloping areas, NBSs have proven effective in reducing geomorphological hazards, such as erosion and shallow landslides. Strategies such as permanent vegetative covers, contour terraces and bioengineering structures stabilize slopes by enhancing infiltration, reducing runoff velocity and improving soil cohesion [2,17]. These interventions also provide co-benefits, including biodiversity enhancement, soil regeneration and water retention. Their application in rural and agricultural landscapes has demonstrated high effectiveness, low implementation costs and good social acceptance [18,19]. As climate change intensifies rainfall extremes, NBSs offer a sustainable, multifunctional response to mitigate risk and strengthen slope resilience. Nevertheless, improvements are needed in the implementation and monitoring of the NBS under consideration, as these may be dependent on the local and subjective context, lacking direct quantitative validation, biased because they are applied in laboratory conditions and not in "real world" studies and lacking standardized guidelines and long-term monitoring to assess the effectiveness and resilience of NBS over time.

Some of the fundamental points are how, when, why, and where they should be applied. Each case must be evaluated individually, and the effectiveness of NBS must be studied depending on what is to be achieved. Nature-Based Solutions (NBS) are implemented to mitigate wildfires, floods, and hillslope processes for their capacity to provide multifunctional, resilient, and cost-effective risk reduction while delivering significant co-benefits such as enhanced biodiversity and carbon sequestration. The optimal temporal window for application is the pre-disaster, preventive phase to reduce inherent vulnerabilities, though their integration into post-disaster recovery is crucial for building back better. Spatially, deployment is strategically targeted across scales: creating landscape mosaics and managing the Wildland-Urban Interface for fire; restoring upper catchments and floodplains for floods; and applying bioengineering on unstable slopes. This systematic integration across temporal phases and spatial scales provides a holistic, adaptive framework for disaster risk reduction that complements traditional engineering approaches. In this paper, we provide an updated view on the effectiveness of NBSs against some of the most damaging and frequent extreme events. In this sense, and despite their growing popularity, the evidence for their effectiveness remains fragmented and context-dependent, or by highlighting a critical methodological flaw common across studies, we have aimed to provide a critical and reflective view based on the latest scientific advances on the usefulness of these techniques in the current context.

2. Nature-Based Solutions in Wildfire Events

The NBSs for disaster risk reduction are complex and multidimensional interventions. Recent research has pointed to the introduction of livestock, especially in wildland–urban interface areas, as one of the possible solutions to reduce such risk [20]. This prescribed grazing system has co-benefits for policy-makers, land-planners and managers, private investors, industry players and local communities. The different techniques used are intended to improve land governance and reduce the risk of forest fires mainly in areas close to inhabited areas [21]. Integrated fire management-an approach that combines fire prevention, response and recovery, while integrating ecological, socioeconomic and cultural factors into management strategies-is of particular interest, even more so in the context of altered fire regimes. According to Oliveras Menor et al. [22], it is the most effective NBS for forest fire prevention in the context of global change.

Mitigating environmental impacts refers to implementing measures to reduce or minimize negative effects on the environment. Among such measures is prevention, not only through silvicultural treatments or using public awareness and sensitization about this socioenvironmental problem, but also by trying to control and attenuate the impacts. In this sense and in the context of global change, developing public policies and integrating forest fires into territorial management and planning are necessities [23]. Some studies have focused on preventive fuel management to reduce fire risk through practices such as prescribed burning or the introduction of grazing livestock [24]. Another potential policy option to support NBSs would be to explore community-based insurance strategies and the opportunities and limitations of public and private insurers in wildfire risk management [25].

The management and mitigation of fire-induced land degradation requires strategies that combine engineering principles with ecosystem functionality. This is one of the challenges facing the scientific-technical approach when implementing NBS in these areas recently affected by fire disturbance. In this regard, it is considered that, given the heterogeneity of wildfires, different NBS should be proposed and applied in the territory based on the assessment of experts who determine, for example, whether wood should not be removed from an area to prevent higher rates of erosion, destabilization of the hillside and its collapse causing a landslide, but rather to encourage the growth of regrowth species that allow the soil to be fixed and erosion to be reduced by applying it manually. This approach combines landscape architecture, soil mechanics, hydrology, plant ecology and ecosystem services management. In this sense, the role of policy actors is fundamental in mitigating the impact of forest fires through forestry practices that favor rapid ecosystem recovery [6]. It is considered essential in this sense to intervene in public policies and management practices, and important that these are based on scientific evidence to adequately manage the disturbed ecosystems in each case [26]. Such policies focus on carrying out measures related to the mitigation of, and adaptation to, these events. Collective mitigation progression is strongly associated with a policy domain more focused on reducing wildfire susceptibility/danger. The mitigation progression and adaptation effort seem to be promoted by different policies and policy domains, with both paths converging towards a common goal of reducing the impact of wildfires on wildfire-affected ecosystems [27]. The mitigation of these events in the context of global change requires the creation and implementation of national and international pacts that incorporate land management and consider the projections of the different climate scenarios, thereby increasing society's preparedness for these events and environmental sustainability [28].

After the wildfire, some of the most frequent hillslope management practices include using burned trees to construct log and log-residue erosion barriers along contour lines. The aim is to slow runoff, collect eroded sediments, and increase water infiltration. In addition, one of the emergencies, protective and stabilizing treatments for bare burned soil that has proven quite effective is mulching [29]. These post-fire treatments aim to reduce soil erosion and prevent sediment deposition in undesirable areas, as well as retain soil moisture by significantly reducing soil loss due to erosion. These mulches can be made from straw or wood chips and plant debris, although more research is needed for the consolidated use of mulching in areas affected by wildfires [9]. Salvage logging is one of the most implemented management practices in the short to medium term after fires. The timing of extraction (a few months after the fire or up to almost a year later, but before spring), as well as the method (manual, animal or mechanical) is essential to prevent soil degradation. Despite the interest in this type of management, little research has been conducted on it [30]. Despite their proven benefits, the performance of Nature-based Solutions (NBS) during last summer's events demonstrates they are insufficient for preventing large-scale, intense wildfires. Therefore, to enhance their effectiveness, NBS must be used as a complementary tool within a comprehensive approach to risk and land management

There have been very few studies on the direct effects of the introduction of livestock on post-fire soil, and even fewer when considering the 'fire + livestock passage' sequence. Although there are studies on the erosion caused by overgrazing, there are fewer on biochemical soil degradation. Recent studies have shown substantial improvements in soil quality in areas with low intensity grazing due to the increased organic matter and nutrients [12]. In this regard, this study provides valuable information on the subject, although it focuses solely on a very specific case study, making it difficult to make categorical statements. Therefore, more studies like this should be conducted with different types of livestock, in different environments and with respect to different fire intensities, being. However, it is crucial not to exceed the livestock carrying capacity for each location and time, and important that livestock are introduced after the first spring, not before, to avoid negative effects.

Therefore, burned areas must be managed to prevent their vegetation fuel from regaining horizontal and vertical continuity that could lead to high-severity fires. A high-intensity fire can consume practically the entire forest mass, which can lead to events of ash dragging by heavy rainfall [9] or geomorphological changes [31] that can affect the ecosystem and its recovery in a severe way. Thus, there is a need to clearly establish the most appropriate post-fire forest management, such as NBSs, for each case to avoid a concatenation of deleterious events. Despite the interest generated by this type of post-fire management, practically no studies have focused on evaluating NBSs as a forest management tool or compared them with other management types. Given the context of global change, and the water and nutrient stress and associated risks that forest areas are experiencing, it would be useful to establish protocols for action and the implementation of NBSs in a combined manner to facilitate more-rapid ecosystem recovery.

Finally, one of the NBSs related to fire is the application of forest management techniques that, through the application of prescribed fire, can be useful for land management. In this regard, the use of fire as a management tool must be carried out by experts in the field, attempting to control fundamental parameters such as the intensity of the fire and the time the fire remains on the ground in a prescribed burn so that the objectives of the burn are met and it is an appropriate NBS. In this sense, it is necessary to integrate fire management into national and supranational legislation and policies as one of the more sustainable solutions to prevent large forest fires in the highest-risk areas [8]. Other authors have pointed out the importance of stakeholders perceiving forest fire management strategies as NBSs [7]. Although the authors questioned the extent to which fuel management strategies can be considered NBSs, based on the International Union for Conservation of Nature (IUCN) standard, they stated that fire should be managed, and supported fire prevention rather than fire suppression policies. In addition, they pointed out that promoting agricultural and livestock uses, modifying forest species compositions to increase fire resistance, and introducing large herbivores are NBSs that improve vegetal fuel management, are key to addressing socioeconomic challenges in high fire risk areas and decrease the potential impact of a potential wildfire.

3. Nature-Based Solutions in Hydrological Events and Floods

Foundational works have defined NBSs as nature-inspired strategies for addressing environmental and societal challenges [32]. Their economic benefits in flood prevention are being increasingly recognized [16,33], with several case studies highlighting their value in territorial planning [34,35]. Recent evaluations in river basins under current and future climatic conditions have underscored their effectiveness in reducing flood risk [16,35], although their implementation and long-term monitoring remain key challenges [36]. There are various types of NBSs, including natural systems, green infrastructure and hybrid or integrated approaches—all effective tools for flood prevention in riverine areas [37]. Also, NBSs support ecosystem services, such as aquifer recharge, carbon sequestration, slope stabilization and flood buffering [14]. Although the green approach is gaining ground, comparisons with traditional grey infrastructure remain relevant [38]. Because floods are influenced by climatic conditions, and preventing high-frequency events involves extremely high costs, total flood avoidance is not achievable [39]. Nonetheless, a broad, interconnected network of NBSs could help address urban development issues and support efforts to mitigate climate change [16] and its effect on flood hazards. Therefore, specifically in the context of flood prevention, the literature indicates that the implementation of NBSs strengthens management efforts in a more sustainable way than traditional methods [14,16,37,39]. Other studies have underscored the need for further research into the implementation of certain measures, while still recognizing their potential as primary prevention strategies [36].

Regarding mitigation measures, several authors have argued that NBSs can be part of a range of options to reduce flood risk. To evaluate the present and potential future effectiveness of NBSs in reducing flood risk, large-scale analytical tools that rely on global datasets are already in use to provide initial estimates. However, to enhance their relevance and accuracy, these tools need to be complemented with validation data obtained through field observations, remote sensing, questionnaires, interviews, focus group discussions and participatory mapping, in this sense, NBSs can be considered validated when their implementation has been assessed and proven effective. Therefore, they represent a reliable option whenever a mitigation measure needs to be applied. Large-scale flood risk reduction (e.g., at the regional level) can be achieved by implementing a network of NBSs [40]. Some examples include the Saguenay and Red River valleys in Canada, as well as the Engelberg Aa River in Switzerland, where a 'basin-centric' approach, focused on managing flood risks across the entire watershed rather than just along the river, has been employed [41]. In fact, NBSs are increasingly being implemented due to their significantly lower cost–benefit ratios compared to traditional technical mitigation measures [15]. Conventional technical mitigation measures often come with high implementation and maintenance costs, can significantly alter the visual character of the landscape, and may have considerable negative environmental effects—challenges that NBS strategies may help to address [42]. Offering a sustainable alternative to traditional engineering-based measures, NBSs represent a highly effective and increasingly preferred approach to flood risk mitigation. Unlike conventional interventions, which are often costly, visually intrusive and environmentally disruptive, NBSs provide multifunctional benefits because they work with natural processes at the landscape scale. Their lower implementation and maintenance costs, combined with their capacity to enhance ecological resilience and social acceptability, position NBSs as a forward-looking strategy for addressing flood risks in a changing climate [15].

With regard to actions implemented in the aftermath of extreme or catastrophic events, NBSs have become some of the most widely adopted measures in recent years [43]. Post-flood contexts often present a critical window of opportunity, the significant damage caused prompting the implementation of measures aimed at mitigating the impacts of future events. In this sense, some studies have highlighted the need for interventions that combine both preventive and mitigative functions [44]. Enhancing biodiversity, improving aquifer water quality and creating natural flood retention areas, in tandem with avoiding sediment compaction or obstruction, are all actions that, when implemented after a flood, can significantly reduce the severity of damage during subsequent extreme events [16,32,34]. Post-event measures can therefore be understood as long-term investments that not only address the immediate consequences of flooding but also contribute to improving river dynamics and the resilience of the surrounding ecosystems to future flood events.

4. Nature-Based Solutions in Hillslope and Geomorphological Processes

Geomorphological hazards on slopes occur primarily when destabilizing stimuli or forces (gravity) exceed the soil shear strength. For example, when it rains and the soil saturates, the weight and pore pressure increase, which, in turn, decreases the friction and strength of the material, increasing the likelihood of landslide events [45]. As an alternative to mitigate the risk associated with these events, nature-based solutions are also emerging in this area. They play an important role in preventive strategies aimed at reducing the incidence and intensity of geomorphological hazards on slopes. They can be used, for example, to maintain soil cover and vegetation structure, which are essential for mitigating erosion, improving infiltration, and reducing surface runoff on sloping terrain, thus contributing to both soil stability and landscape multifunctionality [2]. One widely adopted soil conservation strategy involves the implementation of mechanical inventions, such as contour terraces, vegetative barriers or slowly forming terraces, all of which help control slope dynamics and reduce water flow velocity [17]. Complementing these findings, Rehman et al. [18] demonstrated that the application of vegetation-based solutions, such as grass cover on degraded hillslopes, significantly improves soil retention and delays runoff peaks during intense rainfall events. These approaches not only reduce erosion and enhance infiltration but also minimize sediment transfer to downstream areas.

When preventive measures do not fully respond, or when a process associated with the geomorphological dynamics of hillside areas is already underway, the NBS approach focuses on damage mitigation. In this dimension, the main purpose is oriented towards reducing the magnitude, speed, and impact of geomorphological events, such as erosion or landslides. However, the mitigating capacity of NBSs is largely conditioned by the type and scale of the process for which they are used [46,47]. This requires the specific selection of techniques and species depending on the case or context in question or, going further, through the joint use of NBSs and traditional engineering solutions as a standard provision to ensure better results.

It is certainly important to keep in mind that the suitability of NBSs has been established only for some types of slope instabilities, not for all. Scientifically, in the context of landslide risk reduction, it has been categorically established that the best results from the implementation of NBSs can be seen in shallow landslides or shallow erosion processes [48]. However, when considering the effectiveness of landslides involving deeper layers or larger-scale scenarios, it is considered that further research is still needed, in conjunction with other engineering solutions, to establish their usefulness more broadly [49].

A key point to consider among the influencing factors that impact the effectiveness of NBS implementation and maintenance in the context of damage mitigation lies in identifying and selecting the key plant species. Species analysis in damage mitigation strategies or applications has shown that the technical effectiveness of NBSs is largely determined by the plant selection made for each case, which is primarily dependent on hydrological, biomechanical and socioeconomic criteria [50–52]. This selection points more to the functional role that the plant would play than to a universal species to be applied because it possesses specific characteristics. That is, NBS-based interventions use vegetation as a fundamental structural component for slope stabilization, aiming to mitigate potential magnitudes of events, but at the same time providing co-benefits, such as improved biodiversity and soil health, that would work to favor the task [53].

In the context of geomorphological and fluvial dynamics, NBSs have emerged as a valuable alternative for the restoration of degraded ecosystems. In the context of erosion or landslides, NBSs are capable of integrating ecological, biophysical and social functions to reduce potential hydrogeomorphological risks, all while regenerating the landscape. This provides a sustainable alternative to traditional hard engineering mechanisms [19,54,55]. Recovery following geomorphological events that alter the original or previous condition of an environment can materialize at various scales and over a variety of contexts, from slope and riverbank stabilization to the restoration of areas degraded by mining activities. For example, in slope areas, previous experience has shown that combinations of living wood and revegetation can be used to strengthen the soil and prevent future events, while simultaneously improving water regulation and promoting biodiversity. Meanwhile, in the context of sites affected by mining activity, NBSs can contribute to addressing soil and water pollution by reshaping and improving the terrain using techniques such as biochar, while also contributing to the reconstruction of water systems and vegetation using pollution-tolerant native species [19,55].

The implementation of NBSs can provide significant advantages and benefits in the context of climate change, fostering preventive, mitigating and adaptive processes in response to the geomorphological and fluvial dynamics that can develop in hillside areas. In the future, an increase in the frequency and intensity of meteorological events, such as droughts, heavy rains triggering floods and landslides, heavy snowfall and deleterious winds, is generally expected [56]. Due to their intensity and frequency, such events may aggravate some geomorphological processes or increase the number of areas experiencing instability. These changes may generate greater socioeconomic impacts than in the past, given the additional pressures of global population growth and increasing urbanization [56].

Faced with the expected series of changes, considering and addressing a rebalancing approach to adaptation strategies becomes increasingly important as a way of promoting the resilient management of watersheds and other susceptible areas. This rebalancing must be directed at structural and non-structural measures, and the role of NBSs will be an essential component in the process, complementing traditional engineering strategies in some cases and offering superior alternatives in others [56,57]. At the same time, addressing current challenges in the effective implementation of NBSs will also be vital in order to establish a robust foundation for the future. The need for interdisciplinary approaches, and the development of standardized assessment methodologies and integrated public policies that foster community and environmental resilience in the face of the new challenges posed by climate change will be to ensuring the future usefulness of NBSs in the context of global change [58,59]

Despite the above, and despite the growing acceptance and recognition of the promising potential of NBS in this field, critical analysis of their effectiveness, particularly in the context of extreme geomorphological events such as deep landslides or large-scale erosion, reveals significant gaps and knowledge gaps. The scientific community that has developed recent work in this area agrees on the existence of significant gaps in the understanding of NBS effectiveness. This is mainly based on critical knowledge gaps, the need for further research, and insufficient models to validate the effectiveness of NBS in more intense events [60–62].

Regarding the above, in recent years, parameters have been proposed to facilitate the evaluation of NBS performance, particularly in the area of landslide prevention and mitigation. However, the lack of indicators that combine ecosystem services, engineering performance, and monitoring has been highlighted, highlighting the significant limitations in the practical validation of NBS effectiveness in events of this nature [60].

In this sense, in the current field of hillslope and geomorphological processes, NBS continue to hold promising potential despite its low risk reductions as engineering solution [5]. However, their practical validation in the face of extreme or larger events remains a challenge yet to be overcome in the scientific field. Therefore, the need for greater research efforts, the development of more robust models, and the creation of comprehensive indicators that allow for a better evaluation of the performance of NBS implementation in this area will be crucial going forward (Figure 1).

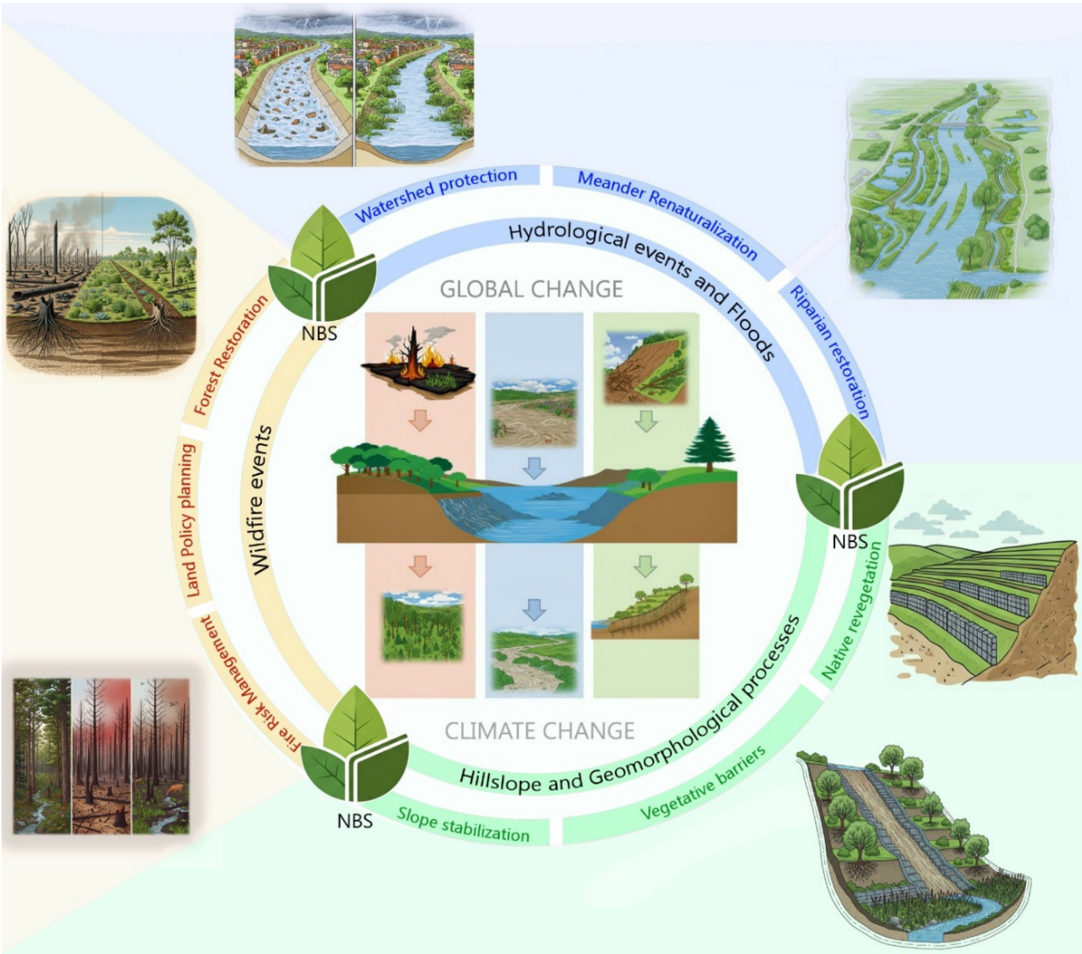

Figure 1. NBS in natural disaster events in Global and Climate Change context.

5. Final Remarks

Nature-Based Solutions have emerged as a transformative approach in the face of growing environmental and climate-related challenges. In this article, we explored the application of NBSs in three different hazard contexts-wildfire events, hydrological events and geomorphological/slope events. Despite differences in their spatial scales, ecological settings and intervention typologies, in all of the cases, there was the capacity for NBSs to reduce risk while delivering ecological, social and economic co-benefits. Nature-based solutions provide adaptive and low-impact responses that align with broader territorial resilience objectives. Their benefits extend beyond hazard mitigation to include biodiversity enhancement, water regulation, carbon capture and cultural ecosystem services. Unlike conventional grey infrastructure, whose functionality often degrades over time, the effectiveness of NBSs can improve as ecological processes are restored or enhanced.

Not only do vegetal swales, wetlands or hillside reforestations reduce runoff or sediment transfer, they also generate habitat continuity and landscape connectivity. Moreover, their social acceptance tends to be higher, especially in rural or peri-urban areas where local knowledge, sense of place and traditional land practices can be used as assets in their implementation. However, implementing NBSs is not easy nor free of challenges. The main obstacles are a lack of interdisciplinary collaboration, institutional decision-making and the absence of robust monitoring frameworks. Although the European Union strategies and technical guidelines have increasingly promoted NBSs (e.g., the European Green Deal and Biodiversity Strategy), their mainstreaming into land-use planning, disaster risk reduction frameworks and local policies remains inconsistent, and they often suffer from short-term-project-based funding schemes that limit their capacity to mature and demonstrate full effectiveness. The lack of standardized performance indicators and long-term monitoring further hampers the accumulation of evidence needed for widespread adoption. To advance the integration of NBSs, several actions are required. First, territorial and environmental planning frameworks must explicitly recognize and prioritize NBSs as primary tools in hazard mitigation and ecosystem restoration. To achieve this, it is necessary to update guidelines, institutional coordination and the alignment of funding mechanisms with long-term landscape objectives. Second, pilot projects should be scaled up through adaptive management schemes, combining scientific knowledge with community-based monitoring. This participatory approach would enhance both their legitimacy and efficiency, especially in local contexts. Third, education and training programs are essential to equip planners, engineers and decision-makers with the tools and vocabulary needed to design and manage NBSs across disciplines.

The involvement of local populations is crucial to the success of NBS initiatives because they are the main guardians of the territory. The increasing frequency and intensity of climate-related disasters demand a paradigm shift in territorial planning. Nature-Based Solutions are necessary foundations for resilient and sustainable landscapes and, consequently, should not be framed as optional or supplementary measures, but rather as foundational components of planning and governance. Solutions should be tailored to the specific characteristics of the ecosystem, climate and local communities.

Looking ahead, Nature-Based Solutions (NBS) in these areas are expected to focus on their holistic integration into land-use planning. Specifically, the key points will be modelling and assessment (developing more accurate models that simulate the effectiveness of NBS at different scales, from river basins to entire landscapes, studying peatland restoration, strategic reforestation and artificial wetlands, and the risk mitigation described in this study), governance and policy (promoting policy frameworks that incentivize their adoption, such as "green taxation" or programs that reward conservation so that NBS are considered essential, not complementary, infrastructure), multifunctionality (researching how NBS can offer multiple simultaneous benefits, such as improving biodiversity, water quality and social well-being) and social participation (involving local communities in the design and maintenance of these solutions, encouraging the creation of more resilient and less vulnerable landscapes). Therefore, the future lies not in isolated solutions, but in the creation of resilient and multifunctional landscapes. This requires integrated land management that combines science, policy and community participation.

Author Contributions

M.F.: conceptualization, methodology, software, data curation, writing—original draft preparation, visualization, investigation, supervision, writing—reviewing and editing; C.S-G.: conceptualization, methodology, data curation, writing—original draft preparation, visualization, investigation, writing—reviewing and editing; R.F-H.: data curation, writing—original draft preparation, investigation, writing—reviewing and editing; O.C-G.: software, data curation, writing—original draft preparation, visualization, investigation, writing—reviewing and editing. All authors have read and agreed to the published version of the manuscript.

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Use of AI and AI-Assisted Technologies

No AI tools were utilized for this paper.

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