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Review

Scientific Evidence for the Effectiveness of Mangrove Forests in Reducing Floods and Associated Hazards in Coastal Areas

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Abstract: The evidence for the capacity of mangrove forests for coastal protection gained more importance within the recent decade because of important international agreements, such as the Sustainable Development Goals and Sendai Framework for Disaster Risk Reduction. However, the degree to which researchers agree on the capacity of mangroves to reduce coastal hazards is not fully established. This study employed a multilevel review process that selected 45 peer-reviewed articles for detailed analysis. Significant findings revealed a strong agreement amongst scientific literature on the benefits of mangrove forests in reducing coastal hazards. However, findings also revealed the dominance of single-discipline research, and less representation of countries in Africa and South America. Limitations in sampled studies highlight the limited number of global studies conducted on mangrove forests' effectiveness in attenuating coastal hazards, and the limited representation of development and disaster studies. It is recommended that future research on mangrove forests and their coastal hazard reduction capacity should explore multidisciplinary approaches, and synergies in fieldwork and simulation methods while considering possible future climate change situations.

Keywords: mangrove forests; coastal hazards; effectiveness; level of agreement; ecosystem-based disaster risk reduction

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1. Introduction

With the adoption of global frameworks such as the Sustainable Development Goals and the Sendai Framework for Disaster Risk Reduction, ecosystems and their role in climate change adaptation and disaster risk reduction gained importance and more attention from political stakeholders [1,2]. However, the degree to which nature-based solutions such as mangrove forests can reduce the impacts of natural hazards and climate change is not entirely understood [1]. However, a holistic understanding of nature-based solutions is essential as scientific evidence is needed to convince policymakers to consider, and eventually implement, mangrove forests as nature-based solutions in their local context [1]. Moreover, decision-makers often do not possess detailed understanding of the conditions under which nature-based solutions offer benefits for disaster risk reduction [3]. Trends such as rapid urbanisation, infrastructure build-up close to the coast or the increased frequency of extreme natural events make coastal communities vulnerable to climate change and natural hazards [4].

McIvor et al. [5] pointed out that by the end of this century, a significant part of the world's population will be threatened by sea level rise. Furthermore, the annual economic losses and costs of maintaining traditional built-up infrastructure against natural hazards will increase. Therefore, new long-term strategies beyond engineering solutions are needed. Hence, this paper focuses on the coastal region and related hazards. Nature-based solutions, of which mangrove forests are a part, can contribute two-fold to protecting communities from coastal hazards. First, ecosystems can reduce the exposure of coastal human and natural systems to extreme events by acting as an ecological defence structure or buffer zone [2]. Second, by offering provisioning services such as "[. . .] income-generating activities and livelihoods" [2] (p. 1) that increase resilience and post-disaster capacities [6]. One ecosystem that can potentially protect coastal communities and their infrastructure from multiple hazards is mangrove forests [2,7–9]. Nevertheless, their capacity to provide protection services is highly dependent on the context [3]—this highlights why it is crucial to understand their effectiveness for disaster risk reduction.

Mangroves and their associated ecosystem services have only been discussed for a few decades, although their benefits have been documented since colonial times [10]. These benefits include providing timber and non-timber products for fuel, construction and support of fisheries. Within regulating and supporting services, sediment accretion, the control of erosion rates and the attenuation of waves are mentioned. Spiritual enrichment, aesthetic and recreational experiences, reflection, and cognitive development are all considered examples of cultural ecosystem services of mangroves. Disservices of mangroves, which are rarely discussed in the current discourse, include a negative perception of forests as gloomy and dark, and as a place of danger inhabited by animals that threaten humans. One very common disservice assigned to mangroves is their function as breeding grounds for diseases, such as vector-borne malaria, transmitted by mosquitoes [10,11].

Several related studies have been conducted. For example, Akber et al. [12] studied how mangrove forests provide storm protection services in Bangladesh, by comparing the post-storm damages between villages with surrounding mangroves to those without them. Ataur Rahman and Rahman [4], who studied the natural protection mechanisms of mangroves against cyclones, attested to their effectiveness. Auerbach et al. [13] compared the protection mechanisms of mangroves and engineered embarkments against flood and sea level rise, and attested to mangroves' greater flood-attenuation potential. More related work was conducted by Sudmeier-Rieux et al. [1], and they assessed the scientific evidence of ecosystems in disaster risk reduction. While these related works have assessed ecosystem's potential in reducing disasters and hazards, little or nothing is known about the scientific agreement on the potential of mangrove forest ecosystems in reducing coastal hazards from a global perspective.

While this paper focused on adopting the Sustainable Development Goals and the Sendai Framework for Disaster Risk Reduction as benchmarks, the use of mangroves as a natural-based foreshore protection solution to address coastal hazards dates back to the 1980s and earlier. Saenger and Siddiqi [14] showed that the natural mangrove forests of the Sundarbans protected the area from cyclone damage, which led to the initiation of a mangrove afforestation programme in the area by the Forest Department in 1966. Spalding et al. [15] show that mangroves act as a coastal defence, reduce damage from waves and large storms, reduce erosions, and bind the soil together. Sumeier-Rieux et al. [1] noted that the Indian Ocean tsunami of 2004 drew attention and more investigations into the protective role of the mangrove system. This shows that research into mangroves' protective value against coastal hazards was ongoing before 2015. However, the adoption of the year 2015 as the benchmark in this paper is because the role of mangroves (ecosystems) in reducing coastal hazards gained more importance and attention from policymakers, as highlighted in the Sustainable Development Goals and the Sendai Framework for Disaster Risk Reduction adopted in 2015.

Therefore, this paper seeks to answer two questions. First, what is the scientific evidence for the effectiveness of mangrove forests in reducing coastal hazards? Second, what is already known about their capacity to improve disaster risk reduction, and what research gaps still exist? For this purpose, 45 scientific publications released since 2015 were reviewed and analysed. The time frame was intentionally chosen as 2015 marks the adoption of the internationally important Sendai Framework for Disaster Risk Reduction and the Sustainable Development Goals by political stakeholders worldwide. As mentioned above, scientific evidence is fundamental for decision-makers to consider and implement nature-based solutions to disaster risk reduction. Hence, it is a prerequisite to reach the objectives of the frameworks mentioned above. The next section of this paper will give an insight into the chosen methodology. The subsequent section will present the in-depth results of this paper, before the critical discussion is presented. The last section of the research will conclude the overall paper.

2. Materials and Methods

This paper is based on a systematic review and critical evaluation of 'mangrove forests' effectiveness research'. This field of research refers to studies that seek to understand how mangrove forests reduce or cushion the effects of coastal hazards. This also extends to studies that generally explore coastal hazards in areas surrounded by mangrove forests. This study employed a multi-stage review process, as appraised and applied by various authors [16–19]. This includes the following stages of analysis:

A. Scoping of the study: The thematic scope was limited to the domain of mangrove forests and coastal hazards, especially the interplay between the two. The geographical coverage of this study was open-ended and not limited to any geographical area. For the scope of this study, only papers that assessed the effectiveness/impacts of mangrove forests in the presence of actual or anticipated coastal hazards were selected for the study. This paper considered effectiveness as an umbrella concept which summarises terms that describe the same phenomenon. In this case, effectiveness was used to represent all studies that assessed mangroves' ability or usefulness to reduce, control or attenuate coastal hazards. The IPCC [20] (p. 688) defines hazard as "the potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources". In the case of this paper, this particularly accounts for coastal processes, trends and events that threaten coastal regions, e.g., storm surge, sea level rise or erosion [20].
B. Publication scan and selection for detailed review: The literature search was conducted using the search terms "mangrove forest" and "coastal hazards" on 01 August 2021 on the Web of Science (WOS) and Scopus databases to identify relevant peer-reviewed articles. The search date was limited to papers published between 01 January 2015 and our search date (1 August 2021). This period was used as the benchmark because this was the year the Sendai Framework and SDGs were published. They represent the official start of the disaster risk movement that largely included ecosystem-based solutions [1,2]. This search resulted in 88 publications. Additionally, the search terms "mangrove" and "coast" were employed on Google Scholar using the same period. This resulted in 91 publications, after reviewing their titles. The abstracts of these 88 (from Scopus and WOS) and 91 (from Google Scholar) papers were then screened to select the final papers for analysis. Conditions for selection were (a) papers addressing one or more coastal hazards, and (b) papers reflecting on the possible impact or effectiveness of mangrove forests in the event of coastal hazards. Papers that did not meet these two conditions were excluded, while those that met them were retained for further analysis. This process resulted in 45 relevant articles for detailed analysis. Table 1 shows the review process of the selected articles.
C. Detailed analysis of selected articles: The full text of the 45 articles was reviewed. This enhanced the extraction of details relating to the study objectives from the selected papers under the following headings:
    (i) Study characteristics: This captures the study characteristics in terms of (i) geographical and regional coverage, the scale of analysis, year of publication and disciplines of authors. Because some of the sampled papers comprised more than one author and discipline, the total frequency of all resulting disciplines was greater than 45. (ii) Hazard types and methods employed. Here, we reflected on the hazard types addressed and methods applied in the 45 papers. Because some of the sampled papers assessed more

than one coastal hazard, we documented the frequencies of each coastal hazard. Thus, the total frequency of the coastal hazards exceeded the number of sampled papers (that is, 45).

(ii) Scientific evidence: This captures the scientific evidence for the effectiveness of mangrove forests in reducing coastal hazards in terms of the benefits provided, limitations of mangroves and level of agreement. For the level of agreement, we developed a ranking scale of 1 to 5, ranging from very weak to very strong agreement, which was adapted from [1,20]. To reduce subjectivity in the ranks, the 30 papers were read and ranked by the two authors, and the average ranks were computed for each article. The mean was then calculated from the resulting average ranks of the 45 articles, representing the level of agreement in the scientific literature.

(iii) Research gaps: We highlighted the research gaps suggested in the reviewed papers. However, in the discussion session, more research gaps are presented based on the analysis of the reviewed articles.

D. Raising relevant concerns and prospects for future research: Based on our reflections on the results in (3) above, gaps in the studies were identified, and suggestions were made. The prospects of studies in mangrove forests and coastal hazards were also charted here.

Table 1. Review process of the selected articles.

Literature Database	Initial Results after Title Review	Results after Abstract Review and Exclusion of Duplicates
Web of Science (WOS)	49	18
Scopus	39	12
Google Scholar	91	15
Total	179	45

3. Results

3.1. Characteristics of the Studies

This section captures the characteristics of the studies in terms of geographic and time coverage, scale of analysis, disciplines identified, coastal hazard types, methods employed and future considerations.

3.1.1. Geographic Coverage

As stated in the methods section, the geographic coverage of the selected papers was analysed (Figure 1). Of the 45 selected papers, 16 were global in scope (that is, they assessed the effectiveness of mangroves across different continents). Of the non-global studies, 22 were in Asia (they assessed the above-mentioned study theme in Asian countries), four were in North America and two were in Oceania. One study was not tied to a study location (that is, the analysis of the study theme was conducted via laboratory simulation). In terms of country coverage, eight studies (26.7%) were situated in Bangladesh, seven (23.4%) were global, six (20%) were located in Indonesia and two studies (6.7%) each were situated in the USA and New Zealand. Only one study (3.3%) each was conducted in Vietnam, India, Bahamas and Singapore. One of the studies (3.3%) was simulated in the laboratory and was, thus, not applicable to a study area. Figures 1 and 2 show the geographic distribution of continental and country coverage studies.

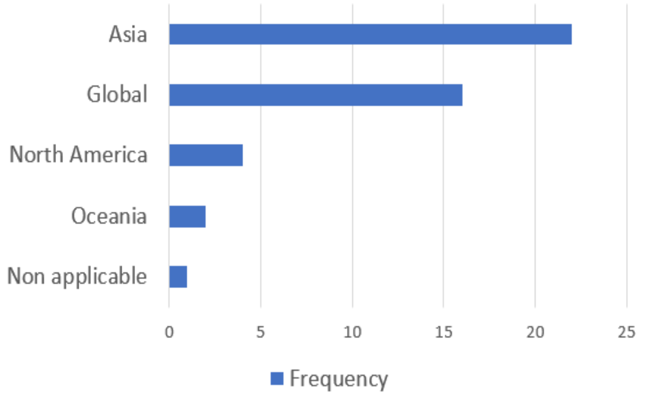

Figure 1. Continental coverage of studies.

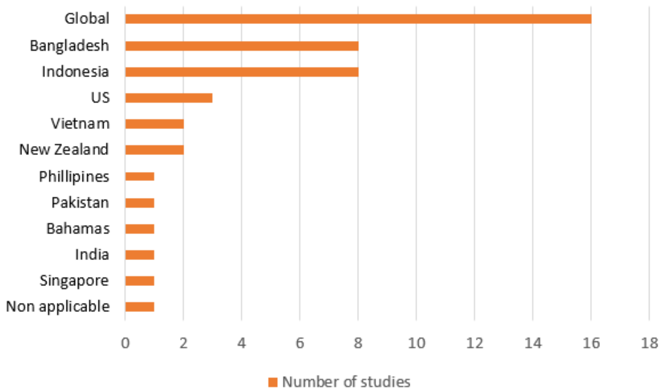

Figure 2. Coverage of studies by countries.

3.1.2. Year Coverage

The selected papers cover studies conducted between 2015 and 2021. Regarding their frequency, six studies were conducted in 2015, three in 2016, seven in 2017, four in 2018, twelve in 2019, five in 2020 and eight in 2021. Figure 3 shows the year distribution of the sampled papers.

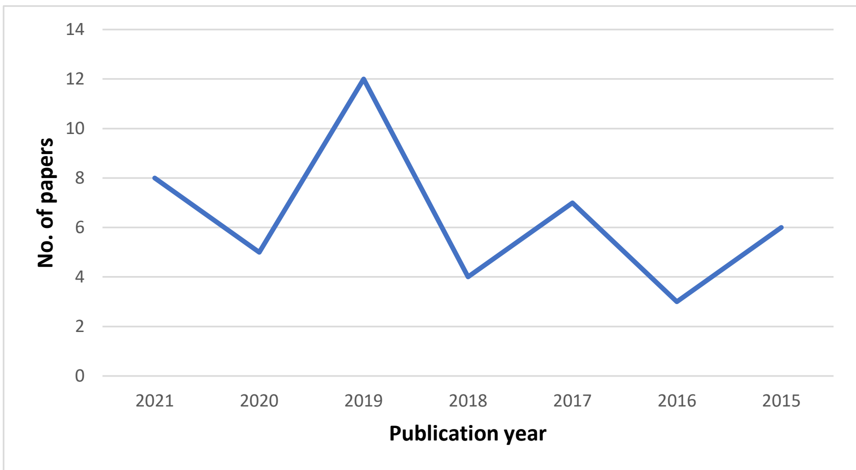

Figure 3. Studies' distribution by publication year.

3.1.3. Scale of Analysis

The sampled papers analysed the subject matter on various spatial scales. Most of the studies (36%) were conducted globally. Others were conducted on a sub-national (i.e., a state or region within a country) level (29%), local (for example, a community or municipality) level (20%), and national level (13%). Only one study (2%) was not applicable to a spatial scale. Figure 4 summarises the studies based on their scales of analysis.

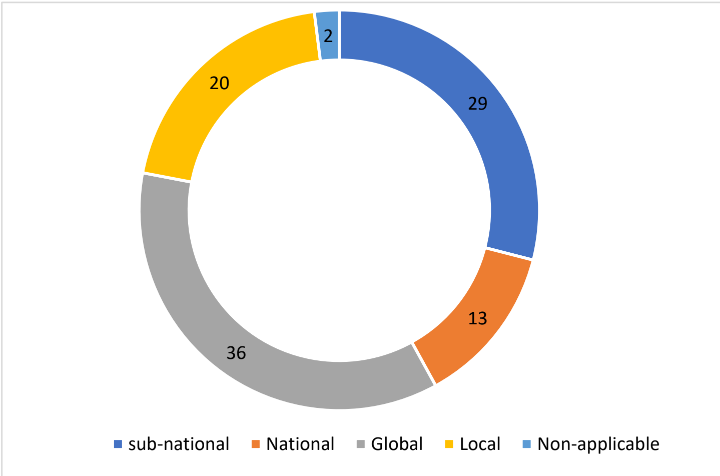

Figure 4. Scale of analysis of sampled studies (in percentages).

3.1.4. Disciplines

In terms of author disciplines, the analysed articles varied. While a majority of the studies were in engineering (16), biological sciences (14), environmental sciences (13) and geography (10), few were in agricultural sciences (4), risk and disaster studies (3), geology (1), physical sciences (4), economics (2) and others (comprising studies in urban planning, ICT, oceanography and development studies) (6). Nevertheless, the sum of the frequency of all represented disciplines here is greater than 30 because some of the sampled papers comprised more than one author and field. In terms of the interdisciplinarity of the studies, twenty-seven studies (60%) were conducted in a single discipline, eight (18%) in two (dual) disciplines, and ten (22%) were multidisciplinary (that is, combined three or more disciplines in a study). Figure 5a,b show the distribution of the studies by discipline.

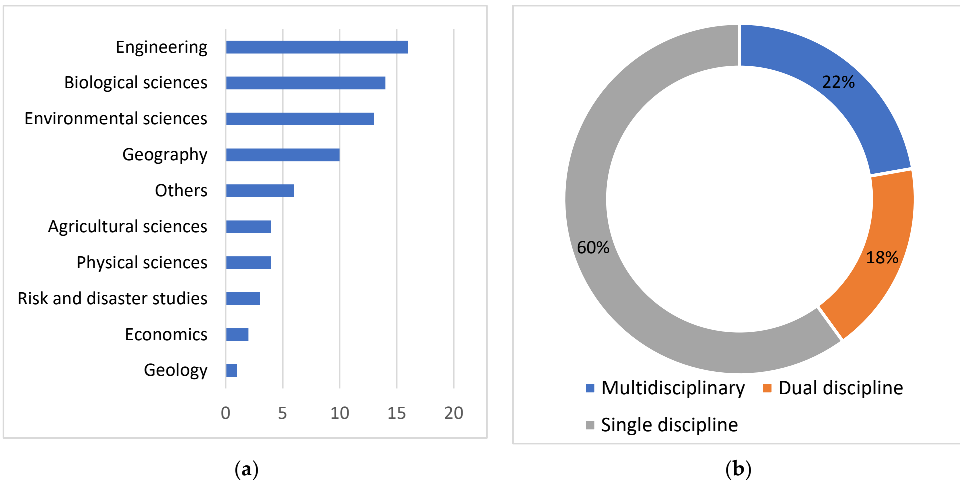

Figure 5. Distribution of studies by (**a**) disciplines and (**b**) interdisciplinarity.

3.1.5. Type of Coastal Hazards

In this section, the coastal hazards analysed in the sampled papers were assessed. As stated in the methodology, some papers evaluated more than one coastal hazard. Thus, the resulting number of all hazards here is greater than n (n = 45, the total number of sampled papers). As can be visualised in Figure 6, most (19%) of the sample papers examined tropical cyclones, 17% examined tsunamis and 14% each examined other hazards (in this case, coastal hazards and waves in general), storms and sea level rise, respectively. On the contrary, just 11% of studies examined both coastal erosion and floods.

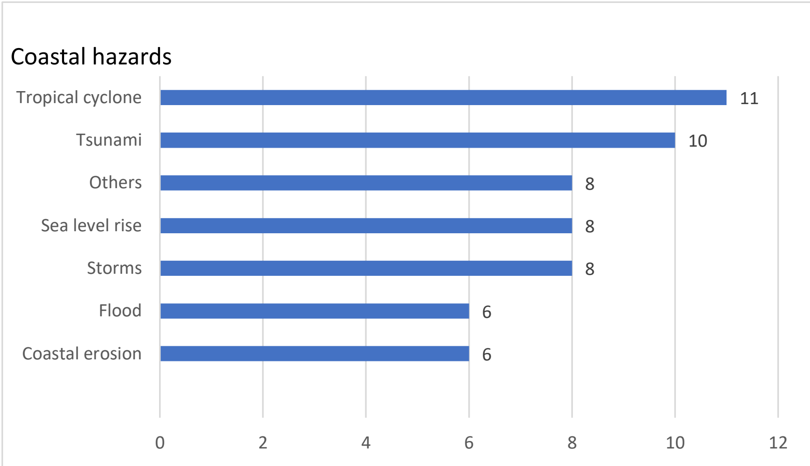

Figure 6. Distribution of studies according to coastal hazard type.

3.1.6. Methods Employed

Here, we assessed the methods employed by the papers to understand the reliability of the assessments. Based on our analysis, four clusters of methods were identified. While 17 studies employed simulation and modelling, 14 applied fieldwork, and 7 studies each applied simulation, fieldwork and reviews. The use of simulation and modelling characterise studies that employ remote sensing, geographic information systems and modelling techniques. For example, Deb and Ferreira [21], in assessing the impacts of Sunderban mangrove degradation on coastal flooding in Bangladesh, simulated the mangrove degradation and flooding at different conditions to predict future scenarios. Fieldwork methods characterise studies that employ interviews, questionnaire surveys and field observation in assessing the effectiveness of mangrove forests in attenuating coastal hazards. For example, Ataur Rahman and Rahman [4] employed stakeholder interviews, workshops and seminars in assessing natural defence mechanisms to reduce climate risks in the coastal zones of Bangladesh. As the name implies, simulation and fieldwork methods characterise studies that employ simulation, modelling and fieldwork. For example, Islam et al. [22] used remote sensing analysis and a questionnaire survey to capture social responses in assessing ecosystems' resilience to tropical cyclones. Reviews, as a method, capture studies that assess the effectiveness of mangrove forests in reducing coastal hazards from a review of the literature (for example, Ghorai and Sen [23]). Figure 7 summarises the methods employed in the sampled studies.

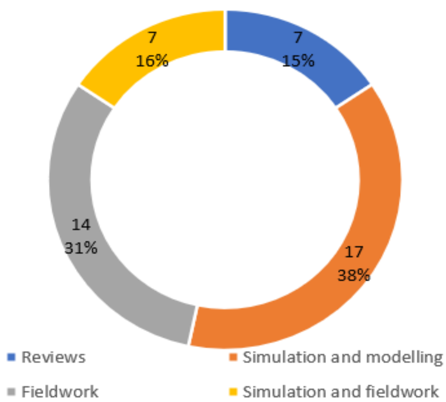

Figure 7. Methods applied by the studies.

3.1.7. Hazard Exposure

As visualised in Figure 8, most of the sampled studies (32; 71%) were exposed to coastal hazards at the time of assessing the effectiveness of mangrove forests in reducing coastal hazards, while the remaining 13 (29%) studies were not exposed to coastal hazards (that is, the hazards were simulated at different scenarios).

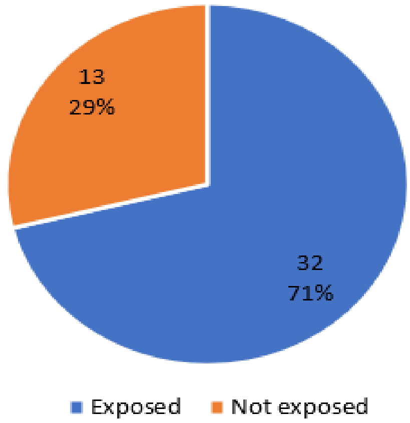

Figure 8. Exposure to coastal hazards.

3.1.8. Future Considerations

While assessing the effectiveness of mangrove forests in reducing coastal hazards, 25 of the studies did not explicitly consider or address future coastal hazards, while the remaining 20 studies assessed/discussed future hazard scenarios (see Figure 9).

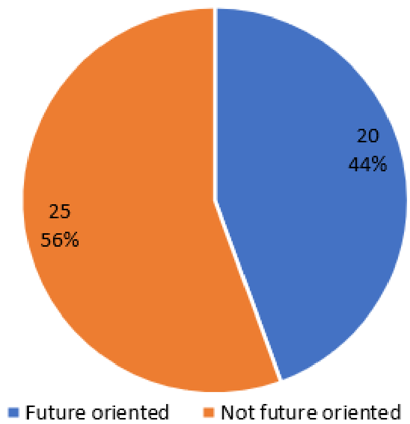

Figure 9. Future consideration of the studies.

3.2. Scientific Evidence for the Effectiveness of Mangrove Forests in Reducing Coastal Hazards

This section captured the scientific evidence regarding the benefits, limitations/trade-offs and level of agreement on the efficacy of mangrove forests in reducing coastal hazards.

3.2.1. Scientific Evidence (Benefits)

Various authors that assessed the efficiency of mangrove forests in reducing coastal hazards generally agreed that mangrove reduces the magnitude and impacts of coastal hazards. Notwithstanding the varied evidence and study setting stated in the papers, selected striking examples (nevertheless, representing the varied spatial scales of assessments) are presented in Table 2.

Table 2. Scientific evidence (benefits) from selected studies.

Source	Evidence Provided (Benefits)
[24]	Flourishing mangrove forests in West Kalimantan (Indonesia) enhanced the rehabilitation of shorelines and reduced erosion by more than 70% in two of the three bays studied.
[12]	Villages with surrounding mangrove forests experienced less damage to their houses than villages without mangroves. The cost of reconstructing cyclone-affected houses in mangrove-surrounding villages was less than in villages without mangrove forests, where the cost was three times greater.
[13]	"[. . .] islands in southwest Bangladesh, enclosed by embankments in the 1960s, have lost 1.0–1.5 m of elevation, whereas the neighbouring Sub-urban mangrove forest has remained comparatively stable" (P. 153). Thus, showing how mangrove forest is effective in controlling flood and SLR compared to engineered embankments.
[25]	This assessment shows that mangroves would attenuate storm surges by 27% in Indonesia, 50% in Mexico, 29% in Myanmar, 47% in India, 28% in the Philippines and 22% in Cuba.
[26]	Assessed tsunamis and cyclones in various countries. 2004 Indian Ocean Tsunami: "They found that the villages sheltered by mangrove forests and Casuarina plantations experienced considerably less damage than those directly exposed to the tsunami" (P. 2). Indian Tropical Cyclone: "[. . .] death toll was negatively correlated with the width of mangrove forests, indicating that wider mangrove forests could save more lives" (P. 3).
[21]	Results from their simulation show that mangrove forest degradation to grassland could raise the elevation of surge to as high as 57% and increase the velocity of flood waves by 2730% for cyclones. Furthermore, this would increase inland inundation by almost 10 km and 18%.
[27]	"The experimental results revealed the significant capability of vegetation in attenuating waves to the tune of 72% to 87%, and controlled flooding in terms of run-up of 0.31 to 0.76 times the wave height" (P. 1322).
[28]	The result shows that mangrove width increases wave height reduction under high storm conditions but not under normal/average conditions. Furthermore, the denser the mangroves are the more the energy wave dissipation during storm events.
[29]	Flood protection benefits of mangroves exceed USD 65 billion per year, with nations such as the USA, China, India and Mexico receiving the greatest economic benefits. However, in terms of people protection, India, Vietnam and Bangladesh received the greatest benefits.
[7]	"Storm surge attenuation is non-linear" (P. 2689), meaning significant attenuation exists at the seaward side, and decreases with greater distance. Mangroves are more effective against fast-moving, short-duration storms than against slow-moving, long-duration storms.

3.2.2. Scientific Evidence (Trade-Offs and Limitations)

Here, the authors presented scientific evidence for the limits of mangrove forests in reducing coastal hazards. As illustrated in Table 3, some striking examples from the sampled papers were selected to highlight the key limitations.

Table 3. Scientific evidence (limitations) from selected studies.

Source	Evidence Provided (Limitations)
[24]	One of the three bays studied was unsuccessful, and coastal erosion increased by 100%. This was due to human activities (sand excavation), lack of budget and inadequate prioritisation between building construction and mangrove planting.
[12]	The damage assessment conducted in this study was based on the memory of respondents and, hence, was not reliable.
[4]	Wrong selection of mangrove species and unplanned resort area development along the coast limited mangrove protective impact.
[25]	The lack of a mangrove database was suggested to have underestimated or overestimated mangrove protective impact in this study.
[26]	"[. . .] the tsunami waves caused by the Tōhoku earthquake led to devastating damage to the coastal areas . . . some protective infrastructures such as seawalls and tsunami gates were destroyed. The main species of coastal vegetation—Japanese pine trees—were largely broken or washed away" (P. 4). Thus, showing how mangroves failed in this context.
[22]	Damage and recovery from a cyclone, which is estimated based on landcover type changes, does not explain functional changes within an ecosystem
[21]	The low-resolution topo-bathymetric datasets used might limit the reliability of the results.
[3]	No social determinants of vulnerability to coastal hazards were considered, thus limiting the credibility of mangrove protection impact.

3.2.3. Scientific Evidence (Level of Agreement)

As deduced from the sampled papers, the level of agreement ranges from 1 to 5 and signifies very weak, weak, moderate, strong, and very strong agreement/evidence. To reduce subjectivity, the mean rank of each sample paper was computed from the ranks assigned by the two authors. As can be seen from Figure 10, the overall average (representing the level of agreement) of the 45 ranks as computed is 3.80 (on a scale of 5). This points to the existence of a strong level of agreement on the efficacy of mangrove forests in reducing coastal hazards.

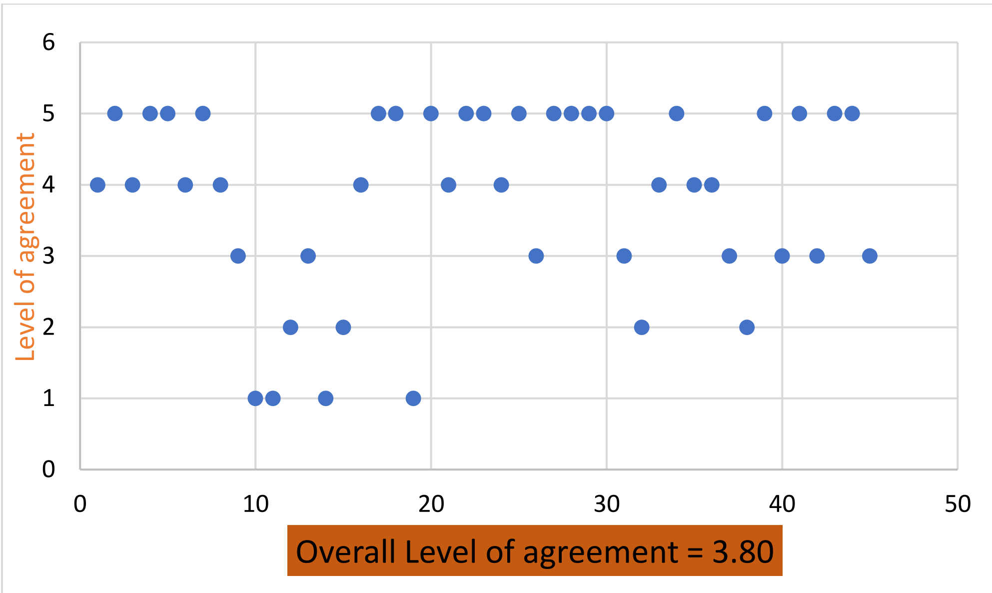

Figure 10. Level of agreement for the effectiveness of mangrove forests in reducing coastal hazards.

3.3. Research Gaps

This section presents research gaps from the study limitations and future research orientation illustrated in the 45 sampled papers. From our analysis of the sampled articles, the research gaps can be generally grouped into policy-related, study scale-related, methods-related and future-oriented gaps. The first, policy-related gaps, addressed the pitfalls in current policies. For example, as a future area of research, Akbar et al. [24] recommended creating and evaluating short-, medium- and long-term strategies between stakeholders to obtain effective synergies between artificial water breaks and mangrove forests in coastal areas. Secondly, the study scale-related gaps addressed the inadequacies in the scale of analysis. For example, Akber et al. [12] faulted their research for its limited sample sites, which were inadequate in identifying the storm protection services of mangroves and, thus, suggested further analysis to consider a larger scale. The third group (methods-related gaps) suggested methods to capture the inadequacies of current studies. For instance, Ataur Rahman and Rahman [4] faulted the merely descriptive qualitative method applied in determining the natural defence mechanisms of mangroves, and suggested that further research should be scientifically evaluated through habitat research and in-depth workshop analysis. Furthermore, Chang and Mori [26] suggested the proper quantification of the effectiveness of mangrove forests in reducing coastal hazards under different wave scenarios. To them, the distance from shore, topography and vegetation conditions of mangroves should be considered in future research. The last group (future-oriented gaps) suggested future research considering future climate and hazard conditions. In this category are Deb and Ferreira [21], who suggested further analysis to consider future climate change and storm intensities in assessing the effectiveness of mangrove forests in reducing coastal hazards.

As can be deduced from the four groups of research gaps stated above, they are case and study-area-specific and, thus, not generally applicable to all studies. However, they point to current studies' limitations and future research needs. To bridge this limitation in the future research areas presented above, we have provided more general research gaps and future research directions based on our analysis of the 45 sampled papers, in the next section.

4. Discussion

This paper has explored the scientific evidence for the effectiveness of mangrove forests in reducing coastal hazards, and key findings revealed a generally strong level of agreement in the scientific literature. Major disciplines evident in the sampled papers are engineering, biology, environmental sciences and geography, with a lesser representation of economics, development studies, risk and disaster studies. Bangladesh was better represented than any other country in the sampled articles. This may be due to the United Nations' classification of Bangladesh as the most vulnerable country to climate extremes [4]. Asia was the most represented continent in the studies, while Africa and South America were not represented at all. Compared with global mangrove coverage [30], it may be deduced that the representation of Asia in the sampled studies reflects the global coverage of mangroves. However, this is not true for Africa (second largest mangrove coverage) and South America (third largest mangrove coverage), which points to the fact that studies on mangrove effectiveness in reducing coastal hazards are lacking or limited.

The results reveal the dominance of single-discipline research with more representation of engineering and biology. This may explain why the majority of the sampled papers either applied 'technocratic-related methods' (in this case, modelling and simulations) or fieldwork (mere descriptions, observations and opinion surveys), and the lesser representation of mixed methods (in this case, simulation and fieldwork). While fieldwork is vital in deriving 'first-hand' primary data, models and simulations are necessary to quantify impacts from coastal hazards and predict future scenarios. Thus, a combination of both is required.

Following from the above, it is essential to articulate that assessing the impacts of coastal hazards (as conducted by some studies in our sample) cannot be holistic without considering the human dimension of 'shock absorbance'. As seen from our results [12,26,29], mangrove protection benefits were extensively assessed by the degree to which mangroves reduced the impacts of coastal hazards such as damage to buildings, infrastructure and economic possessions. However, this might not capture the actual impacts as coping capacity was not accounted for in those studies. This might be due to the lower representation of risk and disaster studies in the sampled papers.

What is known, and what are the gaps, as seen in this study? From a holistic perspective, it is evident that details about the geographical coverage, study scales, represented disciplines, coastal hazard types, the methodology employed and the level of agreement regarding mangroves' capacity to attenuate coastal hazards, are known. Though the sampled studies show a strong level of agreement in the efficacy of mangrove forests in reducing coastal hazards, they attest to how coastal hazards and their resulting negative impacts were prevented or reduced due to the presence of mangroves. For instance, Akbar et al. [24] attested that mangrove forests in West Kalimantan, Indonesia, facilitated the rehabilitation of shorelines and reduced erosion by more than 70% in two of their three sampled bays. In addition, some studies, such as Menéndez [29], provided evidence for monetary savings due to mangroves reducing the effect of coastal hazards. However, sampled studies did not reveal what factors contribute to the success of mangroves' attenuation capacity in the face of coastal hazards. This information would prove helpful to planners and policymakers, especially in planning post-hazard rehabilitation or hazard mitigation. Another gap evident in this study is the lack of quantification of the magnitude of coastal hazards to be considered before drawing inferences on the attenuation of their impacts by mangroves.

Similarly, the average intensity of mangrove forests considered to have the capacity to attenuate coastal hazards is not known. This limitation corresponds with Chang and Mori's [26] suggestion of proper quantification of the effectiveness of mangrove forests in reducing coastal hazards under different wave scenarios, such as distance from shore, topography and vegetation conditions of mangroves.

The major limitation of this study is the limited number of articles (n = 45) used for this assessment. This might be due to the limitations of Scopus and Web of Science in assessing all of the literature sites. This may also be attributed to the limited time coverage of this study (2015–2021), which missed out studies conducted before 2015. Another limitation is that our study did not capture cases in Africa and South America and, thus, might not have captured the global picture. Finally, its entire dependence on peer-reviewed articles is also a limitation of this study.

As an outlook, it is recommended that future studies are more multidisciplinary, with a greater representation of disaster studies. Future studies should also consider case studies in Africa and South America. It is also recommended that future studies consider a broader year coverage before 2015 and incorporate different wave scenarios such as distance from shore, topography and vegetation conditions of mangroves. Finally, given the high degree of climate uncertainties, future research should exploit synergies in fieldwork and simulation methods to assess the potential of mangrove forests in reducing coastal hazards under future climate scenarios.

5. Conclusions

To answer the question, "what is the scientific evidence for the effectiveness of mangrove forests in reducing coastal hazards? What is already known about their capacity to improve disaster risk reduction, and what research gaps can be identified?" this paper conducted a systematic and multi-stage literature review. The scale of this research was limited to publications released after the adoption of important international frameworks and agreements (Sustainable Development Goals and the Sendai Framework for Disaster Risk Reduction) in 2015. After a preselection of the paper, the remaining 45 publications were analysed by two authors, and their perceived scientific evidence was ranked from one to five. In conclusion, the overall level of agreement of the researched papers to the question, "if mangroves are a valid and effective measure to disaster risk reduction and climate change adaptation in coastal areas," was high (3.8).

Nevertheless, this research found specific patterns and gaps that must be addressed. More multidisciplinary, mixed-method research is necessary to anticipate future hazards and climate change scenarios. As the capacity of mangrove forests to reduce the risk of coastal hazards is highly context-specific, local studies are needed as much as global ones, to monitor the global mangrove population and foster support for nature-based solutions amongst essential stakeholders.

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