

Effectiveness and Cost-Effectiveness of Ecosystem-Based Disaster Risk Reduction Interventions in low- and middle-income countries: A Rapid Systematic Review

Final Report, 12 April 2024

Suchi Kapoor Malhotra¹, Ashrita Saran¹, Ratika Bhandari¹, Kevin Ouma Ojiambo², Sujata Shirodkar¹, Gavin Stewart³, Howard White⁴, Hugh Sharma Waddington⁵

1 Campbell South Asia, Global Development Network, India

2 Africa Centre for Systematic Reviews and Knowledge Translation, Makerere University College of Health Sciences, Uganda and Clinical Epidemiology Unit Department of Medicine, School of Medicine, Makerere University College of Health Sciences, Uganda

3 Newcastle University, UK

4 Global Development Network, Campbell Collaboration, India and Lanzhou University, China

5 London School of Hygiene and Tropical Medicine and London International Development Centre, UK

Corresponding authors:

Suchi Kapoor Malhotra skmalhotra@campbellsouthasia.org

Hugh Sharma Waddington: hugh.waddington@lshtm.ac.uk

© Crown Copyright, 2024

This information is licensed under the Open Government Licence v3.0. To view this licence visit Open Government Licence (nationalarchives.gov.uk)

This project was funded with UK International Development from the UK government. The views expressed in this publication do not necessarily reflect the UK government's official policies. Responsibility for the views expressed remains solely with the authors.



Table of Contents	
Executive Summary	4
Summary of findings tables	8
Introduction	13
Increasing risk of natural disasters due to climate change and ecosystem degradation	13
Ecosystem-based initiatives to address disaster risk.	14
Scope and Eco-DRR review framework	16
Objectives	22
Methods	23
Criteria for including and excluding studies.	23
<i>Types of populations and settings</i>	23
<i>Types of interventions</i>	24
<i>Types of outcome measures</i>	25
<i>Types of studies</i>	26
Search sources	26
Data collection and analysis	27
<i>Data collection</i>	27
<i>Tools for assessing confidence in included studies</i>	28
Analysis and presentation	28
<i>Measures of effect</i>	28
<i>Unit of analysis</i>	28
<i>Data synthesis</i>	29
<i>Deviations from protocol</i>	29
Results	30
Search results	30
Presentation of evidence and gap map	31
Characteristics of evidence	34
<i>Populations and settings</i>	34
<i>Study designs</i>	35
<i>Interventions</i>	36
<i>Outcomes</i>	37
Confidence assessment	38
<i>Effectiveness studies</i>	38
<i>Modelling studies</i>	39
<i>Economic evaluations</i>	40
Synthesis of findings	42
Effectiveness studies	42
Modelling studies	55

Economic evaluations	60
Conclusions	70
Implications for policy	70
Implications for research	70
References	72
Included studies	72
Additional references	79
Appendixes	84
Appendix A Benchmark studies used in piloting of search strategy	84
Appendix B Study screening tool	86
Appendix C Codebook and variable definitions	88
Appendix D Assessment tools	95
Appendix E Table of included studies	99
Appendix F Confidence assessments	129
Appendix G Data collection from economic evaluations	134
Appendix H Excluded qualitative evaluations	148
Appendix I PRISMA checklist	150
Appendix J Evidence and gap map	153

Executive Summary

Background

Climate change and widespread environmental degradation have increased the risk of natural hazards in recent decades. Several weather-related natural hazards, including hydrological, meteorological, and climatological disasters, have become more frequent in both high-income countries (HICs) and low- and middle-income countries (L&MICs) (Parry et al., 2007; Cavallo & Noy, 2009; CRED, 2022; EM-DAT). Over 3.9 billion people have been affected globally by climate-related disasters since 2000, with losses and damages totalling USD 2.2 trillion (EM-DAT, 2020). However, it is in L&MICs where the greatest losses to natural habitats and human consequences are felt. Nearly 90 per cent of deaths due to natural hazards occurred in L&MICs between 2000 and 2018 (World Meteorological Organization, 2021).

This rapid systematic review (RSR) aimed to assess and synthesise the evidence on the effects and cost-effectiveness of ecosystem disaster risk reduction (Eco-DRR) interventions on the prevention and mitigation of hazards and natural disasters, and consequences for natural capital and human development outcomes.

Methods

This REA includes empirical primary studies measuring the impacts and cost-effectiveness of Eco-DRR interventions. We searched for and included studies that evaluated primary outcomes including hazard prevention, hazard mitigation and natural capital stocks; we also included secondary human development outcomes if reported in these papers. Eligible designs included ex-post impact evaluations using randomised assignment (randomised controlled trials, RCTs), quasi-experimental designs (QEDs) and qualitative impact evaluation designs, and ex-ante impact evaluations using statistical modelling approaches. To measure the cost-effectiveness of interventions, we included economic and financial evaluations, which could use cost-effectiveness (including cost-efficacy, or studies comparing costs with numbers reached), cost-utility and cost-benefit analyses.

Two reviewers were assigned to screen the title and abstract for each study. Potentially relevant studies were then assessed at full text by two coders working independently, following which data collection for included studies was double-coded. A third reviewer resolved all disagreements. All included studies were assessed using a pre-validated critical appraisal tool, which used the “weakest link” principle, where the most uncertain category determined the overall confidence in the findings for each study. Comparisons between studies were conducted by developing general categories of outcomes measured, grouped into hazard prevention and mitigation, natural capital, and human development outcomes.

Results

We included and synthesised findings from 58 studies, of which 28 were effectiveness studies, 20 were economic evaluations and 10 were modelling studies. The effectiveness studies were all in green infrastructure – nearly all concerned forestry and natural land use interventions, primarily protected areas – although one study also evaluated geophysical hazards (public investment and early warning about urban landslides). Most evaluations were of interventions in Latin America and the Caribbean (21 studies), although there was a small number in sub-Saharan Africa (5 studies) and East Asia and Pacific (16 studies); five evaluations were done at the global (L&MICs) level. All evaluations used quasi-experimental designs, primarily with baseline and end-line data collection in intervention and comparison groups. No studies used RCT, or qualitative impact evaluation methods and one study was a protocol (and therefore not included in the synthesis of findings).

The effectiveness studies were assessed as being of moderate confidence (6 studies) or low confidence (21 studies). The synthesis of outcomes, using meta-analysis of effect sizes (g), found beneficial effects of Eco-DRR interventions on hazard incidence and exposure and natural capital outcomes. These included large effects on the reduction of forest fire ($g=0.32$; 95% confidence interval (CI)=0.23, 0.48; evidence from 4 studies), and medium- and small-sized beneficial effects on forest cover ($g=0.12$, 95%CI=0.07, 0.18; 16 studies) and vegetation cover ($g=0.06$, 95%CI=0.01, 0.11; 4 studies). The synthesis of secondary human development outcomes was more limited because only a small subset (3) of papers that primarily measured hazard exposure and natural capital also reported these outcomes, which included loss of life, property damage, income, expenditure, and agricultural revenues.

There were ten modelling papers, of which half were for countries in Latin America and the Caribbean, four from East Asia, and one for South Asia. There were no papers conducted in sub-Saharan Africa or the Middle East and North Africa (MENA) region. Five of the papers were concerned exclusively with flooding, two concerned storm surges (and thus also with flooding), and two more included flooding among the hazards assessed. One paper concerned landslides. Each paper used a different model and reported different outcomes. However, many papers used some form of hydrological model including flood frequency curves and used the frequency metric of an “X years” flood event. All papers used a range of different data sources including satellite data, existing meteorological and other data sources, and primary data collection by the study team. None of the papers reported economic analysis. Two of the ten papers were rated as high confidence in study findings, five at moderate confidence, and three at low confidence. The areas with the largest number of papers not receiving high confidence related to the clarity of the assumptions used and model testing. Most of the modelling papers concluded that the intervention being assessed should be adopted.

Twenty economic evaluations assessing the cost-effectiveness of eco-DRR measures were included. All the included papers were cost-benefit analyses (CBAs), with two papers accounting for income differences and incorporating equity weights to estimate social welfare benefits. Multiple ecosystems were considered, with river and wetland ecosystems receiving the most attention, followed by coastal ecosystems, mountains, and forests. Twenty papers discussed hydrometeorological hazards, primarily floods. Few studies addressed environmental geological and geophysical hazards such as landslides and earthquakes. Most studies focused on implementing blue and green infrastructure, such as mangroves, which serve as natural flood buffers, early warning systems, and land use planning. While direct costs for structural measures were widely included, indirect costs and benefits were rarely reported. These indirect costs include the loss of productivity due to evacuations, repairs, and disruptions to economic activity.

Similarly, the benefits of non-structural measures, such as reduced flood damage and avoided societal disruptions, are often difficult to quantify and not reported. Hazard mitigation and exposure outcomes measured included damage to homes, physical assets, agriculture, livestock/fodder, infrastructure, livelihoods, and wages. Human development outcomes included lives saved and productivity gains. In most studies, physical assets and maintenance were valued, while averting damage to crops and agriculture was also commonly measured. Several studies identified livelihood disruption due to its importance in affecting a community during and after a disaster. In addition to quantitative items, a few studies included qualitative items, such as vulnerability assessments.

Five of the twenty papers were rated as having high confidence in the study findings, eight were at moderate confidence. At the same time, the remaining seven were categorized as having low confidence, primarily due to a lack of sensitivity analyses and reporting of discount rates. Among the key metrics of economic efficiency within CBAs, fourteen reported benefit-to-cost ratio (BCR), three reported internal rate of return (IRR), and three reported net present value (NPV). Most results support the economic effectiveness of Eco-DRR interventions. Benefit-cost ratios of 4 and above were regularly reported. The case studies also highlighted the importance of contextual factors in shaping the BCRs and the ability of these strategies to

generate high returns. For example, an extremely high BCR of 1,800 was reported for drought risk reduction measures in the Sudan for irrigation supporting communal gardens. The IRR values provide insights into the financial performance and potential returns on investment for different interventions aimed at mitigating flood-related damages, with early warning systems demonstrating exceptionally high potential financial returns (IRR of 409%). Three studies reported net benefits, and all three indicated the positive financial outcomes and cost-effectiveness of the implemented interventions in mitigating and preventing hazards, including floods and landslides.

Nineteen of the twenty studies compared Eco-DRR intervention with baseline scenarios with no intervention. Only one study, Meir et al. (2016), evaluated the economic viability of selected measures, including floodplain and wetland development, sediment pool installation, riparian zone improvement, and engineering measures, such as reservoir dredging (that is, a comparison with grey infrastructure). The analysis revealed that floodplain and wetland development, sediment pool installation, and riparian zone improvement, demonstrated positive BCRs, indicating their economic attractiveness and cost-effectiveness in addressing water scarcity and sedimentation challenges. These measures also showed positive ecological aspects such as groundwater recharge, crop yield increase, flood retention, and biodiversity conservation, contributing to their ecological prioritization. In contrast, the grey infrastructure engineering measure of dredging showed a negative NPV and a BCR smaller than one, indicating its economic undesirability. Additionally, the ecological prioritization of engineering measures was lower compared to EbA measures, as they were primarily focused on addressing water scarcity without the same level of positive ecological impacts.

Conclusions

The evidence base on the effectiveness and cost-effectiveness of Eco-DRR is compartmentalised. Most studies of the effectiveness of implemented actions have evaluated green infrastructure interventions, particularly protected areas, whereas most of the modelling and cost-effectiveness studies evaluated blue and hybrid infrastructure technologies.

Green infrastructure interventions like protected areas have generally shown large effects on increasing natural capital stocks, especially forestry reserves, and in reducing the incidence of or exposure to hazards like fire, although fewer studies have measured the latter.

However, the evidence on effectiveness is not representative across all Eco-DRR interventions and Sustainable Development Goal areas. Effectiveness studies that consistently evaluate disaster exposure, natural capital and human development outcomes are needed, including green infrastructure. It is important to evaluate effects on both natural capital and human development outcomes like incomes and livelihoods, to evidence possible trade-offs in disaster mitigation efforts which may need to be mitigated through complementary social and economic policies.

In modelling studies, most of the papers concluded that the intervention being assessed should be adopted. But in the absence of economic analysis, such a conclusion cannot be drawn from the demonstrated impact alone. For example, one study recommended that one-third of paddy fields in a province in Vietnam be reforested, as the paddy provides no regulating ecosystem services (RES), but there is no consideration of the cost to livelihoods and nutrition from such a policy.

Economic evaluations generally supported the benefits exceeding costs (benefit-cost ratios > 1) of eco-DRR, particularly in reducing flooding, especially structural hybrid interventions, but also capacity building, early warning systems, and mangrove restoration. However, these studies have significant limitations regarding information about distributional effects, non-monetized values, and indirect costs and benefits.

Interventions with the highest BCRs included early warning systems for floods and non-structural interventions like land use planning and capacity building.

Future economic evaluations should be more comprehensive, considering direct and indirect costs and benefits. In addition, economic evaluations that do not provide sensitivity analyses give decision-makers an insufficient understanding of the uncertainty surrounding the findings. The discount rate plays a significant role in determining the net present value of Eco-DRR projects since they accrue gradually over time while costs are often incurred upfront. This can be addressed by focusing on internal rates of return. Most included CBAs used discount rates that were not sufficiently transparent. Therefore, it is essential to consider internal rates of return in future studies to ensure meaningful DRR project evaluation.

It is crucial to carefully consider the local factors and variables that can influence the benefits and costs of implementation. Improvements in understanding different approaches to Eco-DRR and the relative role of directly targeted versus systemic approaches to risk management are essential.

We found very limited research on environmental hazards and geological and geophysical hazards, such as landslides and earthquakes, suggesting that these topics require investigation in L&MICs in future primary studies of whatever type (both effectiveness and cost-effectiveness). Understanding the potential economic impacts of these types of hazards on ecosystems and developing effective mitigation strategies is urgently needed.

More studies that evaluate topics relating to equity, such as the effects on the social welfare of vulnerable populations, are needed. Studies of the effectiveness in these areas might usefully draw on established methods of qualitative impact evaluation.

Summary of findings tables

Table S.1 Summary of findings on effectiveness

<i>Sector & intervention</i>	<i>Outcomes</i>	<i>Country</i>	<i>Summary of findings</i>
Protected areas (incl PES)	Forest cover	Brazil, Colombia, China, Costa Rica, Ecuador, Indonesia, Madagascar, Mexico, Peru, Russia, Tanzania, L&MICs	Medium-sized, statistically significant effect on forest cover ($g=0.17$; 95%CI=0.09, 0.24) measured across 14 low-medium confidence studies with high heterogeneity ($I-sq=96\%$).
	Natural land cover	Africa	Small, statistically significant effect on natural land cover ($g=0.05$, 95%CI=0.02, 0.08) measured in 1 low-confidence study.
	Vegetation cover	Brazil, Central America, Tanzania	Small, statistically significant effect on vegetation cover ($g=0.08$, 95%CI=0.00, 0.16) measured across 3 low-medium confidence studies with high heterogeneity ($I-sq=97\%$).
	Reduced fire	Brazil, Colombia, Madagascar, L&MICs	Large, statistically significant effect on reduced fire ($g=0.32$, 95%CI=0.23, 0.41) measured across 4 low-medium confidence studies with low heterogeneity ($I-sq=0\%$).
	Income	Tanzania	Medium-sized, statistically significant effect on income ($g=0.24$, 95%CI=0.01, 0.46) measured in 1 medium-confidence study.
Land tenure (including natural timber concessions)	Forest cover	Indonesia, Peru	Medium-sized, statistically significant effect on forest cover ($g=0.10$, 95%CI=0.09, 0.12) measured in 2 low-medium confidence studies with low heterogeneity ($I-sq=0\%$).
	Vegetation cover	Brazil	Null effect on vegetation cover measured in 1 medium confidence study.
	Expenditure	Vietnam	Null effect on expenditure measured in 1 low confidence study.
	Income, savings	Vietnam	Harmful, statistically insignificant effect on income and savings measured in 1 low confidence study.
	Revenue	Vietnam	Large, statistically significant effect on agricultural revenue ($g=1.02$; 95%CI=0.26, 1.77) measured in 1 low-confidence study.
	Cost	Vietnam	Harmful effect on cost ($g=-1.02$; 95%CI=-1.77, -0.26) measured in 1 low-confidence study.
	Public audit	Forest cover	Brazil
Public investment and early warning system	Landslides	Colombia	Small, statistically significant effect on landslides ($g=0.06$, 95%CI=0.02, 0.11) measured in 1 low-confidence study.

Death, injury	Colombia	A small, statistically significant effect reduced death and injury ($g=0.09$, 95%CI=0.02, 0.17) measured in 1 low confidence study.
Property destruction	Colombia	Small, statistically insignificant effect on reduced property destruction measured in 1 low confidence study.
Number affected	Colombia	Small, statistically significant effect on reduced numbers affected ($g=0.05$, 95%CI=0.00, 0.10) measured in 1 low confidence study.

Table S.2 Summary of findings from modelling studies

<i>Sector & Intervention</i>	<i>Outcomes</i>	<i>Country</i>	<i>Summary Of Findings</i>
Forest Restoration and Land Use Planning	Hazards Prevention And Mitigation	Brazil	The Low-Confidence Study Measures The Effects Of Hypothetical River And Peri-Urban Land-Use Changes On Flooding In Brazil. Time Series Of River Discharge Volumes (M ³ /Second) For The Two Rivers Are Also Presented, Indicating A Reduction In One River And A Slight Increase In The Other.
Tree Planting	Hazard Prevention And Mitigation Human Development Outcomes- Human Casualties And Structural Damages	Indonesia	The Medium Confidence Study Utilised Regression Models To Analyse The Effect Of Tree Belts And Coastal Vegetation On The Maximum Flood Distance, Casualties, And Distribution Of Structural Damage, The Authors Employed A Hydrologic-Hydraulic-Economic Model That Integrates Rainfall-Runoff Simulation, Flood Routing, Flood Inundation Mapping, And Flood Damage Estimation. They Use A Combination Of Existing Data And Their Primary Data Collection
Urban Green Spaces and Agroforestry	Hazard Prevention And Mitigation	Bolivia	The Low-Confidence Study Measures The Effects Of Different Urban Land-Use Scenarios On Run-Off, Percolation And Rainfall In Santa Cruz, Bolivia. The Authors Find Increases In Surface Runoff And Reductions In Percolation To The Shallow Aquifer And Recharge To Deep Aquifer, From The Worst-Case Scenario (2 Full Urbanisation), Over The Base Case Scenario 1. Green Infrastructure (Scenario 3) Performs Slightly Better But Is Still Worse Than The Base Case. Green Infrastructure With Agroforestry (Scenario 4) Fully Alleviates The Run-Off But Only Partially Addresses The Percolation Problems. Agroforestry (Scenario 5) Fully Addresses The Runoff And Improves Shallow And Deep Groundwater Recharge.
Forest Restoration and Land Use Planning	Hazard Prevention And Mitigation	Vietnam	The Medium Confidence Study Examines The Effects Of The Existing Ecosystem On The Hazards Of Landslides. The First Stage Of The Analysis Is An Equation To Estimate Soil Erosion Under Different Land Uses. Second, They Estimate The Landslide Risk With And Without Anthropogenic Impacts From Differing Land Use. They Thus Work Out The Distribution Of Res And The Human Contribution To That. They Conclude That Res Better Protects Against Soil Erosion Than Landslides. One-Third Of Paddy Offers No Natural Res So, The Authors State That, Ought To Be Re-Forested.

Forest Restoration and Land Use Planning	Hazard Prevention And Mitigation	Bangladesh	The High-Confidence Study Examines The Protective Effect Of Pandanus Trees On Saint Martin's Island, Bangladesh, Which Have Been Planted And Conserved By The Ngo Poush Since 2006. The Analysis Shows That Pandanus Trees Reduce The Surge Height From An Average Of 3.89m To 3.58m, Which Will Ultimately Preserve (I.E. Prevent Flooding In) 75% Of The Area Of The Island. The Minimum Required Patch Width For The Pandanus Tree Belt Was Calculated As 4.53 M.
Forest Restoration and Land Use Planning	Hazard Prevention	China	The Medium Confidence Study Uses A Hydrological Model To Simulate The Effect Of Forest Reconstruction On Flooding In The Upper Reach Of The Tingjiang River, China. The Authors Report That Replacing Coniferous Forests With Broad-Leaved Forests Had A Limited Reduction Effect On Flood Peak Discharge And Flood Volume. Replacing Bamboo Forests With Broadleaved Worsens The Risk Of Flooding – A Flood Peak Discharge Of A 10-Year Return Period Event Was Reduced To A 7-Year Event.
Revegetation	Hazard Prevention And Mitigation	Haiti	The Low-Confidence Study Quantifies The Benefits Of Community-Scale Flood Mitigation Measures, Such As Hillslope Revegetation, Channel Revegetation, Gabion Placement, And Storage-Capacity Alternatives In Reducing Flood Losses And Enhancing Resilience. The Findings Indicate That The Presence Of Gabions Leads To An Increase In Peak Discharge For Return Periods Ranging From 1 Year To 35 Years. The Results Indicate That Gabion Dams Have The Potential To Enhance Flood Control By Increasing The Peak Discharge Capacity.
Urban Green Space	Hazard Prevention And Mitigation	Ecuador	The High-Confidence Study Combines Geospatial Satellite Data To Identify Green Spaces With City Population Data To Estimate The Capacity Of The Green Spaces To Provide Temporary Accommodation. This Figure Would Increase To 8-40% If Other Green Spaces Were Also So Designated. The <i>Ex-Ante</i> Analysis, Which Uses Models Of The Risks Of Hazards Based On Ecological Characteristics, Finds That The Expected Spatial Expansion Of Quito Will Be Into Areas Of Increased Risk Of Hazard. Hence The Authors Recommend That In Planning The Expansion Proper Attention Is Given To Both The Protective Effects Of Greenspaces As Well As Their Use For Emergency Accommodation.
Structural Measures Blue Infrastructure River Reservoir	Hazards Prevention And Mitigation	Brazil	The Medium Confidence Study Shows The Flood Frequency Curves For Three Study Areas Under Three Scenarios: The Full Model Which Has The Actual Reservoirs And Floodplains, Without Reservoirs And Either Reservoirs Or Floodplains. The Study Area, A Ten-Year Flood Has A Discharge Rate Of Approximately 400 M ³ /S, Which Would

				Increase To Around 550 M ³ /S In The Absence Of Reservoirs, And 1,200 M ³ /S With Neither Reservoirs Nor Floodplains.
Hybrid Sponge City	Hazard And Mitigation Improve Quality	Prevention Water	China	The Medium Confidence Study Uses The Swmm Model To Estimate The Impact Of Implementing A Pilot Sponge City Design In A District In Suzhou In Jiangsu Province, China. The Analysis Shows That Sponge City Would Be Highly Effective In Reducing Both Storm Surge And Solids Carried By Flood Waters: The Volume Capture Ratio Of Annual Runoff Was 91% (Higher Than The Control Target Of 80%). The Suspended Solids Reduction Rate Was 56%, Which Meets The Requirement Of Planning Indicators. Whilst No Cost Data Are Presented The Authors Argue That Low Impact Development Approaches Such As Sponge Cities Are Cost-Effective.

Table S.3 Summary of findings on benefit-cost

<i>Sector & Interventions</i>	<i>Outcomes</i>	<i>BCR</i>	<i>Location</i>	<i>Confidence in findings</i>
Non-structural: Early warning systems for hydrometeorological hazards: Floods	Hazard mitigation: Damages averted:(livelihood, infrastructure)	1-7	Fiji	Moderate
	Hazard mitigation: Damages averted: crops and infrastructure	83	Nepal	High
	Hazard mitigation: Damage averted: assets, infrastructure & Human development outcomes: lives saved	4-35	Multi-country	Low
Structural: Blue infrastructure-Mangrove replantation and protection for hydrometeorological hazards: floods	Hazard prevention: Risk reduction: hazard probability and vulnerability assessment	2.0-4.8	Nepal and India	Low
	Hazard prevention: Risk assessment: hazard probability	3.5	Nepal	High
	Hazard mitigation: Damage averted-infrastructure, livelihood, and crop/agriculture	1.4-1.5	Philippines	Moderate
	Hazard mitigation: Damage averted-infrastructure and crops) & Hazard prevention: risk reduction-hazard probability	3-3.3	Bangladesh	Low
	Hazard mitigation: Damage averted and health and safety (lives saved) and Hazard prevention: Risk reduction	69-105	Vietnam	Moderate

Structural: Green infrastructure-Forest restoration for geophysical hazards-earthquakes and landslides	Hazard prevention: Risk Reduction-Hazard probability and vulnerability	0.1-1.7	Peru	High
Structural: Eco-DRR mix 1. Hybrid 2. Green (tree planting) and blue (wetland restoration) infrastructure for hydrometeorological hazards-drought	Hazard mitigation: Damages averted (crops)	1.0-2.7	Thailand	Moderate
Eco-DRR mix Non-Structural Measures: Early Warning System and land use planning; Structural measures: blue infrastructure-wetland restoration for hydrometeorological hazards-floods	Hazard prevention: Risk reduction: hazard probability and vulnerability assessment Human capital: Health and safety: lives saved Hazard mitigation: damages averted: infrastructure	1) 8.6-9.3 2) 1.0 3) 1.3	Pakistan	Low
Structural measures: green infrastructure-green space plantation of broom grass (Thysanolaena maxima) for hydrometeorological hazards-floods	Hazard mitigation: Damages averted livestock/fodder, livelihood/wages	1.3	Nepal	High
Non-structural measures: land use planning sustainable grassland management for environmental hazard: soil degradation	Hazard mitigation: Damages averted livestock/fodder, livelihood/wages	1.3	Peru	High
Non-Structural measures: Capacity Building for hydrometeorological hazards-floods	Hazard mitigation: damages averted: infrastructure	3.5	India	High
Structural measures-hybrid-sustainable drainage for hydrometeorological hazards-floods	Hazard mitigation: damages averted: Infrastructure	18.6	Nepal	Moderate

Note: BCR Benefit-cost ratio.

Introduction

Increasing risk of natural disasters due to climate change and ecosystem degradation

According to the *Sendai Framework on Disaster Risk Reduction*, disaster is defined as a serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability, and capacity, leading to one or more of the following: human, material, economic, and environmental losses and impacts (UNDRR, 2016). Natural hazards include geological hazards such as earthquakes, volcanic eruptions, and landslides, as well as meteorological hazards like hurricanes, tornadoes, and blizzards, hydrological hazards such as floods and droughts, and biological hazards like epidemics and pandemics.

Disaster risk is usually expressed as the interaction between hazards, exposure, and vulnerability (UNDRR, 2019). Climate change and widespread environmental degradation have increased the risk of natural hazards in recent decades. Several weather-related natural hazards, including hydrological, meteorological, and climatological disasters, have become more frequent in both high-income countries (HICs) and low- and middle-income countries (L&MICs) (Parry et al., 2007; Cavallo & Noy, 2009; CRED, 2022; EM-DAT). Over 3.9 billion people have been affected globally by climate-related disasters since 2000, with losses and damages totalling USD 2.2 trillion (EM-DAT, 2020). One of the key ways in which climate change has influenced disasters is through the alteration of weather patterns. Rising global temperatures have led to more frequent and intense extreme weather events (Seymour et al., 2023). For example, warmer temperatures can lead to increased evaporation, which in turn results in more frequent and severe droughts (Naumann et al., 2018). These droughts can then contribute to the occurrence of wildfires, as dry vegetation becomes more susceptible to ignition. Additionally, climate change has also influenced the intensity and frequency of hurricanes and tropical storms (Kossin et al., 2020). Warmer ocean temperatures provide more energy for these storms, making them more powerful and potentially more destructive (Knutson, 2008). As a result, coastal areas are at a higher risk of storm surges, flooding, and wind damage (Hatje et al., 2023).

Ecosystem degradation, including deforestation and habitat destruction, has further exacerbated the impact of climate change on disasters. Healthy ecosystems, such as forests and wetlands, play a crucial role in regulating water flow and reducing the risk of flooding. When these ecosystems are degraded or destroyed, their ability to absorb and retain water is compromised, leading to increased flood risk. Furthermore, deforestation contributes to climate change by reducing the Earth's capacity to absorb carbon dioxide from the atmosphere (Francesconi et al., 2022). This, in turn, leads to more greenhouse gases in the atmosphere, exacerbating the warming effect and further intensifying the impacts of climate change on disasters.

L&MICs are disproportionately affected by natural hazards, including floods, hurricanes, cyclones, and earthquakes. Nearly 90 percent of deaths due to natural hazards occurred in L&MICs between 2000 and 2018 (World Meteorological Organization, 2021). Although low-income countries experienced 44 percent of disasters, they suffered 68 percent of the fatalities (Kharb et al., 2022). The disparity in disaster outcomes between high-income and low-income country contexts can be understood as a function of both pre-event vulnerability and post-event response (Ekpeni & Ayeni, 2018). Low-income countries lack access to resources, infrastructure, and funding needed to respond to natural hazards. Additionally, these

countries have fewer resources to prepare for, mitigate, and recover from natural hazards compared to higher-income countries.

Natural disasters like floods, storms, and earthquakes can have significant long-term consequences in many regions, especially in L&MICs. They disrupt economic development and livelihoods (Shabnam, 2014; Davis & Alexander, 2015), worsen poverty levels (Hallegatte & Rozenberg, 2017), and increase government debt (Koetsier, 2017). L&MICs saw the most natural disaster fatalities during the first half of 2022, according to the disaster database (EM-DAT, 2022). Floods are the most frequent type of natural disaster and can cause widespread devastation, resulting in loss of life, damage to settlements, and associated displacement of populations, as well as loss of personal property and critical public health infrastructure (WHO, 2023). Pakistan's 2022 floods, which caused roughly one-third of the nation to be underwater, have affected over 33 million people (UNICEF, 2023; Rentschler et al., 2022). There were over 1,000 deaths caused by the earthquake in Afghanistan in 2022, 289 deaths caused by Tropical Storm Megi in the Philippines in 2022, and in the same year 121 deaths were caused by Cyclone Batsirai in Madagascar (CRED, 2022).

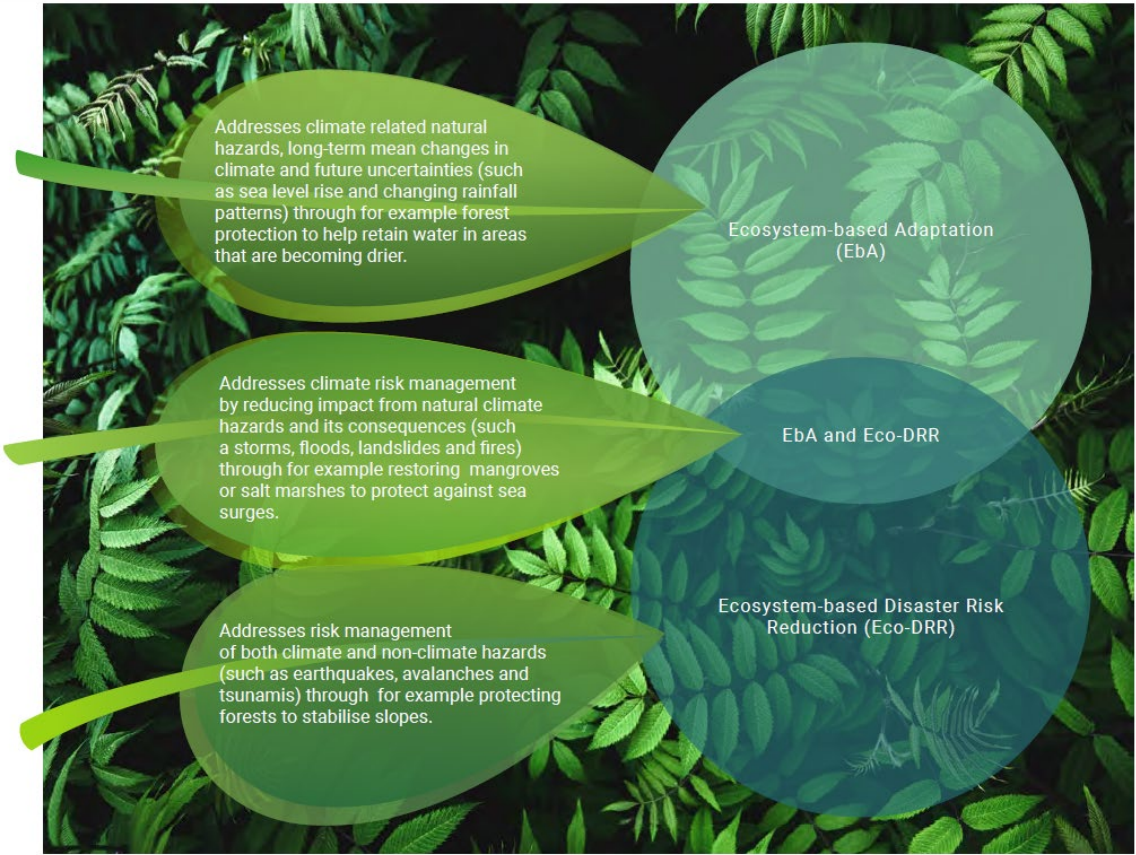
Factors such as geography, personal resources, community infrastructure, and political stability all significantly influence the severity and consequences of natural hazards. Natural hazards are also influenced by land use and land management practices. Flood-prone areas and unstable slopes can increase disaster risks because of poor land use planning, whereas landslides and erosion can be caused by poor land management practices, such as deforestation (Mack et al., 2023). Understanding these factors is crucial to developing effective disaster preparedness, response strategies, and disaster risk reduction. For example, geography plays a vital role in determining the severity of natural hazards. Areas prone to earthquakes, such as the Pacific Ring of Fire, are more likely to experience devastating seismic events. Similarly, regions located in hurricane-prone zones, like the Gulf of Mexico and the Caribbean, are at higher risk of destructive storms. The topography of an area, including its elevation, slope, and proximity to bodies of water, can also amplify the impact of natural hazards. Low-lying coastal regions are more susceptible to flooding during hurricanes or tsunamis. (Alcántara-Ayala, 2002; Kunze, 2022). Communities with access to resources and appropriate infrastructure are more likely to have effective response plans in place. Similarly, community infrastructure plays a crucial role in mitigating the impact of natural hazards. Well-designed infrastructure, such as flood control systems and early warning systems, can significantly reduce the damage caused by disasters (Sufri et al., 2020). Governance is also thought to be key in fostering resilience to disasters; for example, countries with relatively stable governments are more likely to have adequate resources allocated to disaster preparedness and response.

Ecosystem-based initiatives to address disaster risk.

There are many initiatives to promote investment in healthy ecosystems to reduce disaster risks, including the 2030 Agenda for Sustainable Development Goals (SDGs), the Sendai Framework for Disaster Risk Reduction (SFDRR 2015-2030), and the European Union's nature-based solutions (UNDRR, 2015; Faivre et al., 2017). During the World Conference on Disaster Risk Reduction in Sendai, Japan, in 2015, "investing in disaster risk reduction" was defined as one of the four priority areas for action over the next 15 years (UN, 2015). Following the Sendai Agreement, the Paris Agreement and the SDGs, there is growing recognition that climate adaptation and disaster resilience play an important role in supporting sustainable economic development. That is, they may have a positive role in generating economic development (through public investment, employment, and economic growth) rather than merely preventing the negative consequences for human life and livelihoods.

One way of promoting resilience to natural hazards is through natural solutions (NS) or nature-based solutions (NbS), which are ecosystem-based approaches defined as “actions to protect, conserve, restore, sustainably use and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems, which address social, economic and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services and resilience and biodiversity benefits” (UNEA, 2022). NS/NbS are umbrella terms for all-natural management ecosystem-based approaches, including those undertaken for disaster-risk reduction or climate change adaptation. Thus, ecosystem-based approaches include ecosystem-based mitigation (EbM), which uses ecosystems for their carbon storage and sequestration services to aid climate change mitigation; ecosystem-based adaptation (EbA), which involves the use of biodiversity and ecosystem services as part of an overall adaptation strategy to help people adapt to the adverse effects of climate change (CBD, 2009); and ecosystem-based disaster risk reduction (Eco-DRR), which aims to conserve, restore and sustainably manage ecosystems, such as forests, wetlands, and coastal areas, to enhance their ability to provide natural protection against disasters such as floods, landslides, and storms (Estrella and Saalismaa, 2013). Eco-DRR and EbA are related approaches that work in tandem to mitigate disasters, such as tsunamis and landslides, and adapt to different climatic conditions. They both use environmental management approaches and involve sustainable land management, conservation, and restoration of ecosystems. Eco-DRR addresses climatic and non-climatic hazards, while EbA addresses climatic hazards and adaptation. There are some overlaps between EbA and Eco-DRR, where Eco-DRR encompasses rapid-onset hazards like storm surges but excludes slow-onset hazards like drought (Figure 1).

Figure 1 Ecosystem-based adaptation (EbA) and ecosystem-based disaster risk reduction (Eco-DRR)



Source: UNDRR, 2021

By maintaining the natural functions of ecosystems, Eco-DRR aims to enhance resilience and minimise the impacts of natural hazards. Eco-DRR can be implemented across a range of

ecosystems, including mountains, forests, rivers, wetlands, coastal areas, drylands, volcanic areas, and agroecosystems (Sudmeier-Rieux et al., 2019). It recognizes the importance of ecosystems in reducing disaster risk and promotes the integration of ecosystem management into disaster risk reduction and prevention strategies and policies, such as early warning systems and emergency planning. Eco-DRR approaches also emphasise the need for community participation and engagement in disaster risk reduction (ibid.).

Ecosystem-based approaches to disaster risk reduction utilising 'blue infrastructure' (involving the water cycle) and/or 'green infrastructure' (involving land or vegetation) are claimed to be cost-effective compared to traditional 'grey infrastructure' based on human-engineered materials (UNDP, 2016; World Bank, 2012). Ecosystem-based approaches, which also include 'hybrid infrastructure' (involving a mix of green, blue, and/or grey), are thought to be less expensive to implement and maintain than traditional approaches, which require significant infrastructure investments such as dams, levees, and seawalls. Additionally, ecosystem-based approaches can provide multiple benefits such as carbon sequestration, biodiversity conservation, and sustainable livelihoods for local communities, contributing to long-term economic and social development. However, the cost-effectiveness of ecosystem DRR is likely to depend on various factors, such as the type and condition of the ecosystem (natural capital), the time taken for the infrastructure to be put in place (since green and blue infrastructure may take more time to foster or build than grey infrastructure), the level of community participation and engagement (social capital), the integration of ecosystem management into disaster risk reduction policies and strategies (human capital) and public resource availability (financial capital).

Despite the growing popularity of Eco-DRR, and NbS more generally, the 2019 Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) found a paucity of knowledge on this topic (IPBES, 2019). Several studies and reviews have assessed the role of ecosystems and their services in regulating various forms of climatic and geophysical hazards (Bimrah et al., 2021; Dissanayaka et al., 2022; Ogunwumi & Armstrong, 2022). However, many of these studies are limited to examining the role of individual ecosystems in attenuating specific hazards. A recent systematic map by Sudmeier-Rieux et al. (2021) summarised the evidence on the impacts and cost-effectiveness of a range of Eco-DRR interventions, finding significant evidence gaps, especially concerning L&MICs. In this rapid systematic review (RSR), we aim to go one step further to enhance understanding of the current evidence on Eco-DRR in L&MICs, by updating the searches and synthesising the findings from these studies on the effectiveness and cost-effectiveness of blue, green and hybrid infrastructure approaches, and presenting the implications for policy, practice and research.

Scope and Eco-DRR review framework

Table 1 defines the possible categories of hazards as environmental, geological, geophysical, hydrometeorological, biological and technological hazards. Hazards can be also defined as being of natural, anthropogenic, or socio-natural origin. Natural hazards are associated with natural processes and phenomena, whereas anthropogenic hazards are induced predominantly or entirely by human activities and choices. Socio-natural hazards are a combination of natural and anthropogenic factors, such as environmental degradation and climate change.¹

¹

<https://www.undrr.org/terminology/hazard#:~:text=Hazards%20may%20be%20single%2C%20sequential,or%20magnitude%2C%20frequency%20and%20probability.>

Table 1 *Types of hazards*

<i>Hazard type</i>	<i>Definition</i>
Environmental hazards	Environmental hazards may include chemical, natural, and biological hazards. They can be created by environmental degradation or physical or chemical pollution in the air, water, and soil. Many of the processes and phenomena that fall into this category may be termed drivers of hazard and risk rather than hazards in themselves, such as soil degradation, deforestation, loss of biodiversity, salinization, and sea-level rise.
Geological or geophysical hazards	Geological or geophysical hazards originate from internal earth processes. Examples are earthquakes, volcanic activity and emissions, and related geophysical processes such as mass movements, landslides, rockslides, surface collapses, and debris or mud flows. Hydrometeorological factors are important contributors to some of these processes. Tsunamis are difficult to categorise; although they are triggered by undersea earthquakes and other geological events, they essentially become an oceanic process that manifests as a coastal water-related hazard.
Hydrometeorological hazards	Hydrometeorological hazards are of atmospheric, hydrological, or oceanographic origin. Examples are tropical cyclones (also known as typhoons and hurricanes); floods, including flash floods; drought; heatwaves and cold spells; and coastal storm surges. Hydrometeorological conditions may also be a factor in other hazards such as landslides, wildland fires, locust plagues, epidemics, and in the transport and dispersal of toxic substances and volcanic eruption material.
Biological hazards	Biological hazards are of organic origin or conveyed by biological vectors, including pathogenic microorganisms, toxins, and bioactive substances. Examples are bacteria, viruses, or parasites, as well as venomous wildlife and insects, poisonous plants, and mosquitoes carrying disease-causing agents.
Technological hazards	Technological hazards originate from technological or industrial conditions, dangerous procedures, infrastructure failures, or specific human activities. Examples include industrial pollution, nuclear radiation, toxic wastes, dam failures, transport accidents, factory explosions, fires, and chemical spills. Technological hazards also may arise directly as a result of the impacts of a natural hazard event

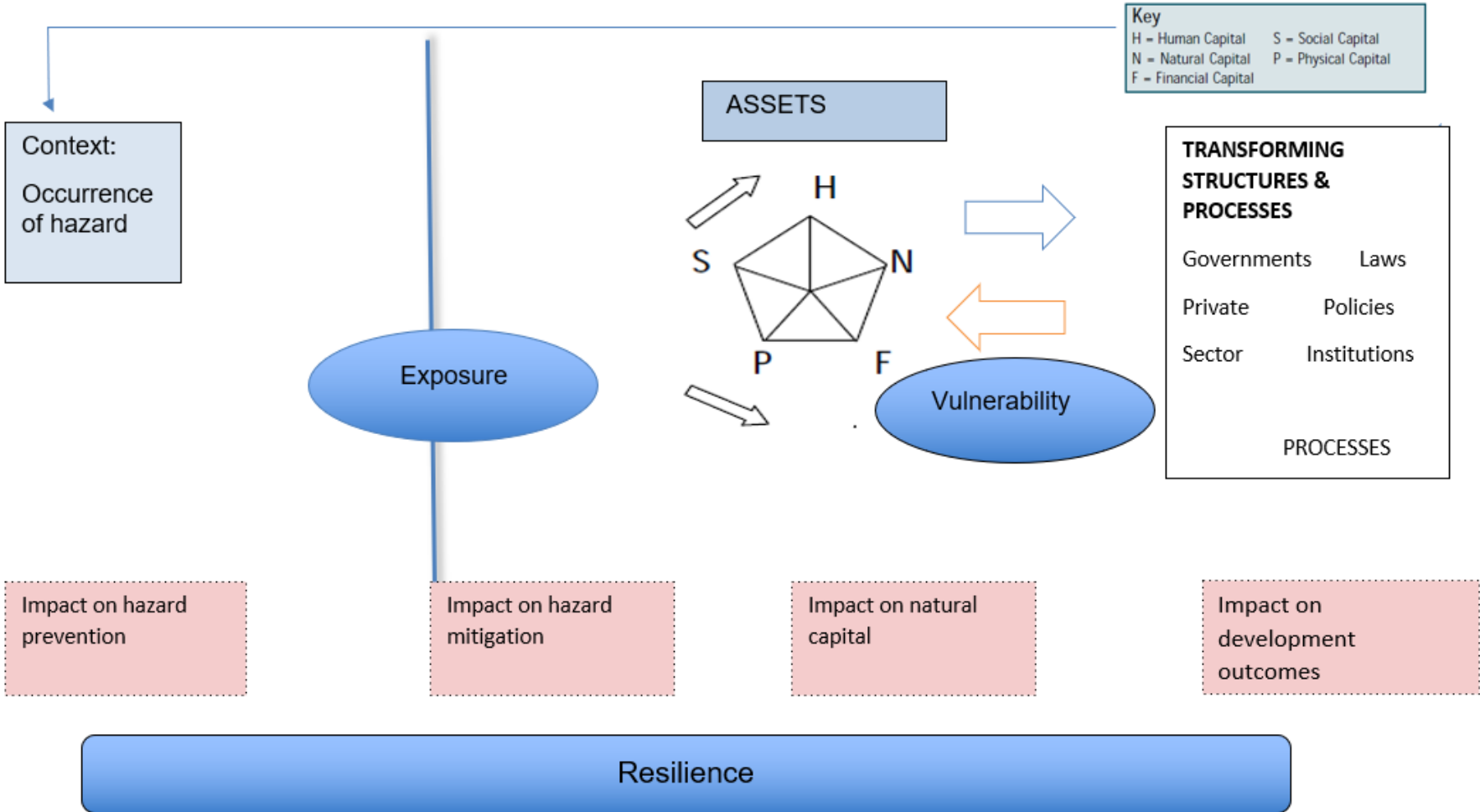
Source: UNDRR Sendai Framework.

We developed a framework for examining the effectiveness of Eco-DRR based on the sustainable livelihoods model (Scoones, 1998) (**Figure 2**). It aims to conceptualise the effects of exposure, to the occurrence and severity of natural hazards on assets (natural, physical, social, financial, and human capital), and how ecosystem-based interventions can work at different stages to reduce hazards, exposure, and vulnerability to improve resilience. Ecosystem-based interventions do this by either preventing natural hazards from occurring or reducing their severity, mitigating exposure to hazards and/or reducing the vulnerability of assets to hazards.

The framework aims to indicate where interventions may operate and the outcomes they aim to achieve along the causal pathway. For example, interventions that aim to prevent or reduce landslides include maintaining proper green cover on hill slopes. Interventions can also focus on mitigating exposure to the hazards and their effects. For example, mangrove ecosystems aim to reduce exposure to the effects of storms by presenting natural buffers. Similarly, early warning systems work by giving sufficient time to reduce the exposure of humans and other assets to hazards. Interventions can also reduce vulnerability to hazards, for example by

identifying and mapping hazard-prone areas and including measures such as land-use planning and zoning regulations.

Figure 2 Hazard, exposure, vulnerability and resilience framework



Source: authors drawing on Sustainable Livelihoods Framework (Scoones et al., 1998).

The intermediate outcomes related to these interventions include the effects on different assets. This review framework identifies five types of assets:

- Natural capital means the capacity of the ecosystem. Some of the examples are forest quality, water quality, soil productivity, ground/air pollution, erosion, awareness of DRR measures, management of land for Forest management practices and grazing management practices, and access rights to forest resources.
- *Human capital* represents people and their skills, knowledge, and ability to cope with disaster.
- *Social capital* represents the existence of community organisations, social support mechanisms, the age structure of the community prone to hazards, family size, and other social resources that help individual survivability and community readiness. Examples include community leadership, NGO assistance, government assistance, women's groups, mutual assistance, extra kinship ties, disaster management committees, early-warning monitoring systems, and evacuation plans.
- *Physical capital* includes the infrastructure and structures (houses, roads, bridges, irrigation canals) that support the communities in hazard-prone areas (in flood plains or a coastal location exposed to cyclones). Examples include emergency water supply, sanitation, telephones, electricity, emergency health care, safe houses, schools, and shelters, access to roads, the means of evacuation, search and rescue equipment, and structural hazard protection.
- *Financial capital* denotes sufficient assets and reserves to withstand loss. (food stocks, employment, remittance income, savings, crop diversification, access to markets, house ownership and Land ownership).

We define the vulnerability of assets as an important component of this framework, where our focus is on the natural capital stock. We did this because Eco-DRR interventions, whether utilising blue, green or hybrid technologies, aim to reduce the occurrence, frequency exposure, or vulnerability of the natural capital stock, to hazards.

Resilience is a key underlying concept for intervention impacts, cutting across effects on hazard prevention, exposure, vulnerability, and development outcomes because ecosystems and socio-ecological systems operate along the scales of recovery, adaptation, and transformation. The IPCC defines resilience as “the capacity of interconnected social, economic and ecological systems to cope with a hazardous event, trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity and structure”.² Resilience, in its traditional definition as “returning to a normal state” (or passive resilience), be a useful concept to describe a more efficient recovery process after a crisis as one step in the disaster management cycle, but it will not necessarily change a population's everyday risks, wellbeing, and sustainability or reduce vulnerability in the long run. Tierney and Bruneau (2007) use the “R4 Framework”, which describes resilience as:

- Robustness, or the ability of systems and other units of analysis to withstand disaster forces without significant degradation or loss of performance.
- Redundancy, or the extent to which systems or other units are substitutable if significant degradation or loss of functionality occurs.
- Resourcefulness, or the ability to diagnose and prioritise problems and initiate solutions by mobilising material (monetary, informational, technological, and human resources).

² IPCC, 2023: Annex I: Glossary [Reisinger, A., D. Cammarano, A. Fischlin, J.S. Fuglestedt, G. Hansen, Y. Jung, C. Ludden, V. Masson-Delmotte, R. Matthews, J.B.K Mintonbeck, D.J. Orendain, A. Pirani, E. Poloczanska, and J. Romero (eds.)]. In: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, pp. 119-130, doi:10.59327/IPCC/AR6-9789291691647.002.

- Rapidity, or the capacity to restore functionality in a timely way, containing losses and avoiding disruptions.

Transforming structures and processes include the technologies, institutions, organisations, policies, and legislation that support ecosystem-based disaster risk reduction interventions. *Structures* are considered in the framework as hardware: the technologies and organisations, both private and public, that implement policy and legislation and Eco-DRR services, which work in all phases of disaster management. It also includes governmental and international organisations such as the United Nations Office for Disaster Risk Reduction (UNDRR), the Partnership for Environment and Disaster Risk Reduction (PEDRR), the International Federation of the Red Cross and Red Crescent Societies (IFRC), and Conservation NGOs. *Processes*, or software, determine how the structures operate at the different stages of a disaster: the response process, the process for recovery, where restoration and reconstruction take place, and the phase for mitigation, decreasing vulnerabilities, building capacity, and preparation so that if there is another disaster, plans are in place to reduce the impact of the disaster. This includes policies, culture, and institutions. Institutions include public services, planning, emergency preparedness, and response, including international agreements such as the UN International Strategy for Disaster Risk Reduction (ISDR) and the Sendai Framework for Disaster Risk Reduction 2015–2030 (SFDRR), and national-level agreements, such as India’s Disaster Management Act of 2005.

Development outcomes include socioeconomic outcomes such as farm production and productivity, income and consumption, poverty and consumption smoothing, human development outcomes (e.g. health status and educational attainment) and outcomes measured specifically among sub-groups of vulnerable people such as poor people, women and children, and people living with a disability.

Objectives

There are two main research areas, relating to the extent of evidence and gaps (research question 1) and the synthesis of findings (research question 2).

Research question 1 concerns “What is the nature of the literature on Eco-DRR interventions implemented in low- and middle-income countries?” This contains five sub-questions:

- 1.1 What forms of Eco-DRR (including blue, green and hybrid infrastructure) have been found in the academic and grey literature, and where have these evaluations been conducted?
- 1.2 What research methods have been used to evaluate the impact and cost-effectiveness of Eco-DRR?
- 1.3 What cost-effectiveness studies have been done on Eco-DRR and how does it compare to other forms of DRR?
- 1.4 How extensive is the literature on Eco-DRR measures in ODA-eligible countries?
- 1.5 Where are the important evidence gaps in the literature?

Research question 2 concerns “How effective and cost-effective are Eco-DRR interventions implemented in ODA-eligible countries compared to other forms of DRR?” There are two sub-questions:

- 2.1 What is the effectiveness and cost-effectiveness of Eco-DRR measures?
- 2.2 How do effectiveness and cost-effectiveness vary by form of Eco-DRR (including blue, green and hybrid infrastructure) and by geographical location?

Methods

Criteria for including and excluding studies.

Types of populations and settings

We considered all populations exposed to a natural hazard in low and middle-income countries, as defined by the World Bank at the time the intervention was implemented. We excluded studies that only report effects for populations from high-income countries.

We included natural, geological and hydrometeorological hazards. The hazards needed to be rapid onset (also called sudden onset disasters) such as earthquakes, flooding, and volcanic eruptions. We excluded slow-onset disasters defined as those that emerge gradually over time such as drought, desertification, and sea-level rise³. Eligible hazards included:

- Geological and geophysical hazards originating from internal earth processes. Examples include earthquakes, volcanic activity and emissions, and related geophysical processes such as mass movements, landslides, rockslides, surface collapses, and debris or mud flows.
- Hydrometeorological hazards of atmospheric, hydrological, or oceanographic origin. Examples are tropical cyclones (also known as typhoons and hurricanes); floods, including flash floods; drought; heatwaves and cold spells; and coastal storm surges. (Tsunami).
- Environmental hazards including soil degradation, deforestation, and biodiversity loss.

We excluded the following hazards:

- biological hazards of organic origin or conveyed by biological vectors, including pathogenic microorganisms, toxins, and bioactive substances. Examples are bacteria, viruses, or parasites, as well as venomous wildlife and insects, poisonous plants and mosquitoes carrying disease-causing agents (COVID-19).
- technological hazards originating from technological or industrial conditions, dangerous procedures, infrastructure failures, or specific human activities. Examples include industrial pollution, nuclear radiation, toxic wastes, dam failures, transport accidents, factory explosions, fires, and chemical spills. Technological hazards may also arise directly as a result of the impacts of a natural hazard.
- slow-onset hazards, such as desertification, a long process and a type of land degradation which relates to human activities (Abahussain 2002)

Magnitude (intensity and scale), frequency and duration are characteristics that define each hazard and its likely effect. For example, if the hazard covered a larger area, it is likely to affect more people and natural capital than if it covered a smaller area:

- Magnitude, being the strength of the hazard (intensity) and its scale (geographical coverage): we consider all hazards that affect population and infrastructure regardless of their magnitude or scale.
- Frequency, which is the return interval for the hazards: we did not exclude any study based on hazard frequency.
- Hazard duration also indicates its likely effects, particularly (but not exclusively) if the hazard duration is long since it is likely to be more severe. All the major rapid-onset natural hazard events that cause widespread destruction, called disasters, are included.

³ <https://www.preventionweb.net/terminology/disaster>

Types of interventions

This review focuses on environmental, geological, and hydrometeorological hazards of natural, anthropogenic, or socio-natural origin. We included studies of Eco-DRR and excluded studies of only ecosystem-based adaptation and mitigation (EbM) approaches. There are two elements to ecosystem-based disaster risk reduction: “Eco” means working with environmental knowledge and its systems; “disaster risk reduction” entails understanding the risk, opportunities to address it, and working with different stakeholders to minimise it. Interventions necessarily combine both parts. Eco-DRR interventions can be categorised into structural and non-structural measures (**Table 2**). Structural measures include physical construction or restoration of any existing physical infrastructure or structure. They include blue, green, and hybrid infrastructure, which are ecologically engineered structures that use a wide range of natural features (e.g. ecological engineering by restoring wetlands, forests, and coasts). We exclude grey or hard infrastructure, which refers to any hard human-engineered structure such as a sea wall or dyke. However, hybrid infrastructure that combines blue or green with grey (e.g., sponge cities) was included. Hybrid infrastructure is “a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services such as water purification, air quality, space for recreation, climate mitigation and adaptation, and management of wet weather impacts that provides many community benefits” (UNISDR, 2017: 96).

Table 2 *Categories of eco-DRR interventions*

Measures	Interventions	Examples
Structural measures: any physical construction or protection to reduce or avoid possible impacts of hazards, and restoration or protection of the existing infrastructure.	Green infrastructure: landscape- or vegetation-based elements, such as trees, parks, and forests	<ul style="list-style-type: none"> ▪Forest restoration ▪Agroforestry ▪Green space (parks/ urban greening) ▪Tree-planting (e.g., pandanus Trees) ▪Plants ▪Sand dunes
	Blue infrastructure: water-based elements, such as rivers, canals, and ponds	<ul style="list-style-type: none"> ▪Wetlands restoration ▪Rivers, lakes, marshes ▪Floodplains ▪Mangroves ▪Peatland ▪Coral reefs, seagrasses ▪Coastal dune systems ▪Ground Water Restoration
	Hybrid infrastructure: combine blue/green infrastructure with grey engineering structures such as permeable pavements and bioswale drainage.	<ul style="list-style-type: none"> ▪Green roofs, green facades, green dykes ▪Sustainable drainage system, permeable pavements ▪Hybrid defense system: vegetation buffers and engineered structures (hard structural alternatives such as embankments, concrete walls, sea walls and gate control systems, tsunami, and coastal, flooding

Non-structural measures: knowledge, policies, governance, laws, public awareness raising, training, and education for disaster prevention and preparedness.	Early warning planning	<ul style="list-style-type: none"> ▪Early warning systems ▪Response team ▪Emergency drills
	Capacity building Governance	<ul style="list-style-type: none"> ▪Capacity building/training on eco-DRR ▪Governance (e.g. Community-based natural resource management) ▪Community-based disaster management plans ▪Land use plans

Types of outcome measures

Vulnerability to shocks, such as environmental shocks, can be categorised into (i) the likelihood of being exposed to the shock, and (ii) the ability to withstand the shock. Eco-DRR interventions primarily exert effects by operating to reduce both. Hence our primary outcomes include prevention and mitigation of hazards, and effects on natural capital (e.g., soil erosion, coastal erosion, tree cover, flooding). To be eligible for this review, the study must measure a primary outcome.

Secondary outcomes are human development outcomes (e.g., poverty, income from agriculture, other livelihood effects, time use, education, and health outcomes) measured in these studies. We included secondary outcomes where the study also reports a primary outcome, but we excluded studies that report only on secondary outcomes.

Table 3 Categories of Outcomes

Outcomes	Categories and Definitions	Examples
Primary Outcomes	<p>Hazards Prevention and Mitigation</p> <p>Prevention means the intervention aims to prevent or reduce hazards such as forest restoration aims to reduce deforestation.</p> <p>Seconds aims to mitigate exposure to hazards and their effects such as mapping the hazard-prone areas, and mangrove ecosystems to reduce the exposure to the effects of storms.</p>	<ul style="list-style-type: none"> ▪ Reduced occurrence of hazard/disaster ▪ Flood mitigation by improving water flow regulation services, ▪ Tsunami hazard mitigation, ▪ Flood mitigation by reducing urban water runoff, ▪ Soil erosion mitigation. ▪ Reduce fire occurrence. ▪ Reduce Landslides
	<p>Natural Capital Outcome: Natural capital means the capacity of the ecosystem.</p>	<ul style="list-style-type: none"> ▪ Forest quality, ▪ Water quality, ▪ Soil productivity, ▪ Ground/air pollution, ▪ Erosion, awareness of DRR measures,

		<ul style="list-style-type: none"> ▪ Management of land for Forest management practices and grazing management practices, and access rights to forest resources.
Secondary Outcomes :	Human Development Outcomes <i>It includes socioeconomic outcomes such as farm production and productivity, income and consumption, poverty and consumption smoothing, human development outcomes (e.g. health status and educational attainment)</i>	<ul style="list-style-type: none"> ▪ Poverty, ▪ Income from agriculture, ▪ Other livelihoods effects, ▪ Time use, ▪ Education ▪ Health outcome

Types of studies

We included completed empirical primary studies measuring the impacts and cost-effectiveness of Eco-DRR interventions. Eligible impact studies included large-n statistical designs that compared the outcome in the presence of the intervention to the outcome in the absence of the intervention using counterfactual analysis. Eligible designs included randomised controlled trials (RCTs) and quasi-experimental designs (QEDs). QEDs are studies that use statistical methods in the absence of randomised assignment to intervention, such as Regression discontinuity design, Interrupted time series design, Instrumental variable design, Synthetic control design, Fixed effects designs (including difference-in-differences analysis) applied to controlled pre-test & post-test data, and statistical methods applied to post-test cross-sectional data only (e.g. statistical matching and adjusted regression analysis).

Small-n qualitative impact evaluations, which are studies making causal claims that use a study method that explicitly sets out to test the causal relationships between interventions and outcomes, using theory-based approaches with collection of data along a causal pathway were also eligible. Eligible methods included realist evaluation, general elimination methodology, process tracing, contribution analysis, and most significant change analysis. Studies using participatory methods like the success case method and outcome harvesting were also eligible if they incorporated a method to verify causality (e.g., a theory of change approach).

Finally, we included statistical modelling studies, which are ex-ante impact evaluations, or components of ex-post impact evaluations, which modelled the effects of intervention strategies on outcomes which may be difficult to measure ex-post in any given study, including hazard exposures and natural capital outcomes.

To measure the cost-effectiveness of interventions, we included economic and financial evaluations. These involve the systematic identification, measurement, and valuation of the inputs and outcomes of two alternative activities, and subsequent comparative analysis (Drummond, 2005). Economic evaluations provide a measurement of economic efficiency. To be an eligible economic evaluation, a study needed to have two essential features: costs and outcomes must be analysed, and more than one alternative strategy must be compared. Cost-effectiveness studies (including cost-efficacy, or studies comparing costs with numbers reached), cost-utility, and cost-benefit analyses were included.

Search sources

We initially screened the studies from the review by Sudmeier-Rieux et al. (2021) on the effectiveness and cost-effectiveness of a range of Eco-DRR interventions, as this review was global in scope and included 529 articles. We imported the included studies into EPPI Reviewer (Thomas et al., 2010) and screened them for inclusion and exclusion criteria using an agreed pre-validated screening tool.

In parallel with the above, we identified project-level evaluations from OECD DERE, UNDP ERC (which includes GEF), GCF, IFAD, and other relevant agencies and organisations such as PEDDR, Stockholm Environment Institute, UNV collection, green climate fund, and United Nations Office for Disaster Risk Reduction (UNDRR)

Thirdly, we supplement the search with machine learning in Open Alex in EPPI reviewer. The included studies from the first and second steps comprise the “training data set”. Included records get matched to their equivalents in the Open Alex, creating a citation network.

Search results were de-duplicated to manage the screening process. A standardised screening tool was developed and piloted based on the eligible populations, interventions, comparisons, outcomes, and study designs (PICOS). To help prioritise the screening procedure and reduce resource requirements, we employed machine learning at the title and abstract stage. Potentially relevant articles were included in the full-text review.

Full texts of manuscripts were obtained for all potentially eligible studies for further examination. Two teams of independent screeners performed the full-text screening. Discrepancies between reviewers regarding study eligibility were resolved by consensus. Information regarding the primary reason for exclusion was recorded and documented for all manuscripts. The remaining eligible studies were included in the review.

A list of benchmark studies was identified to test the search and screening tools (Appendix A). The searching and screening process was reported using PRISMA.

Data collection and analysis

Data collection

Information from included studies was recorded in a data extraction form piloted before commencement. Piloting was done in parallel with the search and screening (Appendix B). The benchmark studies were used for this purpose. Reviewers extracted information from included studies to ensure consistency and quality of data extraction. We cross-checked a random sample of the studies using independent coding by a second reviewer, resolving discrepancies between reviewers by consensus or, if required, with a third reviewer. The data extraction form (Appendix C) was informed by the review questions and sub-questions. This included country, location (rural, urban, nationwide), vulnerable population, ecosystem types, Eco-DRR strategies, scale of the intervention, study design, risk of bias, outcomes and comparison group.

To answer research question 1, Thomas et al. (2013), the World Health Organisation (WHO) and Tricco et al. (2017) outline best practices for the development of rapid review. The reviewers conducted a descriptive analysis of the variables of interest such as geographical distribution, the most frequently used methodologies, and the scale of the interventions. We also identified gaps in knowledge and evidence synthesis, which we present in the form of an evidence and gap map (Saran and White, 2018).

To answer research question 2, we performed a narrative review of ex-post and ex-ante impact evaluations and economic and financial evaluations. We used statistical meta-analysis and narrative synthesis of studies to examine questions about effects.

Tools for assessing confidence in included studies

All included studies were assessed using a pre-validated tool drafted by the Campbell Collaboration team. This was initially developed for evidence and gap maps and has been used for FCDO-funded maps and reviews (e.g. Malhotra et al., forthcoming). We appraised existing estimates on cost-benefit analysis and cost-effectiveness using a checklist adapted from Drummond et al. (2011) and CHEERS. We appraised modelling studies using a tool we developed specifically for this review.

Analysis and presentation

The results of the synthesis are discussed, and a narrative summary of the findings is presented using tabular and visual presentation. The report noted the limitations of the synthesis the risks of bias, and gaps in the evidence base.

Measures of effect

We extracted comparable effect size estimates with 95 percent confidence intervals from the included studies. Effect sizes were measured as the standardised mean difference (SMD or Hedges' g) for continuous outcomes, and the odds ratio (OR) for dichotomous outcomes. We computed SMD and OR from the available information found in the studies such as means, regression coefficients, or tests from analysis of variance. We computed the OR from available information on proportions and frequencies. All ORs were converted into measurements of SMD (Hedges' g). The effect size calculations were made using an effect size coding tool developed for this review. Effects were calculated as the difference between intervention and comparison observations in a consistent way, such that an increase in the outcome measure reflects a desirable change. Thus, effect sizes where the SMD is greater than zero indicated a positive effect of the intervention on the outcome. An SMD less than zero indicated a negative effect (harm). Where an increase in the effect is presented in the study as an undesirable outcome (e.g., positive values of SMD indicate higher use of pesticides or ill-health among the intervention group compared to the comparison group), SMD was multiplied by -1.

Meta-analyses are presented by outcome category (impact on hazard prevention, impact on hazard mitigation, impact on natural capital stock, impact on development outcomes) and subsequently by subcategories (e.g., for impact on hazard prevention, occurrence of hazard or severity of hazard; for development outcomes, impacts on income, poverty, livelihoods, health, and education). To generate forest plots at the outcome level, we first calculate the single synthetic effect size for each study and outcome construct by taking the weighted average of effect across subcategories of the outcome.

Unit of analysis

We assessed whether studies use appropriate methods to calculate measures of variability in inferential statistics (e.g., standard errors). Where the studies are assessed as not using appropriate methods, we applied the standard formula to calculate the standard error or similar inferential statistic (Waddington et al., 2012), applying a design effect of 1.5 which was the mean design effect we were able to calculate from the studies that did use an appropriate unit of analysis.

Criteria for determination of independent findings

If the same programme is studied at different points in time (more than two years between data collection), and with different outcomes these were treated as separate studies, unless

the later study is focused on long-run effects of participants treated at an earlier point in time. If there were multiple versions of the same paper then the most recent versions were used, unless an older version provided estimates not available in the later version.

Data synthesis

Where possible, an inverse-variance weighted random-effects meta-analysis was conducted for each outcome using Stata. This calculates a weighted mean effect size for each outcome using a random effects model (which assumes that studies come from multiple underlying populations since they are done in different contexts, using different interventions, for different outcomes, populations, and counterfactual scenarios). For studies where statistical meta-analysis was not possible, including all the modelling and economic evaluations, we used narrative synthesis of outcomes grouped along the causal pathway.

Deviations from protocol

We have created evidence and gap maps as a useful way to articulate the clear gaps in evidence across the range of Eco-DRR interventions.

We envisaged constructing scatter plots to compare effectiveness and cost-effectiveness for each intervention, following approaches presented in the Royal Society (2014, p.60). Unfortunately, we were not able to identify sufficient numbers of studies that evaluated interventions to present the findings in this way.

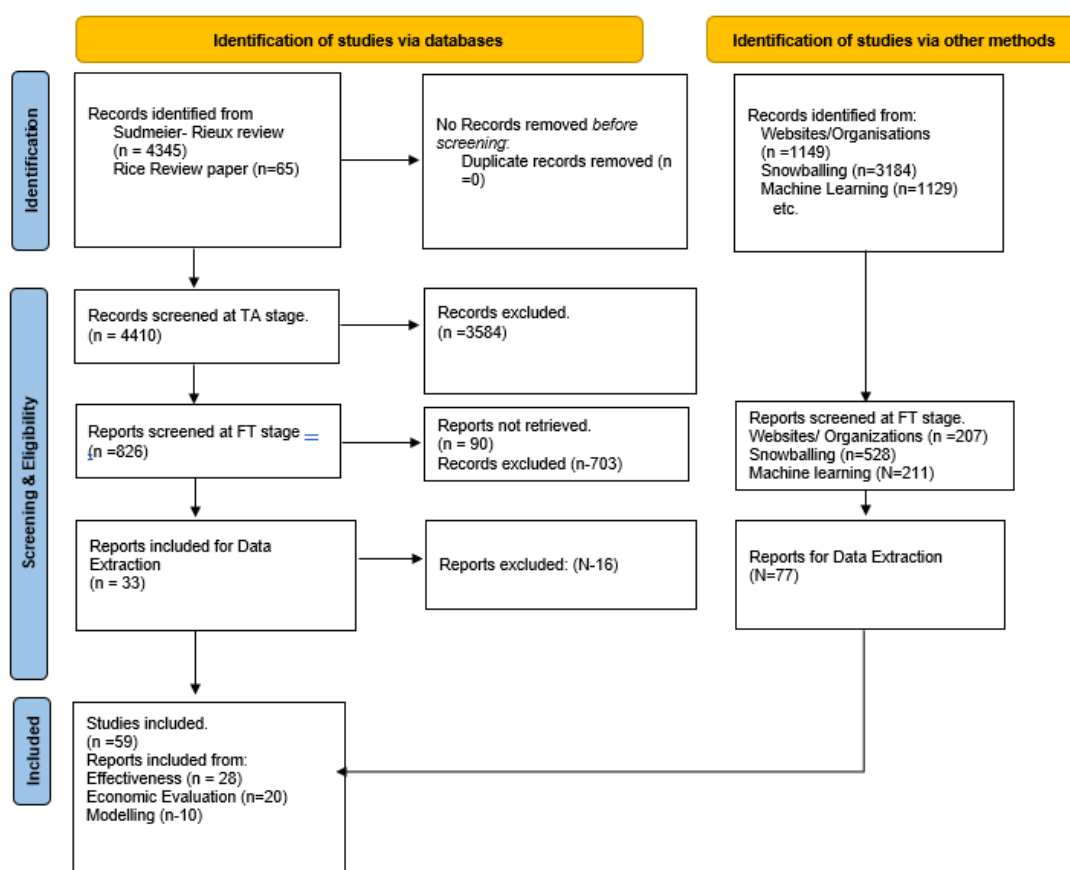
We also planned to assess the overall confidence of the findings in the review, drawing on suitable presentation methods like GRADE. However, no GRADE guidelines are presently available for presenting evidence from modelling and economic evaluations.

Results

Search results

The studies identified from the review by Sudmeier-Rieux 4,345 studies and the review by Rice 65 studies, a total studies 4,410 studies for the title and abstract screening, plus an additional 14 benchmarking studies.⁴ We have also identified 3170 records from snowballing, 1149 from websites/ organisations and 1129 records from Open Alex. Of these, 1,772 studies were screened for full text. We have excluded 1,662 studies at the full-text screening stage. Finally, we have included 110 studies for coding, among them 77 studies from the grey literature search. The final included studies in the rapid systematic review are 28 effectiveness studies, 20 economic evaluation, and 10 modelling studies (**Figure 3**). Approximately 74 percent of studies (43 studies) were found from other sources and 26 percent of the included studies (15) were from previous reviews.

Figure 3 PRISMA study search flow diagram



Note. N = Number of studies; E = Number of effectiveness studies; EE = Number of economic evaluations; MS = Number of modelling studies.

⁴ Studies identified before the search to test the search. There were 14 studies, among them six studies included in REA.

We excluded most of the studies from the previous reviews due to the population, and most of the studies from HICs. To give a few examples:

1. Adamovic et al. (2015) was excluded as the intervention was in France.
2. Adoor et al. (2011) was excluded as it used data from Switzerland.
3. Martínez-García et al. (2022) was of an intervention in Spain.

Other reasons for exclusion included intervention, outcome, and study design, for example:

4. Hearn (2009) is concerned with the management of roadside slope failures in Bhutan and Ethiopia, which is grey infrastructure.
5. Moench et al. (2014) concerned resilient shelter which is also purely grey infrastructure.
6. Barlow et al. (2012) examined forest fires in the context of REDD+ programs but did not use a valid causal inference methodology to evaluate impacts.
7. Thorlakson et al. (2012) evaluated the effects of agroforestry in Kenya on natural capital (soil erosion) using factual analysis (i.e., without a relevant counterfactual or another relevant approach such as qualitative impact evaluation or statistical modelling).

While qualitative literature does of course exist on Eco-DRR topics, we found no qualitative impact evaluations that used eligible methods to assess the contribution of Eco-DRR interventions to outcomes. Of the twelve qualitative studies we identified for full-text assessment, none used an explicit theory of change “” collected data on outcomes along a causal pathway, or adequately described an analytical strategy to measure the causal relationship (e.g., Akber 2018; Nehren 2016) (**Appendix H**).

Presentation of evidence and gap map

We generated an evidence and gap map (EGM) to map the studies by interventions, outcomes, study designs and study confidence. **Figure 4** shows the evidence map for studies of ECO DRR interventions as a mosaic map, according to the main intervention categories, outcome domains, and types of studies. The EGM is also available as a supplementary file (**Appendix J**).

Figure 4 *Presentation of Evidence and Gap Map*

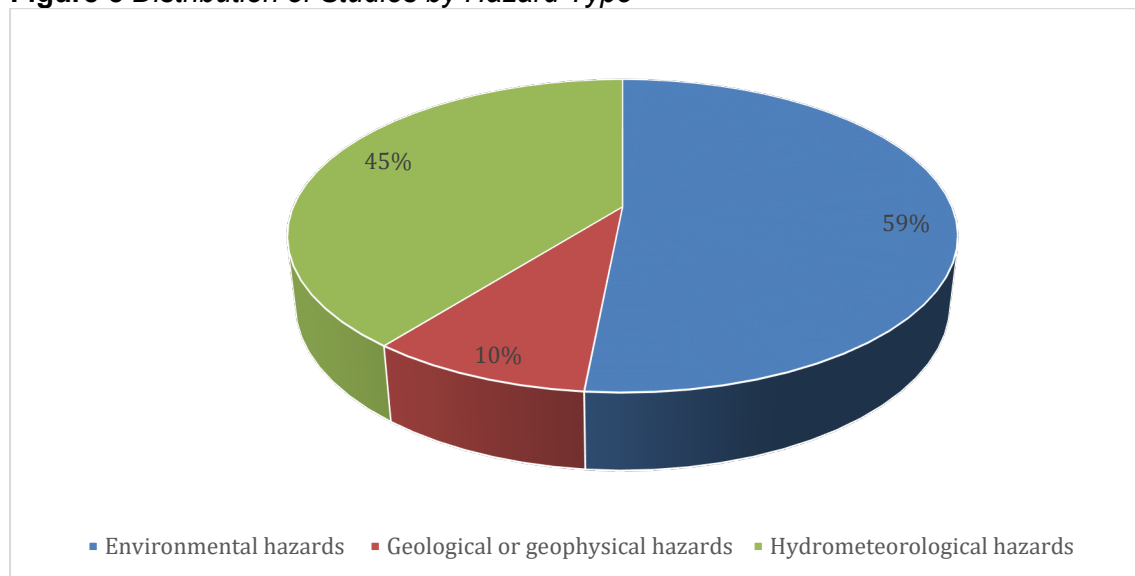


Characteristics of evidence

Populations and settings

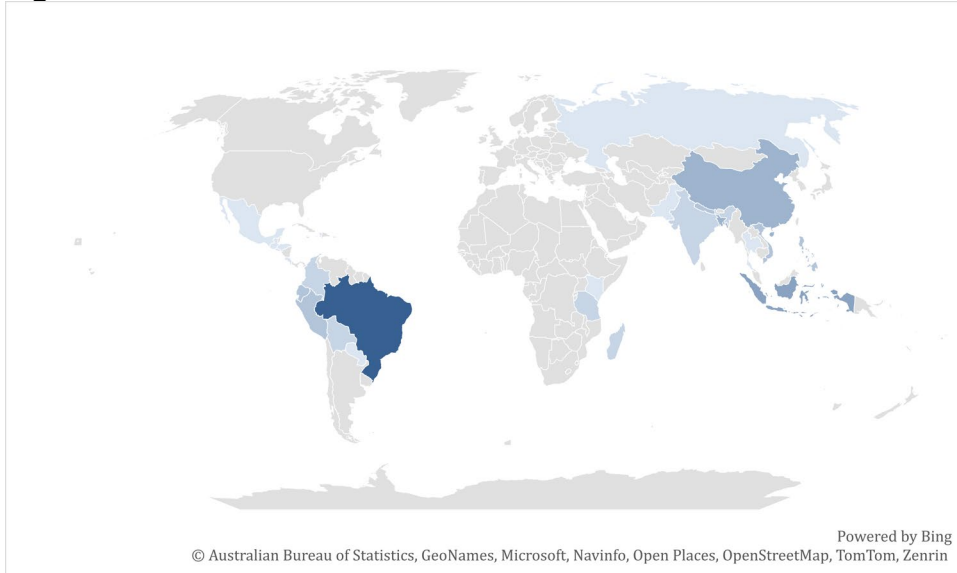
We categorized hazards into three types: environmental hazards, geological or geophysical hazards, and hydrometeorological hazards. Among them, environmental hazards appeared to emerge as the most prevalent, accounting for 59 percent of included documented disaster events. These included soil degradation, deforestation, loss of biodiversity, salinisation, and forest fires; loss of biodiversity (74%) and deforestation (76%) were the most prevalent. For example, Andam et al. (2015) and Feng et al. (2021) evaluated the effects of protected areas on deforestation, while BenYishay et al. (2017) was concerned with land rights and deforestation. Hydrometeorological hazards, including tropical cyclones, floods, droughts, and landslides, comprised 45 per cent of included reports, of which floods were the most frequently evaluated (e.g., Baig, 2016; Burton, 2009; Zhang, 2021). Geological or geophysical hazards, while important sources of hazards, represented only 10 per cent of studies, of which concerned two studies on earthquakes (e.g., Chabba, 2022) and concerned six studies on landslides (e.g., Watson, 2022; Ayala-García, 2022).

Figure 5 *Distribution of Studies by Hazard Type*



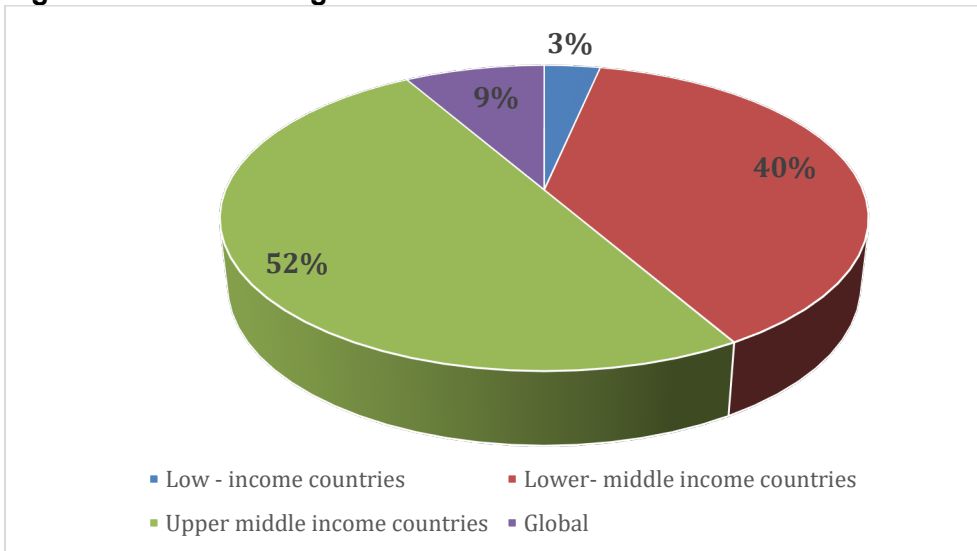
The greatest proportion of studies were of Eco-DRR interventions in Latin America and the Caribbean (LAC) (36%), in particular Brazil, of which 9 studies were included. East Asia and the Pacific (EAP) and South Asia followed with, respectively, 28 percent and 19 percent of studies. Indonesia is the second most represented country with 5 studies, followed by Bangladesh and China with four studies each. There were also five studies with global representation. Europe and Central Asia (2%) and Sub-Saharan African countries (9%) have very limited representation with only one study each from Russia, Ecuador and Kenya. We found no studies conducted on interventions in the Middle East & North Africa (MENA).

Figure 6: Global distribution of studies



The findings suggest that the majority of research is conducted in middle-income countries, especially in upper-middle-income countries like Brazil, which contributed nine studies. Indonesia followed suit with five studies, and China with four. Lower-middle-income countries were well represented, with Bangladesh contributing four studies, Vietnam contributing three, the Philippines contributing three, and Nepal contributing three studies. Additionally, 9% of the studies had a global representation. And 3% of the studies (2) are from low-income countries, with representation from Madagascar.

Figure 7: Studies categorized based on the income classification.

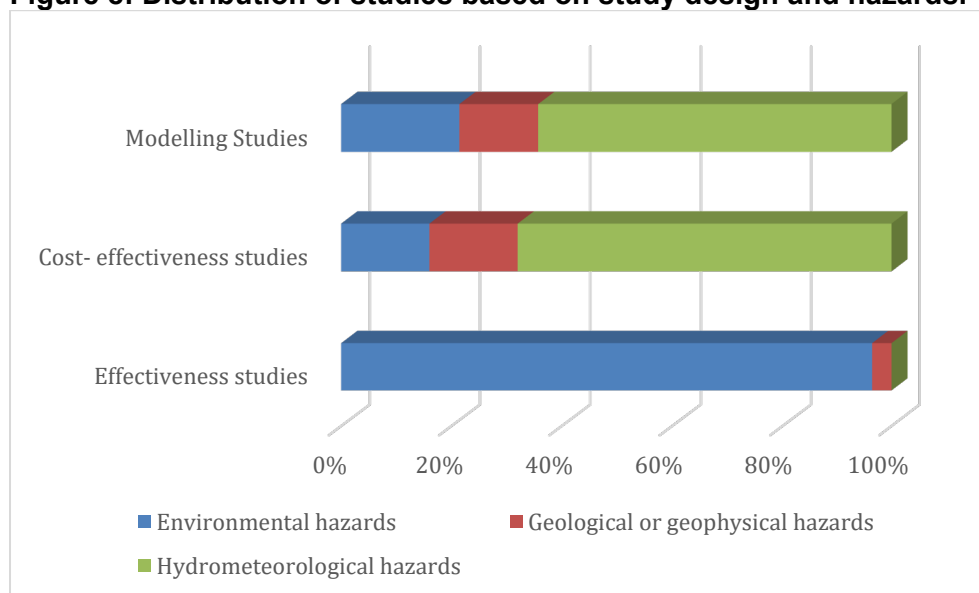


Study designs

Around half (48%) of the studies evaluated the effectiveness of implemented interventions using quasi-experimental designs including difference-in-differences, statistical matching, and interrupted time series as data analytical methods. The vast majority were of environmental Hazards, particularly forestry and deforestation. None of the effectiveness studies were randomised control trials.

Just over one-third (34%) of the studies were economic evaluations, the majority of which were cost-benefit analyses reporting one or a combination of benefit-cost ratios, net present values, internal rates of return and/or willingness to pay, and mostly of hydro-meteorological hazards (floods). The final 17% of the studies were modelling papers, which also examined hydrometeorological hazards (floods).

Figure 8: Distribution of studies based on study design and hazards.



Interventions

As noted above, Eco-DRR interventions were categorised into structural and non-structural measures. Structural measures included physical construction or restoration of any existing physical infrastructure or structure. They included blue, green and hybrid infrastructure, which are ecologically engineered structures that use a wide range of natural features, so combining blue-green infrastructure with grey engineering structures (e.g., sustainable drainage systems, hybrid defence systems, vegetation buffers and engineered structures like hard structural alternatives such as embankments). Non-structural measures included interventions based on governance and regulation, education, knowledge, public awareness raising and training for disaster prevention and preparedness. They were classified as early warning planning and capacity building. **Figure 9** presents the distribution of studies by intervention categories.

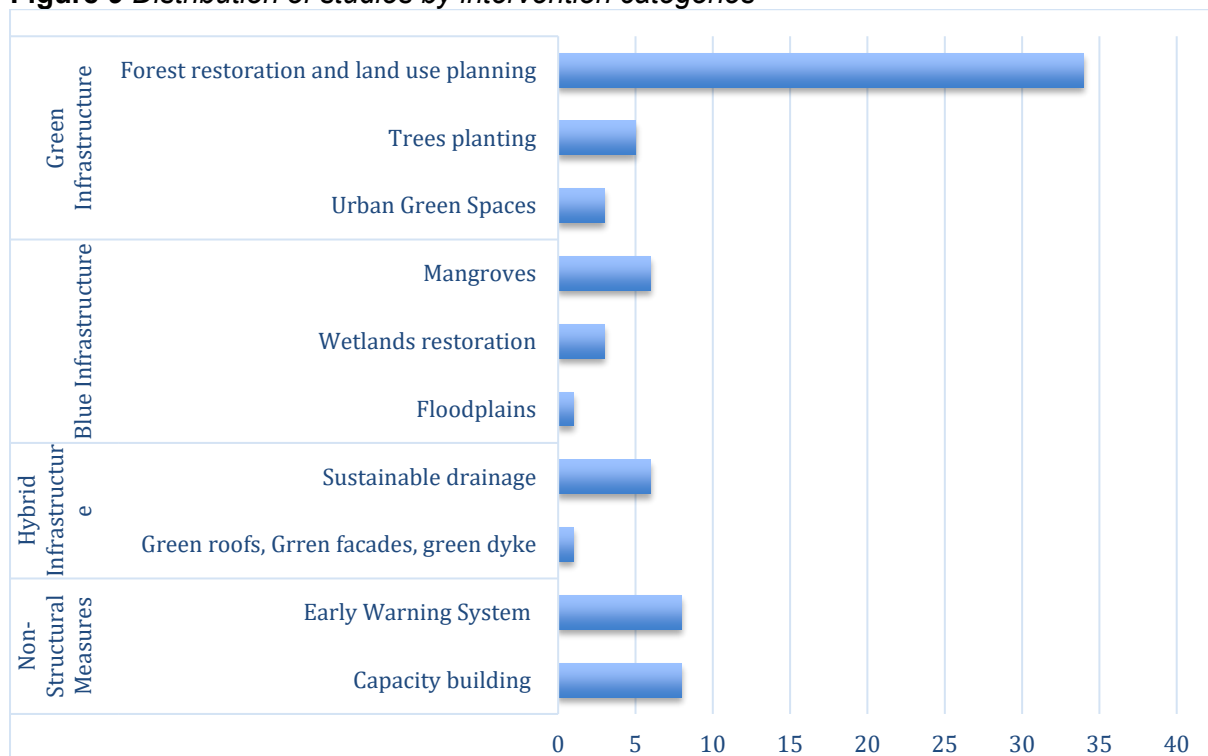
Structural measures made up the majority, consisting of 89 per cent of studies, among which green infrastructure interventions dominated (71%) followed by blue infrastructure (17%) and hybrid infrastructure (12%). The majority of green infrastructure concerned forest restoration although there were three studies on urban green spaces (parks/urban greening) and five on tree-planting. Blue infrastructure studies included (Karanja (2018), Baig (2016), Menendez (2018), Golub (2016), Sarker (2020), Meier (2016), Kiely (2021)). Six studies were done on interventions on mangroves (Karanja 2018, Baig 2016, Menendez 2018, Golub 2016, Sarker 2020), including one evaluation of the annual coastal protection benefits provided by mangroves in the Philippines (Menendez 2018). The six studies of hybrid infrastructure were on sustainable drainage (Castelli 2017, Venton 2004, Meier 2016, Kiely 2021, Haque 2013, Zhang 2021, Kull 2008, Khogali 2009, etc).

We did not identify a single study on agroforestry, green roofs, or coastal dune restoration in L&MICs.

There were eight studies on capacity-building measures such as training on Eco-DRR, governance (e.g. community-based natural resource management) and community-based

disaster management plans (Khogali 2009, Venton 2004, Tabor 2017, Ayala-Garcia 2022 etc). Early warning systems, early warning planning, response teams and emergency drills were reported in eight studies (e.g., Khan 2008, Holland 2008, Rai 2020, Hallegate 2012 etc). For example, White (2010) evaluated flood prevention in Nepal including capacity building and training, early warning systems, small-scale mitigation, education, and facilitation of coordination. Taking another example, Ayala-Garcia (2022) evaluated landslide prevention in urban Colombia. The intervention was a pre-emptive investment that covered the following groups of expenditures: (i) information systems to monitor weather conditions; (ii) building resilient infrastructure to protect human settlements and public and private infrastructure; (iii) relocating population living in risk-prone areas to safer locations; and (iv) educational programmes about natural disaster's risk.

Figure 9 Distribution of studies by intervention categories



Outcomes

Most studies reported a combination of natural capital outcomes, hazard prevention or mitigation and human development outcomes (**Figure 10**). We excluded studies that did not report on either hazard prevention/mitigation or natural capital outcome which were our primary outcomes. Most of the studies reported on the reduction and/or prevention of deforestation, forest cover, loss of biodiversity and greenness of vegetation.

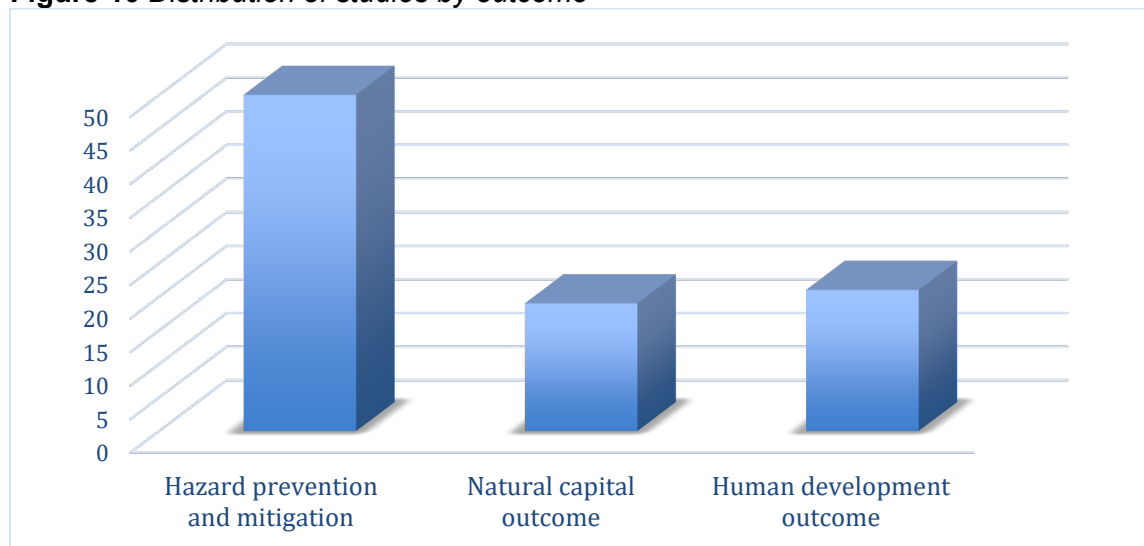
The immediate outcomes of Eco-DRR are defined as the prevention of the occurrence of hazards or mitigation of the magnitude of the hazards, hence 86 per cent of the studies reported hazard prevention and hazard mitigation such as soil erosion, deforestation, biodiversity loss and flood volume (e.g., Dancer (2013), Gaveau (2012), Brum (2019), Brenes (2018), Jones (2015), Blackman (2015), reduction in the occurrence of landslides, fires, and floods and rate of deforestation (e.g., (Aguirre (2021), BenYishay (2017), Des Bureaux (2015), Gaveau (2012), and Kim (2021)).

The environment and its components are intermediate outcomes associated with Eco-DRR interventions, therefore 33 per cent of the studies reported on the impact of hazards on natural

capital outcomes such as normalized density vegetation index (NDVI), forest cover loss or increase, area of sustained mangroves, loss biodiversity and soil degradation (e.g., Shah (2015), Maher (2013), Kim (2021), Nelson (2011), and Tersitsch (2017)).

Hazards also have direct and indirect impacts on human development, hence 36 per cent of the studies reported on human development outcomes including income, property destroyed by hazards, fatalities due to hazards and benefits in terms of savings and assets (e.g., Ha (2014), McNally (2011), Kim (2021), Hallegate (2012), and Chabba (2022)). One paper also assessed the direct impact of hazard risks relating to landslides on human life and property (Jhorland and Dall-Erba, 2022), while two assessed the indirect impacts of forest fires and floods on livelihoods for instance change in shrimp income as a result of loss of mangrove cover (Ha, 2014; McNally, 2011).

Figure 10 *Distribution of studies by outcome*

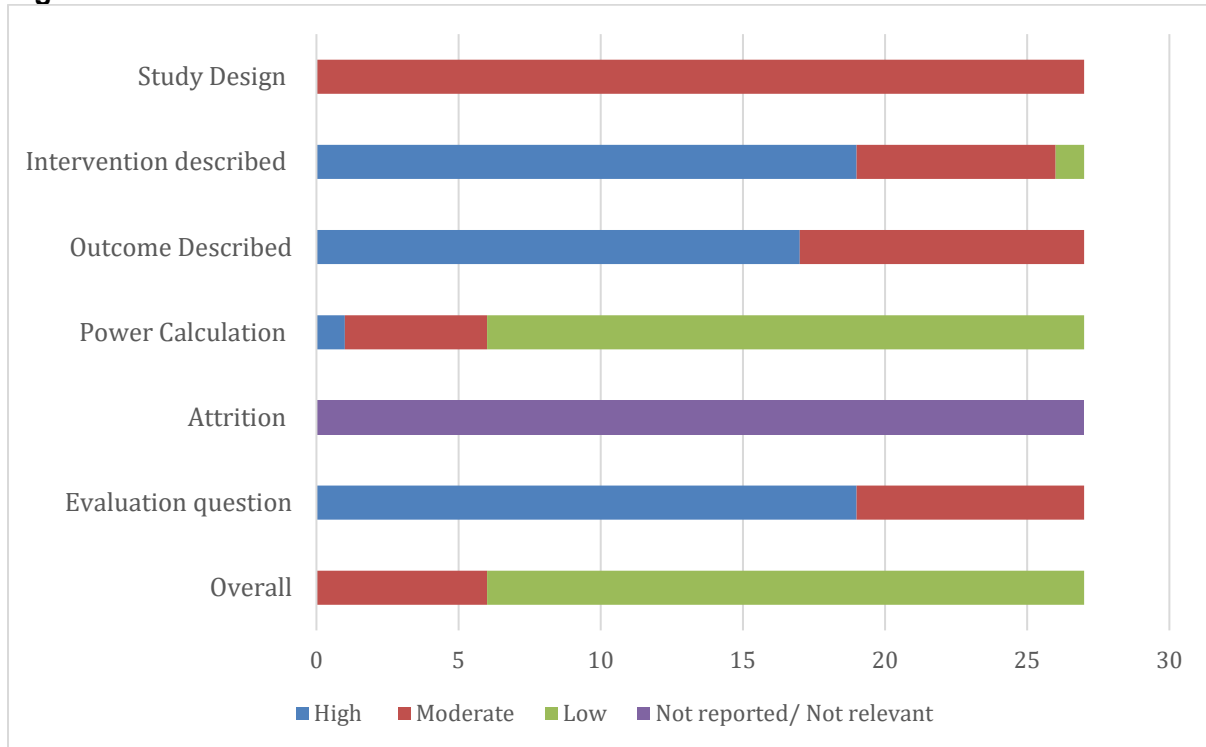


Confidence assessment

Effectiveness studies

We critically assessed studies using a tool containing six domains, five of which (study design, power calculation, clarity of intervention, outcome, and evaluation question description) were considered critical items (**Figure 11**). Overall, 21 out of the 27 studies (78%) were rated as at 'low confidence' largely because they did not report power calculations. This is due to the type of data and nature of sampling units that were used in the studies. Most of the studies used secondary administrative data and/or observations using geographical information systems (GIS), where the units of analysis were pixels or areas affected. This is the reason most of the studies also did not report attrition, hence attrition was not considered a critical item for the overall confidence rating. The remaining 6 out of 27 (22%) studies were rated at moderate confidence (Appendix F). No studies were assessed as of high confidence.

Figure 11 Confidence assessment in effectiveness studies



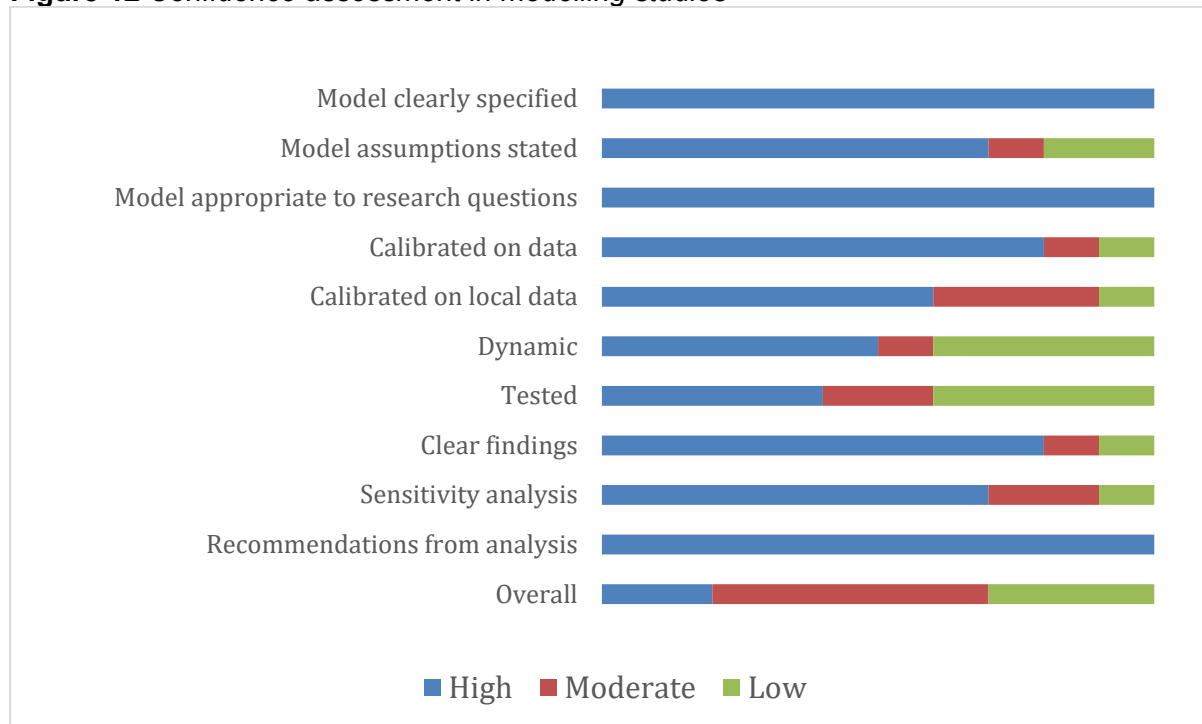
Modelling studies

The results from assessments showed that study confidence was high on many items (**Figure 12**). All papers were coded as at high confidence for the first and last items ('model specified' and 'recommendations based on analysis respectively'). Areas with the largest number of papers not receiving high confidence related to the assumptions not being specified, the model being tested and whether the model was dynamic (the last of these did not enter into the overall assessment).

The papers used a variety of data sources. These included satellite imaging data, hydrological data from existing data sources, existing land use maps, and own surveys in the study area. Data from the study area were the most common means of calibration. However, some studies used data from other areas, and some used model parameter values given by the model designers which had been calibrated elsewhere. Model testing was carried out in most, but not all cases. However, this testing was done using the same data as are used to calibrate the model.

The weakest link principle meant that only two of the ten papers were rated as high confidence in study findings, whereas five were at moderate confidence, and three at low confidence (Appendix F).

Figure 12 Confidence assessment in modelling studies



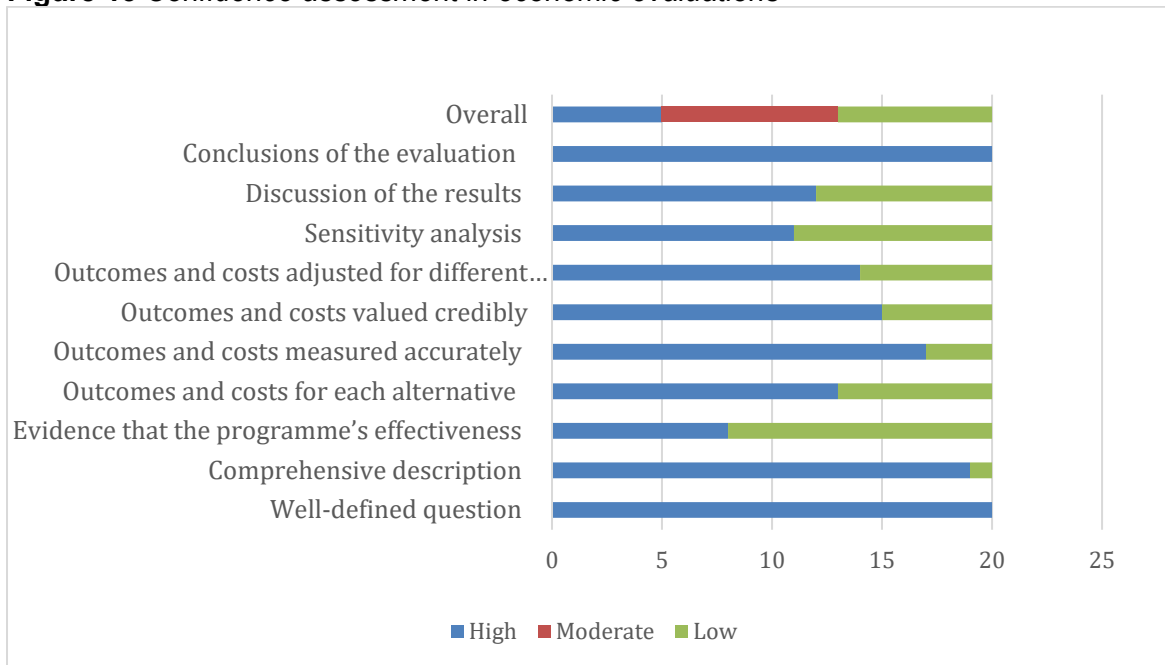
Economic evaluations

The assessment of economic evaluations also suggested studies performed reasonably well on most items (**Figure 13**). However, there were several areas where a significant number of papers did not receive a high confidence rating. The areas with the highest number of papers not meeting the required standards include sensitivity analysis and the reporting of discount rates. Not reporting sensitivity analysis and discount rates in economic evaluations can significantly impact confidence in their findings. When sensitivity analysis is not provided, decision-makers may lack a comprehensive understanding of the uncertainty surrounding the evaluation results. This can lead to inadequate decision-making and suboptimal resource allocation.

Similarly, not reporting the discount rate can introduce confusion and ambiguity in the economic evaluation. Without a clear understanding of the discount rate, decision-makers may misinterpret the findings or draw incorrect conclusions about the cost-effectiveness of the intervention. This lack of clarity can undermine confidence in the overall validity of the economic evaluation. Additionally, the absence of evidence regarding the establishment of the program's effectiveness was identified as a concern.

Five of the twenty papers were rated as having high confidence in the study findings. Eight papers were found to have moderate confidence, while the remaining seven were categorised as having low confidence. The weakest link principle indicates that the most uncertain paper determines the overall confidence in the study findings. (Appendix F)

Figure 13 Confidence assessment in economic evaluations



Synthesis of findings

Effectiveness studies

The meta-analysis included 25 studies and 192 effect sizes, most of which examined the effectiveness of green infrastructure interventions in forests and natural lands in Latin America. The most commonly evaluated interventions were protected areas, including in Brazil (Brum et al., 2019; Carmenta et al., 2016; West Thales et al., 2022), Colombia (Nolte, 2013), China (Sarathchandra et al., 2018), Costa Rica (Andam et al., 2015), Indonesia (Gaveau et al., 2012; Shah and Baylis, 2015), Madagascar (Desbureaux et al., 2015), Mexico (Blackman et al., 2015), Peru (Julio et al., 2021), Russia (Jones and Lewis, 2015), Tanzania (Dancer, 2019; McNally et al., 2011), and L&MICs in general (Do-Hyung & Anupam, 2021; Nelson and Chomitz, 2011). Some studies of protected areas evaluated interventions including natural forest timber concessions in Indonesia (Gaveau et al., 2013), payments for ecosystem services in Ecuador (Jones and Lewis, 2015) and PES/REDD+ in Madagascar (Tabor et al., 2017). A small number examined hybrid or non-structural interventions. For example, Anderson et al. (2018), BenYishay et al. (2017) and Ha et al. (2014) evaluated the effects of land tenure interventions in Peru, Brazil and Vietnam, respectively. Jhorland & Dall'erba (2022) evaluated the effects of public investment, early warning systems and information on landslides in urban and peri-urban Colombia. Cisneros and Marco (2017) evaluated public audits.

The studies evaluated four main types of outcomes: hazard exposure outcomes such as forest fires and landslides; hazard prevention outcomes such as deforestation; natural capital outcomes such as forest cover, vegetation cover, and natural land cover; and livelihoods and human development outcomes, in particular incomes, expenditures and agricultural revenues. All studies used quasi-experimental designs, the majority being based on pre-and post-intervention data with controls (controlled before-after or difference-in-difference studies) (e.g., Andam et al., 2015; BenYishay et al., 2017; Brum et al., 2019). One study used interrupted time series (Carmenta et al., 2016) and another cross-sectional design (Ha et al., 2014). Detailed information about the studies is contained in **Table 4**. **Table 5** presents findings from studies that are included in this review, but which we could not incorporate in the meta-analysis. Feng et al. (2021) and Buntaine et al. (2015) presented their results in the form of graphs and with no summary in the write-up that would help in the extraction of effect sizes. Both papers did not provide supplementary materials that would contain raw data used to generate the graphs, making it difficult to obtain point estimates needed for analysis. Maher et al. (2013) presented a study protocol but its results have yet to be published.

In this section, we present findings from the synthesis of effect sizes contained in these studies, using meta-analysis to generate pooled effects which indicate the weighted average effect across the studies, and measure statistical heterogeneity indicating how representative and generalisable the pooled effect is across the different contexts in which the interventions have been evaluated. Effect sizes are measured in units of standard deviations of outcomes (Hedges' g), with large values indicated by values of $g \geq 0.25$, moderate values lying in the range $0.1 \leq g < 0.25$, and small values in the range $0 \leq g < 0.1$. All outcomes have been transformed so that an increase represents a desirable effect; for example, forest fires are not desirable effects, hence a positive value of g indicates a reduction in forest fires. Therefore, values of $g < 0$ indicate an undesirable effect (harm) on the outcome measure, an example being increased costs to farmers in one study.

Table 4 Descriptive information on studies included in the meta-analysis

<i>Study</i>	<i>Intervention</i>	<i>Location</i>	<i>Comparison type</i>	<i>Outcome</i>	<i>Data source</i>	<i>Study design</i>	<i>Sample size</i>	<i>Risk of bias</i>
Andam et al. (2015)	Protected areas	Costa Rica	No intervention	Forest cover (forest regrowth)	Observation	Controlled study with measurement at baseline and endline	15,360	Moderate risk
Anderson et al. (2018)	Land tenure	Peru	Alternative treatment (different intervention type)	Forest cover (forest loss)	Administrative data	Controlled study with measurement at baseline and endline	148,213	High risk
BenYishay et al. (2017)	Land tenure	Brazil	No intervention	Vegetation cover (normalized difference vegetation index, NDVI)	Reported survey	Controlled study with measurement at baseline and endline	422,066	Moderate risk
Beresford et al. (2013)	Protected areas	Africa	No intervention	Natural land cover (rate of loss)	Administrative data	Controlled study with measurement at baseline and endline	28,490	High risk
Blackman et al. (2015)	Protected areas	Mexico	No intervention	Forest cover (deforestation rate)	Administrative data	Controlled study with measurement at baseline and endline	137,632	High risk
Brenes et al. (2018)	Protected areas	El Salvador, Guatemala, Honduras	No intervention	Vegetation cover (NDVI)	Observation	Controlled study with measurement at baseline and endline	14,500	High risk

Brum et al. (2019)	Protected areas	Brazil	No intervention	Vegetation cover (vegetation loss)	Administrative data	Controlled study with measurement at baseline and endline	81,698	High risk
Carmenta et al. (2016)	Protected areas	Brazil	No intervention	Reduced fire (fire occurrence)	Administrative data	Interrupted time series	98	High risk
Cisneros & Marco (2017)	Public audit	Brazil	No intervention	Forest cover (log of newly deforested area)	Administrative data	Controlled study with measurement at baseline and endline	4,060	High risk
Dancer (2013)	Protected areas	Tanzania	No intervention	Vegetation cover (enhanced vegetation index)	Observation	Controlled study with measurement at baseline and endline	108,713	Moderate risk
Dancer (2013)	Protected areas	Tanzania	No intervention	Forest cover (% tree cover)	Observation	Controlled study with measurement at baseline and endline	108,713	Moderate risk
Desbureau et al. (2015)	Protected areas	Madagascar	No intervention	Forest cover (forest cover loss)	Administrative data	Controlled study with measurement at baseline and endline	2,841	High risk
Do-Hyung & Anupam (2021)	Protected areas	L&MICs	No intervention	Forest cover (avoided deforestation per sq km)	Administrative data	Controlled study with measurement at baseline and endline	3,888	High risk

Gaveau et al. (2012)	Protected areas	Indonesia	Alternative treatment (different intervention type)	Forest cover (% deforestation)	Observation	Controlled study with measurement at baseline and endline	160	High risk
Ha et al. (2014)	Land tenure	Vietnam	Alternative treatment (different intervention type)	Net revenue (net returns per ha)	Reported survey	Cross-sectional study	42	High risk
Ha et al. (2014)	Land tenure	Vietnam	Alternative treatment (different intervention type)	Savings (per household)	Reported survey	Cross-sectional study	42	High risk
Ha et al. (2014)	Land tenure	Vietnam	Alternative treatment (different intervention type)	Savings (per person)	Reported survey	Cross-sectional study	42	High risk
Ha et al. (2014)	Land tenure	Vietnam	Alternative treatment (different intervention type)	Expenditure	Reported survey	Cross-sectional study	42	High risk
Ha et al. (2014)	Land tenure	Vietnam	Alternative treatment (different intervention type)	Income (net income per household)	Reported survey	Cross-sectional study	42	High risk
Ha et al. (2014)	Land tenure	Vietnam	Alternative treatment (different intervention type)	Revenue (per ha)	Reported survey	Cross-sectional study	42	High risk
Ha et al. (2014)	Land tenure	Vietnam	Alternative treatment (different intervention type)	Operational cost (per ha)	Reported survey	Cross-sectional study	42	High risk
Ha et al. (2014)	Land tenure	Vietnam	Alternative treatment	Harvest loss (%)	Reported survey	Cross-sectional study	42	High risk

			(different intervention type)					
Jhorland & Dall'erba (2022)	Public investment and early warning system	Colombia	Usual services (business-as-usual)	Total landslides	Administrative data	Controlled study with measurement at baseline and endline	7,102	High risk
Jhorland & Dall'erba (2022)	Public investment and early warning system	Colombia	Usual services (business-as-usual)	Num people affected	Administrative data	Controlled study with measurement at baseline and endline	6,187	High risk
Jhorland & Dall'erba (2022)	Public investment and early warning system	Colombia	Usual services (business-as-usual)	Num houses destruction	Administrative data	Controlled study with measurement at baseline and endline	4,078	High risk
Jhorland & Dall'erba (2022)	Public investment and early warning system	Colombia	Usual services (business-as-usual)	Deaths, injured and missing	Administrative data	Controlled study with measurement at baseline and endline	2,709	High risk
Jones & Lewis (2015)	Payments for ecosystem services (PES)	Ecuador	No intervention	Forest cover (% change in cover and binary change from forest to non-forest)	Other	Controlled study with measurement at baseline and endline	784	Moderate risk
Julio et al. (2021)	Protected areas	Peru	No intervention	Forest cover (loss of forest area)	Administrative data	Controlled study with measurement at baseline and endline	2,950	High risk

McNally et al. (2011)	Protected areas	Tanzania	No intervention	Forest cover (mangrove forest area)	Reported survey	Controlled study with measurement at baseline and endline	300	High risk
McNally et al. (2011)	Protected areas	Tanzania	No intervention	Fishing income (per capita)	Reported survey	Controlled study with measurement at baseline and endline	300	High risk
McNally et al. (2011)	Protected areas	Tanzania	No intervention	Shrimping income (per capita)	Reported survey	Controlled study with measurement at baseline and endline	300	High risk
Nelson & Chomitz (2011)	Protected areas	L&MICs	No intervention	Incidence of fire	Administrative data	Controlled study with measurement at baseline and endline	56,078	High risk
Nolte (2013)	Protected areas	Brazil & Colombia	No intervention	Occurrence of fire	Reported/survey	Controlled study with measurement at baseline and endline	22	High risk
Nolte (2013)	Protected areas	Brazil & Colombia	No intervention	Forest cover (gross forest cover loss)	Administrative data	Controlled study with measurement at baseline and endline	15,082	High risk
Nolte (2013)	Protected areas	Brazil & Colombia	No intervention	Forest cover	Administrative data	Controlled study with measurement at baseline and endline	11,704	High risk

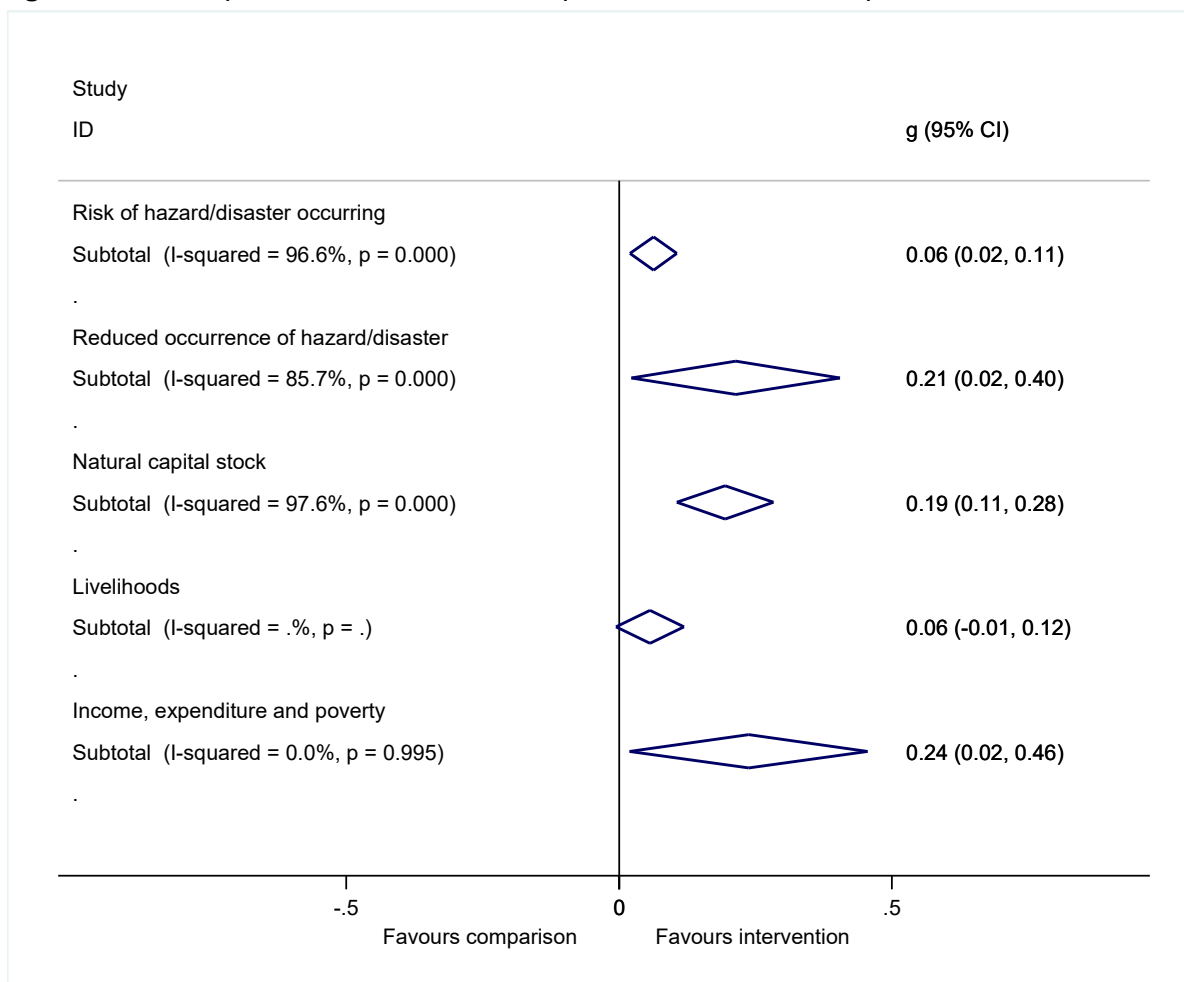
Sarathchandra et al. (2018)	Protected areas	China	No intervention	Deforestation (land use change in km ²)	Administrative data	Controlled study with measurement at baseline and endline	307,985	High risk
Shah & Baylis (2015)	Protected areas	Indonesia	Alternative treatment (same intervention type)	Change in forest cover	Administrative data	Controlled study with measurement at baseline and endline	45,631	High risk
Tabor et al. (2017)	PES	Madagascar	No intervention	Deforestation (%)	Administrative data	Controlled study with measurement at baseline and endline	486	High risk
Tabor et al. (2017)	PES	Madagascar	No intervention	Fire detected	Administrative data	Controlled study with measurement at baseline and endline	567	High risk
West Thales et al. (2022)	Protected areas	Brazil	Alternative treatment (same intervention type)	Absolute deforestation (km ² year ⁻¹)	Administrative data	Controlled study with measurement at baseline and endline	186	High risk

Table 5 Table of effectiveness studies not included in the meta-analysis

<i>Study</i>	<i>Location</i>	<i>Intervention</i>	<i>Comparator</i>	<i>Hazard</i>	<i>Design</i>	<i>Outcomes</i>	<i>Risk of bias</i>
Feng et al. (2021)	China	Protected Areas	No intervention (outside protected areas)	Deforestation	Quasi-experiment: Matching (PSM)	Positive effect on reducing deforestation compared with matched control sites. Thirty-seven PAs had negative effects had nonsignificant effects	Moderate
Maher et al. (2013)	Brazil	Protected Areas: reduce emissions from deforestation and forest degradation and enhance forest carbon stocks (REDD+)	No intervention (before the establishment of protected areas)	Deforestation	Quasi-experiment: Statistical Matching & Fixed Effects Model	Positive effect on progress in land use and land cover change	Low
Buntaine et al. (2015)	Ecuador	Protected Areas: Programa de sostenibilidad y Unio´ n Regional Sur (PSUR program) to support the conservation and strengthen Indigenous land rights	No intervention (before the establishment of protected areas)	Environmental Hazards Deforestation	Quasi-experiment: Difference in Difference	Hazard prevention: reduced deforestation	Low

The meta-analysis was estimated at two levels, firstly at the level of outcome domains, to provide an overarching sense of the intervention effects, and secondly at the level of interventions and outcome sub-domains, providing a more nuanced interpretation of the findings by intervention and outcome. **Figure 14** presents the meta-analysis of effect sizes by outcome domain. The analysis suggested that, on average, the interventions that have been evaluated have been effective in reducing exposure to hazards and disasters, and in improving natural capital stocks and human development. We estimated medium-sized effects on reduced occurrences of hazards and natural disasters ($g=0.21$, 95% confidence interval (CI)=0.02, 0.40; evidence from 5 estimates) and natural capital stocks ($g=0.19$; 95%CI=0.11, 0.28; 8 estimates), and small but statistically significant effects on the risk of hazards/disaster occurring ($g=0.06$; 95%CI=0.02, 0.11; 13 estimates). The effects on human development outcomes were also positive, in the range of medium to large for measures of income, expenditure and agricultural outcomes ($g=0.24$; 95%CI=0.02, 0.46; 2 estimates). Only a single study on landslide protection efforts in Colombia (Jhorland and Dall’erba, 2022) measured outcomes we categorised as relating to livelihoods, including house destruction and deaths and injuries averted ($g=0.06$, 95%CI=0.01, 0.12; 1 estimate).

Figure 14 Forest plot of hazards, natural capital and human development outcomes

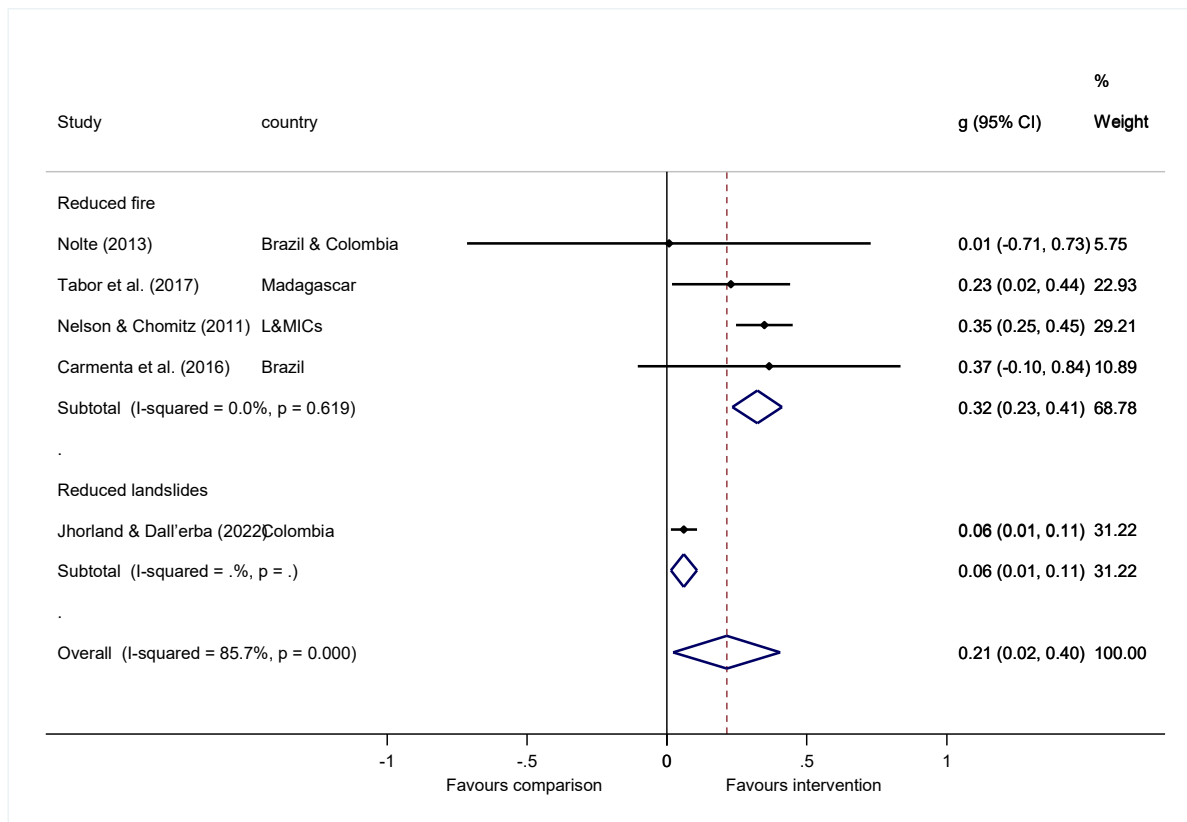


There was significant heterogeneity in some of the pooled effect estimates, measured by values of I-squared=86% (Tau-sq=0.03) for hazards and natural disaster occurrence outcomes, and for risk of hazard and natural capital outcomes (I-sq=97%; Tau-sq<0.01). When there is statistical heterogeneity, we are less sure that the meta-analytic pooled effect is generalisable across all of the study contexts, some of which may differ significantly from the average. We

also conducted meta-analysis and other tests to explore the heterogeneity by outcomes, interventions and other factors.

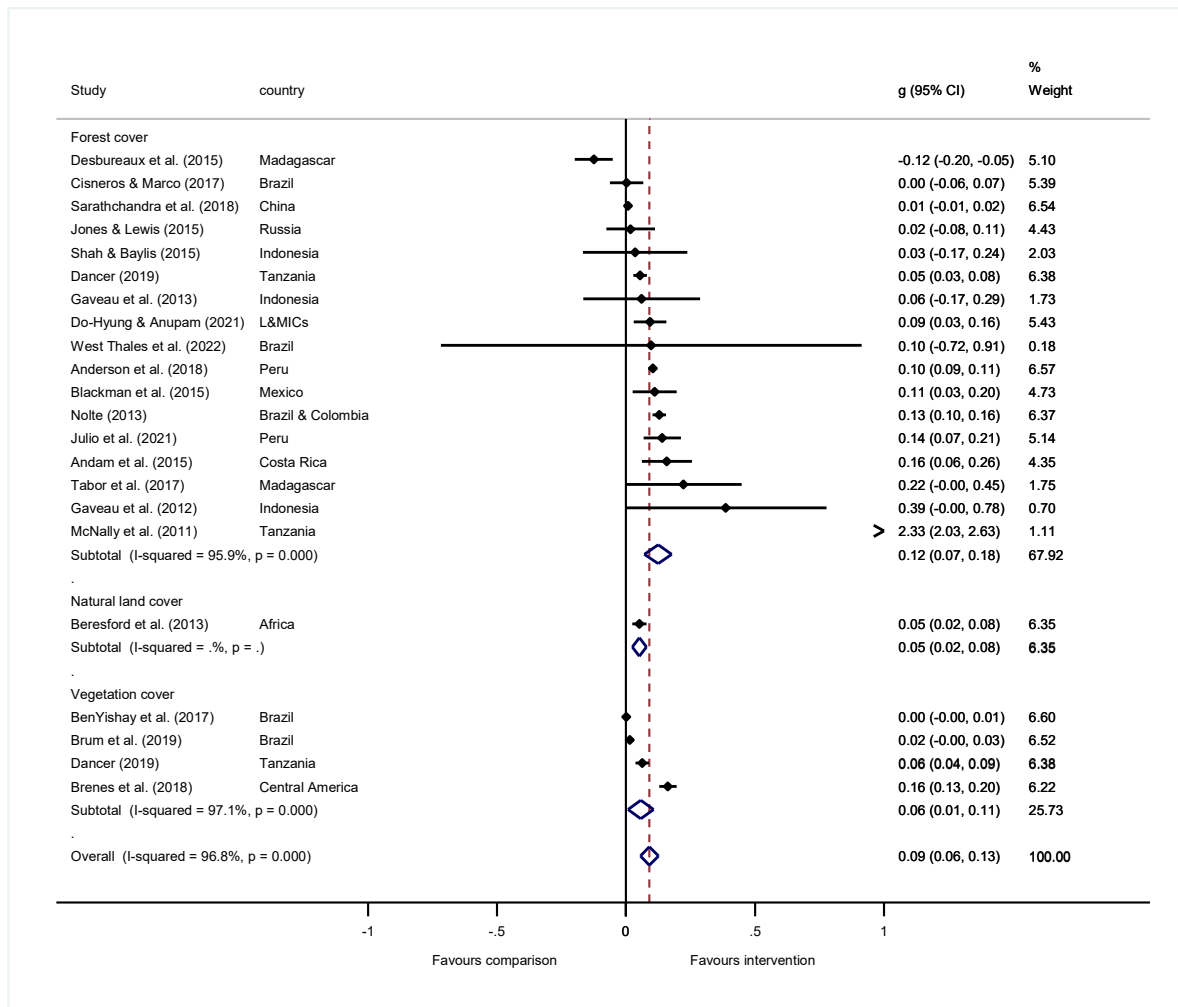
Figure 15 presents sub-group estimates for hazard prevention measures, suggesting that the heterogeneous effects are explained by large pooled effects on reducing the incidence of forest fire ($g=0.31$, $95\%CI=0.22, 0.40$; 4 estimates). Three of the studies concerned protected areas interventions, and one study was of PES (Tabor et al., 2017). One of the protected areas studies (Carmenta et al., 2016) found the reduction in forest fire incidence happening within the forest occurred alongside an increase in fire incidence in the densely populated 10km buffer zones around the forests (effect on buffer zone not shown in the figure). In addition, the study of public investment and landslide early warning systems found a small but significant effect on the incidence of landslides.

Figure 15 Detailed forest plot of hazard prevention and mitigation outcomes



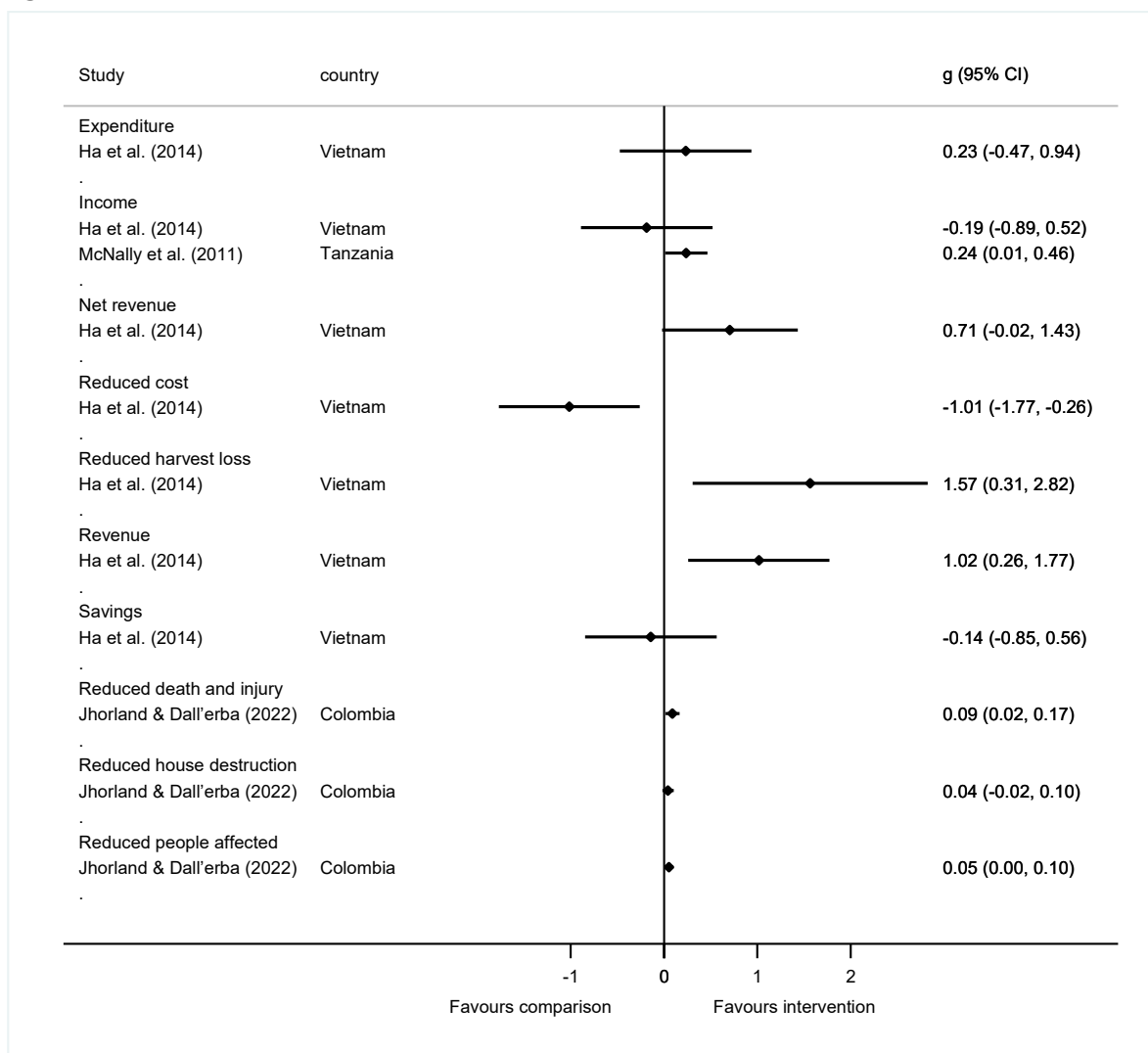
We also analysed natural capital outcome sub-groups (**Figure 16**). The meta-analysis found moderate-sized effects on forest cover ($g=0.11$; $95\%CI=0.06, 0.16$; 17 estimates). The effects were mainly from evaluations of protected areas interventions, although one study estimated an individually significant medium-sized effect on forest cover of overlapping land use allocations (in which one plot can be used for different activities, such as a combination of mining and forestry) in Peru (Anderson et al., 2019). The pooled effects of (primarily protected areas) interventions on vegetation cover were small but statistically significant ($g=0.06$, $95\%CI=0.01, 0.10$; 4 estimates). One study which evaluated the effects of protected areas on natural land cover (Beresford et al., 2013) found increases in closed forests and reductions in open forests (the increase in closed forests is shown in the forest plot).

Figure 16 Detailed forest plot of natural capital outcomes



Only three studies measured human development and livelihood outcomes. These were evaluations of land tenure reforms in rural Vietnam (Ha et al., 2014), public investment and early warning systems against landslides in urban Colombia (Jhorland and Dall'erba, 2022) and protected areas in Tanzania (McNally et al., 2011). Because of the limited number of studies, and because the studies themselves only provide a subsample of the possible population of effects on human development outcomes (because we included studies if they reported hazard exposure and natural capital outcomes primarily) we did not attempt to pool findings by outcome. Instead, we present the effect sizes in a single forest plot to illustrate their magnitudes across the different outcomes (Figure 17). The effect sizes suggested medium to large effects on income in the evaluation of protected areas in Tanzania, and reduced deaths and numbers of people affected by landslides in Colombia. The effects of land tenure reforms in Vietnam varied from very large (reduced harvest losses, increased revenues) to negative (increased costs).

Figure 17 Detailed forest plot of human development and livelihood outcomes



We also examined the meta-analysis findings by intervention group (**Table 6**). As noted, all of the effectiveness studies evaluated green and hybrid-green infrastructure, namely protected areas (including PES), land tenure reforms (including natural forest timber concessions), public audits, and public infrastructure and early warning systems. The assessment of heterogeneity in findings by intervention is limited by the limited number of studies for most intervention groups, where only a single study effect frequently exists.

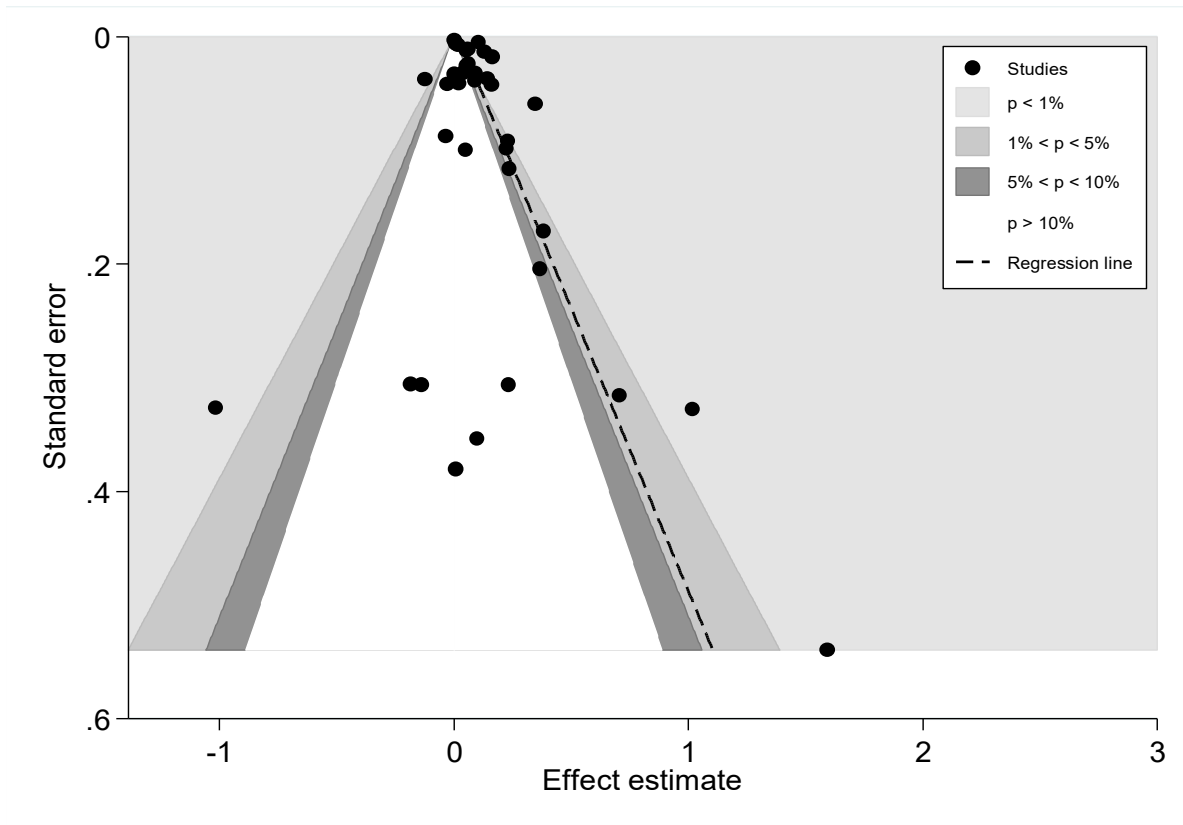
Table 6 Meta-analysis findings by intervention group

Intervention	Outcome	g	95%CI	N	I-sq	Tau-sq
Protected areas	Reduced fire	0.32	0.23 0.41	4	0%	0.00
	Forest cover	0.17	0.09 0.24	14	96%	0.01
	Natural land cover	0.05	0.02 0.08	1	-	-
	Vegetation cover	0.08	0.00 0.16	3	97%	0.00
	Income	0.24	0.01 0.46	1	-	-
Land tenure reform	Forest cover	0.10	0.09 0.12	2	0%	0.00

<i>Intervention</i>	<i>Outcome</i>	<i>g</i>	<i>95%CI</i>	<i>N</i>	<i>I-sq</i>	<i>Tau-sq</i>
	Vegetation cover	0.00	-0.01 0.01	1	-	-
	Income	-0.19	-0.89 0.52	1		
	Revenue	1.02	0.26 1.77	1	-	-
	Reduced cost	-1.02	-1.77 -0.26	1	-	-
	Reduced harvest loss	1.57	0.31 2.82	1	-	-
	Savings	-0.14	-0.85 0.56	1	-	-
Public audit	Forest cover	0.00	-0.06 0.06	1	-	-
Public investment and early warning system	Reduced landslides	0.06	0.02 0.11	1	-	-
	Reduced death and injury	0.09	0.02 0.17	1	-	-
	Reduced house destruction	0.04	-0.02 0.10	1	-	-
	Reduced number affected	0.05	0.00 0.10	1	-	-

Finally, we tested for small study effects, as an indication of possible publication bias – whereby studies are more likely to be produced where they find desirable and significant effects and/or authors undertake multiple hypothesis testing (p-hacking) and report only those tests found to be statistically significant. The funnel graph (**Figure 18**) suggests asymmetry in the distribution of effect sizes by their standard errors (a measure of sample size), which is consistent with publication bias due to small-study effects. The regression line passes through the area at $0.01 \leq p < 0.05$ significance (coeff=2.1, p=0.03). This suggests there is evidence for truncation in the effect size distribution for large variance (smaller sample) studies. Therefore, we might expect the true means of the distributions of effect sizes to be of lower magnitudes than shown in this meta-analysis, due to publication bias. However, it is difficult to say whether this is indeed the case, since we have included all outcomes measures in the funnel graph, including those further along the causal pathway, which we would expect to be smaller (White, 2014).

Figure 18 Funnel graph showing analysis of small-study effects



Modelling studies

Modelling involves specifying a set of equations in which the outcome of interest is a dependent variable, and the intervention is represented by variations in the values of the exogenous variables.⁵ The impact of the intervention is estimated by estimating the outcome in different model scenarios with and without the intervention. Modelling can be used for 'hypothetical interventions' or ex-ante analysis of planned interventions, such as Zhang's (2019) analysis of the proposed 'Sponge City' in Jiangsu Province, China and Barbedo et al.'s (2014) assessment of the effects of hypothetical river and peri-urban land-use changes on flooding in Brazil.

The advantage of modelling is that it gives precise impact estimates. The drawback is that these estimates are only as good as the model. Models are necessarily abstractions, focusing on the key outcomes and processes of interest and ignoring other factors. Models may give unreliable results if the model is poorly specified. In principle, the model is tested by comparing the model estimates with the actual values. However, it is easy to get a good fit of any data displaying a time trend. A highly specified model will accurately estimate the data points where those same data were used to calibrate the model. More rigorous testing of the model would estimate the fit in changes in the outcome rather than its level, and set aside some data points which are not used in calibration and use those data to test the model. However, these practices -which have long since been standard in econometrics – are not used in any of the included modelling papers. The issues of model assumptions, calibration and testing are incorporated into our critical appraisal tool described below.

⁵ An intervention may involve a structural change, represented by a change in parameter values or re-specifying the set of equations. However, none of the included studies use such an approach.

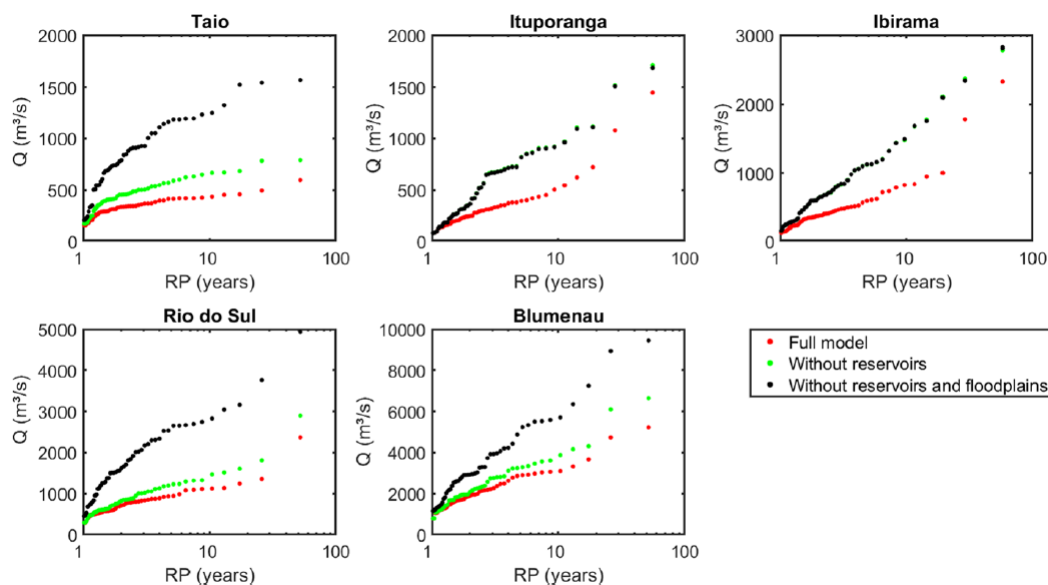
We included ten modelling papers, of which half were for countries in Latin America and the Caribbean, four from East Asia, and one for South Asia. There were no papers concerned with sub-Saharan Africa or the MENA region. Five of the papers were concerned exclusively with flooding. A further two concerned storm surges, and thus also concerned flooding, and two more included flooding amongst the hazards assessed. Just one paper, in which the hazard was landslides, did not concern flooding. Landslides were also included in one of the two multi-hazard papers (Watson, 2022).

No two papers used the same model, though flood frequency curves appeared in several papers. Flood frequency curves plot flood discharge (the volume of water passing over a point) against frequency, so protective measures should shift these curves down (see below). However, given the dominance of flooding as the hazard of interest the majority of papers use a hydrological model, which is sometimes combined with another term: Hydrologic-hydraulic-economic model (Posner, 2017) and hydrologic–hydrodynamic (Fleischmann, 2019).

There were no common outcomes reported in the papers, which limited the synthesis methods we have been able to use to narrative ones.

The most common approach reported event years; for example, a “10-year” flood is to be expected every ten years. The worse the disaster the less frequent it is and so the higher the number of years. This metric is presented in different ways. Figure 19, reproduced from Fleischmann (2019), shows the flood frequency curves for three study areas under three scenarios: the full model which has the actual reservoirs and floodplains, without reservoirs and either reservoirs or floodplains. Taking the top left figure, for the Taio study area, a ten-year flood has a discharge rate of approximately 400 m³/s, which would increase to around 550 m³/s in the absence of reservoirs, and 1,200 m³/s with neither reservoirs nor floodplains. Reading the same result another way, what is currently a 10-year event would become almost an annual event in the absence of reservoirs and floodplains.

Figure 19 Flood frequency curves showing the impact of reservoirs and floodplains



Source: Fleischmann et al. (2019): Figure 7.

Other papers concerned with flooding presented whether the flooding was eliminated or reduced for an X-year event (Barbedo, 2014, and Posner, 2017), and peak discharge volume (i.e., the highest level of floodwaters (Lin, 2017)).

One of the papers concerned with tsunamis or storm surges reported the area protected from flooding (Kayum, 2022). Other outcomes reported were the reduction in surge height (Kayum, 2022) and human casualties and structural damage (Bayas, 2011).

Rain is a flood risk, which can be reduced through more porous surfaces to enable higher rates of percolation and so reduce run-off, or by having green or blue infrastructure which captures the run-off. Urban development has concrete surfaces which have high run-off thus increasing the flood risk. Castelli reported reductions in percolation and increased run-off from full urbanisation compared to options which include green infrastructure. The proposed Sponge City in Jiangsu Province, China, uses porous pavement designs and green spaces to increase percolation and capture runoff. The study also reports a reduction in suspended water (Zhang, 2019). The simulation results of the stormwater management model suggested that the stormwater pipe system could meet the management standard for storms with a five-year recurrence interval.

The paper concerned with landslides considers the protection from soil erosion and landslides from different land use patterns (Dang et al., 2018).

The multi-hazard study is concerned with the capacity of green spaces in Quito, Ecuador, to provide emergency accommodation in the event of a disaster, reporting that capacity as a per cent of the population living within 800m (Watson 2022).

Rai 2020 was conducted in Nepal to prevent floods. This study analyzed the costs and benefits of the early warning system in the Lower Karnali River Basin in Nepal through 453 household surveys, 30 focus group discussions, and 40 key informant interviews. Hallegate 2012 was conducted in LMICS. This analysis estimated the potential benefits of hydro-meteorological information production and early warning capacity in all developing countries.

In principle the impact estimates, especially where the outcome was the value of averted damage, could be combined with cost data to conduct an economic analysis. However, none of the included modelling studies present an economic analysis.

Narrative summary of findings

The lack of common approaches and common outcomes means that quantitative synthesis of the studies was not possible. Hence, a narrative summary is provided.

Dang et al. (2018) examines the effects of the existing ecosystem on the hazards of landslides. The authors analyse the Regulatory Ecosystem Services (RES) provided by different land uses in Sapa, Lao Cai province, Vietnam. They use a combination of existing data and their primary data collection. The first stage of the analysis is an equation to estimate soil erosion under different land uses. Second, they estimate the landslide risk with and without anthropogenic impacts from differing land use. They thus work out the distribution of RES and the human contribution to that. They conclude that RES better protects against soil erosion than landslides. One-third of paddy offers no natural RES so, the authors state that, ought to be re-forested. They report some sources of uncertainty in their analysis but do not present a formal sensitivity analysis. We have moderate confidence in the study findings, marked down as there is an incomplete sensitivity analysis.

Kayum et al. (2019) examine the protective effect of Pandanus trees on Saint Martin's Island, Bangladesh, which have been planted and conserved by the NGO Poush since 2006. The authors use a combination of existing data and their primary data collection. The analysis is based on the estimation of a regression model of wave height as a function of, amongst other things, tree heights (H), tree density (N), and canopy closure % (CC). The analysis shows that

pandanus trees reduce the surge height from an average of 3.89m to 3.58m, which will ultimately preserve (i.e. prevent flooding in) 75% of the area of the island. The minimum required patch width for the Pandanus tree belt was calculated as 4.53 m. The authors conducted a sensitivity analysis, reporting that the effect may vary by only a small amount (2%). We have high confidence in the study findings.

Storms cause flooding and a risk of pollution. Residential areas largely consist of non-permeable services which increase the risk of flooding. A Sponge City incorporates permeable green infrastructure into grey infrastructure to reduce storm runoff. Zhang et al. (2020) use the SWMM model to estimate the impact of implementing a pilot Sponge City design in a district in Suzhou in Jiangsu Province, China. They use data from their survey of the district for the without scenario and the proposed design for the with scenario. Model parameters are taken from the SWMM manual. The analysis shows that Sponge City would be highly effective in reducing both storm surge and solids carried by flood waters: the volume capture ratio of annual runoff was 91% (higher than the control target of 80%). The suspended solids reduction rate was 56%, which meets the requirement of planning indicators. Whilst no cost data are presented the authors argue that Low Impact Development approaches such as Sponge Cities are cost-effective. We have moderate confidence in the study findings. It is marked down as the parameters come from the model manual rather than parameterisation against local data.

Quito is at risk of multiple hazards, including landslides, floods, volcanoes, and earthquakes. Green spaces can provide several Eco-DRR services. The one focused on in the paper of Watson et al. (2022) is providing space for temporary accommodation in the event of a disaster such as an earthquake. The authors present both an ex-post analysis of the current situation and an ex-ante analysis based on future growth projects. The authors combine geospatial satellite data to identify green spaces with city population data to estimate the capacity of the green spaces to provide temporary accommodation. They find that the currently officially designated green spaces to be used in the event of a disaster could take only 2-14% of the population living within 800m (taken to be less than a 10-minute walk). This figure would increase to 8-40% if other green spaces were also so designated. The *ex-ante* analysis, which uses models of the risks of hazards based on ecological characteristics, finds that the expected spatial expansion of Quito will be into areas of increased risk of hazard. Hence the authors recommend that in planning the expansion proper attention is given to both the protective effects of greenspaces as well as their use for emergency accommodation.

Bayas et al. 2011 utilised regression models to analyse the effect of tree belts and coastal vegetation on the maximum flood distance, casualties, and distribution of structural damage, The authors employed a hydrologic-hydraulic-economic model that integrates rainfall-runoff simulation, flood routing, flood inundation mapping, and flood damage estimation. They use a combination of existing data and their primary data collection. We have moderate confidence in the study findings, marked down for lack of sensitivity analysis and failure to test the model calibration.

Poesner et al. (2017) quantified the benefits of community-scale flood mitigation measures, such as hillslope revegetation, channel revegetation, gabion placement, and storage-capacity alternatives in reducing flood losses and enhancing resilience. The authors use a hydrologic and hydraulic modelling framework to simulate flood scenarios in a coastal watershed and compare the flood damages and recovery times under different mitigation strategies. The results obtained from various scenarios of channel roughness coefficients indicate a direct correlation between these parameters and the maximum discharge at the catchment outlet. Additionally, the shape of the rain gauge record curves suggests that storms of all sizes have relatively short durations, regardless of their intensity. The findings indicate that the presence of gabions leads to an increase in peak discharge for return periods ranging from 1 year to 35 years. The magnitude of this increase depends on the roughness condition, with $n=0.095$ and $n=0.135$ showing larger increases compared to $n=0.055$. The results indicate

that gabion dams have the potential to enhance flood control by increasing the peak discharge capacity. The authors conducted a sensitivity analysis to indicate that the impact of rainfall distribution on hillslope revegetation efforts is relatively small and that the spatial distribution of rainfall over the catchment area does not significantly impact the catchment response. We have low confidence in the study findings because of the failure to clearly state the model assumptions.

Byas et al. (2011) specifically examine the effects of coastal vegetation on tsunami impact, considering scenarios with initial water heights below 10 meters. The researchers used 180 transects perpendicular to over 100 kilometres of the west coast of Aceh, Indonesia. Satellite imagery, land cover maps, and land use characteristics were employed to analyse the influence of coastal vegetation, mainly cultivated trees, on tsunami impact. The findings of the study revealed that the existing coastal vegetation in front of settlements significantly reduced casualties by an average of 5%. However, dense vegetation behind villages endangered human lives and increased structural damage. Debris carried by the backwash may have contributed to these varying effects of land cover. No sensitivity analysis was conducted.

Barbedo et al. (2014) measure the effects of hypothetical river and peri-urban land-use changes on flooding in Brazil. The interventions assessed are a combination of grey and blue technologies, specifically river restoration, compact urban development, construction of connected lakes, opening of new channels complementing existing drainage networks, and river dredging (hybrid blue-grey technology). The river flooding would be eliminated across floodplains for 5-yearly rainfall events; flooding reduced (and eliminated in some areas) across floodplains for 25-year extreme rainfall events. The study presents magnitudes of change in flooding maximum depth (e.g. 50cm less than under the baseline scenario). Time series of river discharge volumes (m³/second) for the two rivers are also presented, indicating a reduction in one river and a slight increase in the other.

Castelli et al. (2017) measure the effects of different urban land-use scenarios on run-off, percolation and rainfall in Santa Cruz, Bolivia. Four different scenarios were compared to a base case (scenario 1): complete urbanisation (scenario 2), urbanisation with green infrastructure (scenario 3), urbanisation with green infrastructure and agroforestry (scenario 4), and complete afforestation using agroforestry (scenario 5). The authors estimate the spatial distribution of runoff generation, and percolation to the shallow aquifer, which is seen as an ecosystem service of the Pirai River system that contributes to deep aquifer recharge and river discharge in dry periods as lateral flow or base flow. The authors find increases in surface runoff and reductions in percolation to the shallow aquifer and recharge to deep aquifer, from the worst-case scenario (2 full urbanisation), over the base case scenario 1. Green infrastructure (scenario 3) performs slightly better but is still worse than the base case. Green infrastructure with agroforestry (scenario 4) fully alleviates the run-off but only partially addresses the percolation problems. Agroforestry (scenario 5) fully addresses the runoff and improves shallow and deep groundwater recharge. The paper is rated as low confidence in study findings as the model assumptions are not clearly stated and it is not calibrated on local data.

Lin et al. (2017) uses a hydrological model to simulate the effect of forest reconstruction on flooding in the upper reach of the Tingjiang River, China. They compare scenarios with different forest types: coniferous, broadleaved and bamboo. The authors report that replacing coniferous forests with broad-leaved forests had a limited reduction effect on flood peak discharge and flood volume. Replacing bamboo forests with broadleaved worsens the risk of flooding – a flood peak discharge of a 10-year return period event was reduced to a 7-year event. We have moderate confidence in the study findings because sensitivity analysis does not assess variations in model parameters, and the model is only partly calibrated on local data.

Economic evaluations

The rapid review included 20 papers on economic evaluations and case studies that evaluated the cost-effectiveness of Eco-DRR measures. All papers were cost-benefit analyses (CBAs), with two papers accounting for income differences and incorporating equity weights to estimate social welfare benefits. Among the key indicators of economic efficiency within CBA are benefit-to-cost ratios (BCR) or cost-benefit ratios (CBRs) and internal rates of return (IRRs) and net present values (NPVs), which are, in most cases, equivalent. Table 7 categorizes and lists studies according to population, primary intervention, ecosystem/hazard type, type of interventions, outcomes, and effectiveness units.

In most economic evaluations, multiple ecosystems were considered, with the majority focusing on river/wetland ecosystems (n=13), followed by coastal ecosystems (n=8) and mountains/forests (4). Twenty papers discussed hydrometeorological hazards, including 16 on floods, two on drought, and one on landslides. Environmental hazards were addressed in four of the studies. Two dealt with soil degradation, one with biodiversity loss, and two with forest fires. Three papers on geological and geophysical hazards, including two on landslides, one on rockslides, and two on earthquakes (Table 7).

Fourteen studies involved structural measures and twelve involved non-structural measures. Nine of the fourteen studies on structural measures evaluated the economic impact of blue infrastructure; four looked at green infrastructure, and seven at hybrid infrastructure. Three studies assessed the economic benefits of trees (Pandanus Trees/Afforestation) among the studies investigating green infrastructure. Dewy et al. (2022) evaluated the economic benefits of the vetiver plant as an effective soil conservation and slope stabilization tool. A report by UNDP (2015) reviewed the plantation of broom grass (*Thysanolaena maxima*) in the Kaski, Parbat, and Syangja districts in Nepal's Panchase region regarding its potential for biodiversity conservation. The objective of this study was to evaluate the effect that Broom grass could have on soil erosion and slope stability in various locations: roadside, barren areas, and farmland. A recent study by Meir et al. (2016) investigated the impact of planting trees alongside streams to improve the riparian zone. An urban forest restoration measure, Boca de Sapo (BdS), was studied by Chaba et al. (2022) on a mountainside above the burgeoning El Volante area in the peri-urban Lima district of Peru to assess the outcome of the restoration. It is also worth mentioning that this is a critical biodiversity park with more than 3500 trees and plants. The wetland restoration has been studied in three studies, and mangrove protection and replanting has been studied in five studies. Peatland restoration is considered in two studies (Khan et al., 2008 & Kiely et al., 2021) as regenerating wetland ecosystems that accumulate organic matter over an extended period, primarily plant debris and dead plant material. Meir et al. (2016) describe a marsh system as a system of planted trees and vegetation retaining water and sediment. Community-based mangrove reforestation, plantation, and protection are studied in six studies (Baig et al., 2016; Golub, 2016; IFRC, 2011; Karanja, 2018; Menéndez, 2018; Sarkar, 2020). Six studies have studied hybrid infrastructure, and all six included sustainable drainage interventions. Haque et al. evaluated the economic impact of the Meghna Dhonogoda Irrigation Project (MDIP), which consists of 64 km of embankment, 282 km of canal system for irrigation, and 125 km of drainage canals. Sixteen studies evaluated non-structural measures, eight focused on capacity building and early warning systems, and one on land use planning.

Comparators

Nineteen of the twenty studies compared eco-DRR intervention with baseline scenarios with no interventions.

Only one study, Meir et al. (2016), presents a comprehensive assessment of ecosystem-based adaptation (EbA) measures in the Huai Sai Bat and Tha Di river basins. The study evaluates the economic viability of selected measures, including floodplain and wetland development, sediment pool installation, and riparian zone improvement, as well as engineering measures such as reservoir dredging. The analysis revealed that the constructed wetland intervention showed the highest BCR, with values of 3.29 in the middle term and 5.84 in the long term, indicating its economic viability and attractiveness. The flood control with wetland development and riparian zone improvement measures also showed increasing BCRs over time, becoming economically desirable in the middle and long term. In contrast, the conventional wastewater treatment plant (WWTP) had a lower BCR in the short term but became economically desirable in the middle and long term. The living weirs and floodplain & wetland development measures also demonstrated high BCRs, indicating their economic feasibility in addressing water scarcity and quality issues.

Overall, the BCR analysis highlighted the economic performance and desirability of the ecosystem-based adaptation (EbA) measures compared to engineering measures in addressing the environmental challenges in the river basins.

Discount rates used

Only eleven studies applied a 10-12 per cent discount rate, while six applied a rate lower than 5% (n=6). Six studies conducted sensitivity analyses and explored a range of discount rates. Among these, two studies specifically investigated a discount rate from 0 to 20 per cent. The choice of discount rate significantly influences the NPV calculation. A lower discount rate favours long-term investments, while a higher rate emphasizes short-term gains (Baig et al., 2015 & Chabba, 2022). Venton (2004) recommends a very low or zero discount rate for environmental projects, arguing that protecting the environment for future generations should be treated no differently than protecting it today. Chabba et al. (2022) reported that lower discount rates result in higher returns. It is common practice for development projects to discount development costs by 10–12%, thus assuming future generations will be better off and more able to cope with hazards (Baig et al., 2015; Haque et al., 2013). To better understand the implications of the chosen rate, it is useful to look at the complete sensitivity over 0–20% (Kull, 2008).

Categories of items valued

While estimating direct costs for structural measures is relatively straightforward, indirect costs and benefits are often overlooked or not reported. These indirect costs include productivity loss due to evacuations, repairs, and economic disruptions. Basic comparisons between studies were achieved by developing general categories of items valued. Among the aspects of hazard mitigation included averting damage to homes, physical assets, agriculture and crops, livestock/fodder, infrastructure, livelihoods, and wages. Hazard prevention included assessments of hazard probability and vulnerability. Human development outcomes included lives saved and productivity gains. In addition to quantitative items, studies included qualitative items, such as vulnerability assessments, that are not widely valued.

In most studies (n=11), physical assets and maintenance were valued. These items typically have a market value that is widely accepted, making them easy to value. Averting damage to crops and agriculture was another common category (n=11). Several studies identified livelihood disruption as another common category (n=8), possibly due to community-based studies and the fact that livelihood disruption can significantly impact a community during and after a disaster. Direct costs such as loss of wages (e.g., temporarily closed markets, damage to buildings/infrastructure) are more easily estimated but require qualitative surveys and expert consultations. In eight studies, hazard probability was the primary outcome of hazard prevention. These studies assessed and mitigated potential risks and hazards in various contexts.

The interventions include non-structural measures such as early warning systems for floods (n=6), capacity building (n=1), and land use planning (n=1). Structural measures such as mangrove replantation and protection (n=3), forest restoration (n=1), and eco-DRR mixes (n=2). The early warning systems for floods have been implemented in various countries, including Fiji, Nepal, India, and Vietnam, with reported benefits such as damages averted regarding livelihood, infrastructure, crops, and risk reduction. The quality of evidence for these interventions varies from low to high, based on the references provided. Mangrove replantation and protection have been demonstrated in the Philippines and Bangladesh, showcasing damages averted in infrastructure and crops. Forest restoration, focusing on geophysical hazards such as earthquakes and landslides, has been implemented in Peru, resulting in risk reduction through hazard probability and vulnerability assessment. Drought eco-DRR mixes and flood eco-DRR mixes have been implemented in Thailand and Pakistan, respectively, with reported damages averted and risk reduction. Additionally, the document highlights non-structural interventions such as land use planning, capacity building, and sustainable drainage, each contributing to damages averted and risk reduction in various countries, including Nepal, Peru, and India.

Table 7 Overview of included CBAs

<i>Study aspect</i>	<i>Number of studies</i>
Type of Ecosystem:	
Coastal	7
Mountain/Forest	4
River/wetland	11
Dryland	1
Type of hazards:	
Environmental hazards (Soil degradation- 2; Loss of biodiversity-1; Forest Fires 2)	4
Geological or geophysical hazards (Landslides 2 ; Rockslides -1; Earthquakes-2)	3
Hydrometeorological hazards (Tropical -6; cyclones -15; Landslides- 1)	17
Technology:	
Structural measures	14
Green infrastructure	3
Blue infrastructure	2
Hybrid infrastructure	6
Non-structural measures	10
Discount rate used:	
10-12%	11
5-10%	2
Less than 5%	4
Not reported	3
Benefits or categories of item valued:	
Hazard prevention	8
Hazard probability	8
Vulnerability assessment	4
Hazard mitigation damages averted to:	20
-Infrastructure/assets	11
-livelihood	8

<i>Study aspect</i>	<i>Number of studies</i>
-crop/agriculture	11
-livestock/fodder	4
Human development outcomes	
-lives saved	9
-productivity gains	9

Valuation of benefits

Benefit-Cost-Ratios (BCR)

Table 8 summarises the maximum BCR values reported. While synthesising eco-DRR's economic evolution is challenging due to heterogeneity, most results support its economic effectiveness. Benefit-cost ratios of 4 and higher are widely documented in these studies. The reported benefit-cost ratios (BCRs) for early warning systems for floods vary across target countries and populations, indicating the cost-effectiveness of these interventions. In Fiji and Nauva, the BCRs range from 1 to 7 with moderate quality of evidence, suggesting a moderate return on investment. Conversely, in the Nepal Karnali River Basin, the BCR is 83 with high-quality evidence, indicating a high return on investment. In Nepal and India, Gangetic Basin, the BCRs range from 2 to 4.8 with low-quality evidence, suggesting a relatively lower return on investment. In Nepal, Kailali, the BCR is 3.49, with high-quality evidence indicating a moderate return on investment. Additionally, in Vietnam, the BCRs range from 68.92 to 104.8, with moderate quality evidence suggesting a high return on investment.

It is critical to note that the case studies highlight the importance of contextual factors in shaping the outcome of BCRs and the ability of these strategies to generate high returns. Each study considers the unique circumstances, risks, and costs associated with the specific eco-DRR measures being assessed. It is crucial to consider the local factors and variables that may influence the benefits and costs of implementing such measures. Improvements in understanding different approaches to DRR and the relative role of directly targeted versus systemic approaches to risk management are essential.

Table 8: Reported BCRs from included economic evaluations

<i>Sector & Interventions</i>	<i>Outcomes</i>	<i>Reported BCRs</i>	<i>References</i>	<i>Target country/population</i>	<i>Confidence in evidence findings</i>
Non-structural: Early warning systems for hydrometeorological hazards: Floods	Hazard mitigation: Damages averted:(livelihood, infrastructure)	1-7	Holland, 2008	Fiji, Nauva	Moderate
	Hazard mitigation: Damages averted: crops and infrastructure	83	Rai et al. (2020)	Nepal, Karnali River Basin	Moderate
	Hazard mitigation: Damage averted: assets,	4-35	Hallegate et al. (2012)	Multi-country	Low

	infrastructure & Human development outcomes: lives saved				
	Hazard prevention: Risk reduction: hazard probability and vulnerability assessment	2-4.8	Kull (2008)	Nepal and India, Gangetic Basin	Low
	Hazard prevention: Risk assessment: hazard probability	3.49	White (2010)	Nepal, Kailali	High
Structural: Blue infrastructure-Mangrove replantation and protection for hydrometeorological hazards: floods	Hazard mitigation: Damage averted-infrastructure, livelihood, and crop/agriculture	1.36-1.49	Baig et al. (2015)	Philippines, Barangay Silonay, Calapan City	Moderate
	Hazard mitigation: Damage averted-infrastructure and crops) & Hazard prevention: risk reduction-hazard probability	3-3.3	Golub et al. (2016)	Bangladesh, Kulhna district	Low
	Hazard mitigation: Damage averted and . health and safety (lives saved) and Hazard prevention: Risk reduction	68.92-104.8	IFRC (2011)	Vietnam,	Moderate
Structural: Green infrastructure-Forest restoration for geophysical hazards-earthquakes and landslides	Hazard prevention: Risk Reduction-Hazard probability and vulnerability	0.06-1.7	Chabba et al. (2022)	Peru, peri-urban Lima	High
Structural: Eco-DRR mix 1. Hybrid 2. Green (tree planting) and blue	Hazard mitigation :Damages averted (crops)	0.96-2.72	Meir et al. (2016)	Thailand, Huai Sai Bat, a sub-	Moderate

(wetland restoration) infrastructure for hydrometeorological hazards-drought				basin of the Chi River Basin	
Eco-DRR mix Non-Structural Measures: Early Warning System and land use planning; Structural measures: blue infrastructure-wetland restoration for hydrometeorological hazards-floods	Hazard prevention: Risk reduction: hazard probability and vulnerability assessment	1) 8.55-9.25	Khan (2008)	Pakistan, Lai basin	Low
	Human capital: Health and safety: lives saved	2) 0.96			
		3) 1.34			
	Hazard mitigation: damages averted: infrastructure,				
Structural measures: green infrastructure-green space plantation of broom grass (Thysanolaena maxima) for hydrometeorological hazards-floods	Hazard mitigation: Damages averted livestock/fodder, livelihood/wages	1.3	UNDP (2015)	Nepal, Panchase region	High
Non-structural measures: land use planning sustainable grassland management for environmental hazard: soil degradation	Hazard mitigation : Damages averted livestock/fodder, livelihood/wages	1.27	UNDP (2015)	Peru, Lima	High
Non-Structural measures: Capacity Building for hydrometeorological hazards-floods	Hazard mitigation: damages averted: infrastructure	3.49	Venton (2004)	India, four district in Bihar	High
Structural measures-hybrid-sustainable drainage for hydrometeorological hazards-floods	Hazard mitigation: damages averted: Infrastructure	18.6	Nepal Red Cross, 2008	Nepal, Ilam district	Moderate

The reported damages averted and their associated benefit-cost ratios (BCRs) for mangrove replantation and protection in different target countries/populations indicate the effectiveness of these interventions in averting damages. In the Philippines, Barangay Silonay, Calapan City, damages averted range from 1.36 to 1.49 with a moderate quality of evidence, while in Bangladesh, Kulhna district, damages averted range from 3 to 3.3 with low quality of evidence, reflecting the cost-effectiveness of these interventions in mitigating hydrometeorological hazards.

The reported risk reduction outcomes and their associated benefit-cost ratios (BCRs) for different non-structural and structural flood interventions in various target countries/populations demonstrate the effectiveness of these interventions in averting damages and reducing risks. In Nepal, Panchase region, the flood intervention involving green infrastructure and green space resulted in damages averted, including livestock/fodder and livelihood/wages, with a BCR of 1.3, supported by high-quality evidence. Similarly, in Peru and Lima, the non-structural flood intervention of land use planning led to damages averted, encompassing livestock/fodder and livelihood/wages, with a BCR of 1.27, also supported by high-quality evidence. Additionally, in India, across four districts in Bihar, the non-structural intervention of Capacity Building resulted in damages averted related to infrastructure, with a BCR of 3.49, supported by high-quality evidence. Furthermore, the structural intervention of flood structural-hybrid-sustainable drainage in Nepal, Ilam district, led to damages averted pertaining to infrastructure, with a BCR of 18.6, supported by moderate-quality evidence. These outcomes collectively demonstrate the effectiveness of non-structural and structural flood interventions in averting damages and reducing risks in the respective target countries/populations.

Based on these findings, it is recommended to prioritize and invest in interventions with higher BCRs, such as early warning systems for floods, and non-structural interventions like land use planning and capacity building. Additionally, continuous monitoring and evaluation of the effectiveness of these interventions are essential to ensure their long-term impact on disaster risk reduction.

Internal Rate of Return (IRR)

The internal rate of return (IRR) reported by Haque et al. (2013) as 5.32% for hybrid infrastructure and sustainable drainage for flood mitigation indicates the potential financial performance of this specific intervention. This IRR suggests a moderate return on investment for the implementation of hybrid infrastructure and sustainable drainage in mitigating flood-related damages. On the other hand, Rai et al. (2020) reported an IRR of 409% for non-structural early warning systems for flood mitigation. This exceptionally high IRR indicates a potentially significant financial return on investment for the implementation of early warning systems in mitigating flood-related damages. Additionally, the UNDP reported an IRR of 21% for structural measures, specifically green infrastructure, for flood mitigation. This IRR suggests a moderate return on investment for the implementation of green infrastructure in mitigating flood-related damages.

These IRR values provide insights into the financial performance and potential returns on investment for different interventions aimed at mitigating flood-related damages, with early warning systems demonstrating exceptionally high potential financial returns.

Net benefits

In Nepal, the Nepal Red Cross reported net benefits of 33 million NPR for structural-hybrid-sustainable drainage tree planting on river beds and capacity building for mountains/forests, focusing on geological or geophysical hazards such as earthquakes, landslides, and rockslides. Additionally, the net benefits for structural-blue infrastructure-mangroves restoration and protections for flood mitigation were reported as USD 238-311/ha/yr. Furthermore, Holland reported net benefits between FJ 2.1-4.2 million for non-structural measures, specifically early warning systems for flood mitigation. In summary, the net benefits reported by the Nepal Red Cross and Holland indicate the positive financial outcomes and cost-effectiveness of the implemented interventions in mitigating and preventing various hazards, including floods and geological and geophysical hazards. These net benefits reflect the economic value and returns

on investment associated with these interventions, showcasing their effectiveness in reducing damages and enhancing resilience in the respective regions.

Narrative summary of findings

Appendix G details the main CBA parameters, including primary DRR activities, costs, benefits, and general framing, for the studies reviewed, and Table 8 summarises the maximum BCR values reported. While synthesising eco-DRR's economic evolution is challenging due to heterogeneity, most results support its economic effectiveness. Benefit-cost ratios of 4 and higher are widely documented in these studies. One of the highest BCRs=1,800 was reported for drought risk reduction measures in the Sudan for irrigation supporting communal gardens. It is critical to note that the case studies highlight the importance of contextual factors in shaping the outcome of BCRs and the ability of these strategies to generate high returns. Each study considers the unique circumstances, risks, and costs associated with the specific eco-DRR measures being assessed. It is crucial to carefully consider the local factors and variables that may influence the benefits and costs of implementing such measures. Improvements in understanding different approaches to DRR and the relative role of directly targeted versus systemic approaches to risk management are essential.

Chabba et al. (2022) examined the impact of Boca de Sapo (BdS), an afforestation project in a marginalised peri-urban community near Lima, Peru, on the community exposure risk to rockfall and shallow landslides and curbing further exposure of people and property to risk. The willingness to pay for BdS maintenance averaged \$3.44 ± 0.49 per month. However, risk-based benefit-cost analysis using Monte Carlo simulations indicated that BdS was not viable, considering solely DRR benefits. However, including non-market co-benefits and WTP can significantly impact the economic viability of BdS projects and raise the BCR to 1.70 ± 0.59. The findings of this study emphasise the importance of considering non-market co-benefits and WTP when evaluating the economic viability of afforestation projects, particularly in marginalised peri-urban communities prone to rockfall and shallow landslides.

Meir et al. (2016) include two case studies, one of which concerns risk reduction. This case study focuses on evaluating nine EbA measures (3 x Floodplain & Wetland Development, 3 x Sediment Pool Installation, 3 x Riparian Zone Improvement) and three engineering measures (dredging alternatives) to counteract the water scarcity problem in the Huai Sai Bat Basin, Thailand. Four Scenarios were developed: Scenario 1 ("Engineering"), Scenario 2 ("EbA"), Scenario 3 ("Hybrid") and Scenario 4 ("Business as usual"). Hybrid measures emerge as the most promising alternative for safeguarding water security in the Huai Sai Bat River Basin with NVP (92.849.818), BCR (1,50), and total cost (187.416.645).

Kieyl et al. (2021) assessed the economic impact of peatland restoration in reducing the effects of the six most significant fire events in Indonesia from 2004-2015 and causing a cumulative financial loss of US\$93.9 billion. Overall, peatland restoration could have led to economic savings of US\$8.4 billion from 2004 to 2015. It was estimated that if restoration had been completed earlier, the area burned in 2015 would have been reduced by 6%, resulting in an 18% reduction in CO₂ emissions and a 24% reduction in PM_{2.5} emissions. Overall, peatland restoration could have led to economic savings of US\$8.4 billion from 2004 to 2015.

Baig et al. (2015) included two case studies; the first study focuses on evaluating the economic impact of mangrove replantation and protection in Barangay Silonay, Calapan City. The author examined the financial benefits in the form of damages averted to their houses, livelihood, agriculture/crop, livestock/fodder, and infrastructure. It demonstrates that the protection of existing mangroves is most cost-effective, while additional benefits (estimated to be more than \$170,000 annually) provided by the mangroves significantly outweigh the initial investment. The NPV for mangrove protection was found to be USD 74,150 and a BCR of 1.49. In contrast, mangrove replanting yielded an NPV of USD 69,650 and a BCR of 1.36.

These figures indicate the long-term financial benefits and cost-effectiveness of implementing mangrove protection measures. The second case study measured the total economic value (TEV) of rehabilitation and preservation of the Cagayan de Oro River Basin (CDORB) in Mindanao, Philippines, and utilise these results to provide the rationale behind the adoption of a river basin-wide payment for environmental services (PES) scheme. The economic benefits of river rehabilitation and preservation included damage averted to houses, livestock/fodder, livelihood, and agriculture/crops. They provided substantial financial benefits, ranging from USD 5.1 million to 6.1 million annually.

A case study by Meir et al. (2016) assesses the four EBA measures: flood control with wetland development, constructed wetland, conventional wastewater treatment plant (WWTP) and riparian zone improvement in the Tha Di river basin 145,000 inhabitants with over 60% living in urban areas. The focus is on assessing the impact of these measures on damage reduction, precisely crop and agriculture-related damages. The findings indicate that the costs associated with implementing wetlands for flood control are higher than the corresponding benefits in the short term. However, the benefits exceed the costs in the medium term (10 years), leading to a benefit-cost ratio (BCR) of 1.24. In the long run (25 years), the benefits more than double the costs incurred, resulting in a BCR of 2.32.

Golub et al. (2016) evaluate the benefits and costs associated with mangrove restoration and protection on the economic benefits of damages averted to crops and agriculture. The findings revealed a BCR of 3 when considering all benefits associated.

Haque et al. examine the economic benefits of damages averted in the form of increased agricultural productivity due to reclaimed land and protection against flood for landowners as a result of flood control measures, Meghna Dhonogoda Irrigation Project (MDIP) project in rural Bangladesh. The findings show a negative Net present value of the project -1080 million Taka (US\$ -15.6 million), indicating that the initial investment exceeds future cash flows, and the IRR of 5.32% suggests below-average returns. Therefore, this project is not economically viable.

Another study by Halleguete et al. (2012) evaluates early warning systems to mitigate disaster losses in developing nations. It quantifies economic benefits in the form of asset losses averted and lives saved. The authors reported that upgrading hydro-meteorological information and early warning capacity in all developing countries could yield avoidance of asset losses between 300 million and 2 billion USD per year due to natural disasters; lives saved 23,000 lives annually, valued between 700 million and 3.5 billion USD using the Copenhagen Consensus guidelines and additional economic benefits between 3 and 30 billion USD per year.

Holland et al. (2008) focus on the Navua area in Fiji, which is prone to flooding. The primary goal is to assess the economic value of implementing a flood warning system in mitigating damages such as lives saved, property protection, and reduced financial losses. The findings indicate a high ROI (ranging from 1.1 to 2.2), demonstrating the cost-effectiveness and value of investing in the flood warning system. The net benefits of the flood warning system can be estimated between FJ\$2.1 million and FJ\$4.2 million.

International Federation of Red Cross and Red Crescent Societies (IFRC) in 2011, evaluated the effectiveness of coastal afforestation as a disaster risk reduction strategy in Vietnam in six districts: Dai Hop (Hai Phong province); Thai Do (Thai Binh); Nam Tinh (Thai Binh); Giao An (Nam Dinh) and Dien Bich (Nghê An). The report provides two BCRs. BCR 1, which excludes ecological benefits, amounts to 3 - 68 in the communes studied, and the other BCR 2 incorporates ecological gains; the overall benefit-cost ratio increases significantly between 28 and 104. Coastal afforestation provides direct disaster risk reduction and contributes to environmental restoration.

Karanja et al. (2017) examined the value of mangroves in terms of coastal flood risk reduction estimated using the total economic value framework in Tana Delta in Kenya. The net value of mangroves in the Tana Delta was estimated to be between US\$238/ha/yr and US\$311/ha/yr. The TEVF framework employed by Karanja et al. considers both direct and indirect economic benefits associated with mangroves. These benefits include the protection of coastal ecosystems, fisheries enhancement, tourism opportunities, and the provision of various ecosystem services, highlighting the compelling case for conserving and managing these valuable ecosystems.

Rai et al. (2020) examined the impact of early warning systems on hazard prevention and risk reduction in Nepal's lower Karnali river basin. Overall, the estimated cost-benefit ratio of the flood early warning system makes it highly beneficial and economically sound, with an NPV of NPR 1.80 billion (USD 16.70 million), BCR of 83, and an IRR of 409 per cent.

Despite heterogeneity making it difficult to synthesise the findings, most results supported the cost-effectiveness of eco-DRR. The case studies highlight the importance of contextual factors in shaping the outcome of BCRs. Each study considers the unique circumstances, risks, and costs associated with the specific DRR measures being assessed. It is crucial to carefully consider the local factors and variables that may influence the benefits and costs of implementing such measures.

Conclusions

Implications for policy

The evidence base on the effectiveness and cost-effectiveness of eco-DRR interventions is compartmentalised, which presumably makes evidence-informed policymaking in this area very difficult. Most studies of the effectiveness of implemented actions have evaluated green infrastructure interventions, in particular protected areas, whereas the majority of modelling and cost-effectiveness studies evaluated blue and hybrid infrastructure technologies.

Evaluations of green infrastructure interventions like protected areas have generally shown large effects on increasing natural capital stocks, especially forestry reserves, and in reducing the incidence of fire hazards, although fewer studies have measured the latter. However few economic evaluations have been done of these programmes, so it is not clear whether green infrastructure is also cost-effective. Net present values and internal rates of return provide policymakers with fuller information about the financial costs and benefits of different risk reduction strategies, both for the public purse as well as the costs of implementing these interventions for local communities.

Evaluations of blue infrastructure interventions have tended to support their effectiveness and cost-effectiveness. Economic evaluations generally suggest benefits exceeding costs (that is, benefit-cost ratios > 1), sometimes many times over, such as in the area of flooding, including structural hybrid interventions and capacity building, early warning systems and mangrove restoration. However, there are also important limitations regarding information about distributional effects, non-monetised values, and incomplete modelling of indirect costs and benefits, which are often crucial in disaster-prone areas. Social equity, human health, and environmental impacts, for example, were often not captured in evaluations of eco-DRR interventions. For example, indirect costs such as loss of productivity of fishing during the restoration phase of mangrove rehabilitation were often not accounted for.

From the synthesis of the modelling papers, two broad conclusions can be drawn. First, the interventions which are examined are effective. No model found a null effect of the intervention, and all effects found were desirable. But this is not very surprising as an impact is built into the model structure. The more pertinent questions are: (1) how large an effect?; and (2) is it sufficiently large an impact to be worth the cost? The lack of common outcomes and reporting of the appropriate data in the included studies made it difficult to answer the first question. None of the papers addressed the second question.

Second, the protection provided is found to be less effective against more extreme events. For example, Lin concludes that “the effect of forest conversion on flood volume is increasingly reduced as the rainfall amount increases to more extreme magnitude” (Lin et al., 2017: 1). The most useful of the studies give a very clear policy-relevant finding. These are the finding of the population which could be supported on green spaces for emergency accommodation in Quito, and the required patch width for the Pandanus tree belt to protect from storm surges (4.53 m). The findings regarding the reduction in the risk of hazards are less useful in the absence of a clear statement of the required scale of the intervention and cost analysis.

Implications for research

Evidence on the effectiveness of eco-DRR in L&MICs is not representative across all interventions or Sustainable Development Goal areas. It is crucial to consider carefully the local factors and variables that can influence the benefits and costs of implementation for reducing exposure to, or the consequences of, a particular hazard in a given context. Improvements in understanding different approaches to eco-DRR and the relative role of directly targeted versus systemic approaches to risk management are needed. There is also limited representation from low-income countries.

Studies that consistently evaluate the effectiveness of eco-DRR interventions on disaster exposure, natural capital and human development outcomes are needed. It is important to evaluate effects on both natural capital and human development outcomes like incomes and livelihoods, to evidence possible trade-offs in disaster mitigation efforts which may need to be mitigated through complementary social and economic policies. We also recognise that some types of intervention may be more suited to particular methods (e.g., an evaluation of a sponge-city intervention may be more suited to modelling or small-n impact evaluation), the compartmentalisation of the evidence base suggested greater engagement with both small-n impact evaluation methods to measure the effects of blue infrastructure implemented actions, as well as economic evaluations that examine benefit-cost ratios of green infrastructure.

Future economic evaluations should also be more comprehensive, considering both direct and indirect costs and benefits. In addition, economic evaluations that do not provide sensitivity analyses give decision-makers an insufficient understanding of the uncertainty surrounding the findings. The discount rate plays a significant role in determining the net present value of eco-DRR projects since they accrue gradually over time while costs are often incurred upfront. This can be addressed by focusing on internal rates of return. Most included CBAs used discount rates that were not sufficiently transparent. Therefore, it is essential to consider internal rates of return in future studies to ensure meaningful DRR project evaluation.

We found very limited research on environmental hazards and geological and geophysical hazards, such as landslides and earthquakes, suggesting that these topics require investigation in L&MICs in future primary studies of whatever type (both effectiveness and cost-effectiveness). Understanding the potential economic impacts of these types of hazards on ecosystems and developing effective mitigation strategies is urgently needed.

More studies that evaluate topics relating to equity, such as the effects on the social welfare of vulnerable populations, are needed. Studies of the effectiveness in these areas might usefully draw on established methods of qualitative (small-n) impact evaluation.

References

Included studies

Aguirre, J., Guerrero, E., & Campana, Y. (2021). How effective are protected natural areas when roads are present? An analysis of the Peruvian case. *Environmental Economics and Policy Studies*, 23(4), 831–859.

Andam, K. S., Ferraro, P. J., & Hanauer, M. M. (2013). The effects of protected area systems on ecosystem restoration: a quasi-experimental design to estimate the impact of Costa Rica's protected area system on forest regrowth. *Conservation Letters*, 6(5), 317–323. <https://doi.org/10.1111/conl.12004>

Anderson, C. M., Asner, G. P., Llacayo, W., & Lambin, É. F. (2018). Overlapping land allocations reduce deforestation in Peru. *Land Use Policy*, 79, 174–178. <https://doi.org/10.1016/j.landusepol.2018.08.002>

Ayala-García, J., & Dall'erba, S. (2022). The impact of preemptive investment on natural disasters. *Papers in Regional Science*, 101(5), 1087–1103. <https://doi.org/10.1111/pirs.12700>

Baig, S. M., Rizvi, A. L., Pangilinan, M. J. & Palanca-Tan, R. (2016). Cost and Benefits of Ecosystem-Based Adaptation: The Case of the Philippines. Available at: https://catalogue.unccd.int/756_2016_IUCN.pdf.

Barbedo, J. M. R., Miguez, M. G., Van Der Horst, D., & Marins, M. (2014). Enhancing ecosystem services for flood mitigation: a conservation strategy for peri-urban landscapes? *Ecology and Society*, 19(2). <https://doi.org/10.5751/es-06482-190254>

Bathurst, J. C., Birkinshaw, S., Cisneros, F., Fallas, J. A., Iroumé, A., Iturraspe, R. J., Novillo, M. G., Urciuolo, A. B., Alvarado, A., Coello, C., Huber, A., Miranda, M., Ramírez, M., & Sarandón, R. (2011). Forest impact on floods due to extreme rainfall and snowmelt in four Latin American environments 2: Model analysis. *Journal of Hydrology*, 400(3–4), 292–304. <https://doi.org/10.1016/j.jhydrol.2010.09.001>

BenYishay, A., Heuser, S., Runfola, D. M., & Trichler, R. (2017). Indigenous land rights and deforestation: Evidence from the Brazilian Amazon. *Journal of Environmental Economics and Management*, 86, 29–47. <https://doi.org/10.1016/j.jeem.2017.07.008>

Beresford, A. E., Eshiamwata, G. W., Donald, P. F., Balmford, A., Bertzky, B., Brink, A., Fishpool, L., Mayaux, P., Phalan, B., Simonetti, D., & Buchanan, G. M. (2013). Protection Reduces Loss of Natural Land-Cover at Sites of Conservation Importance across Africa. *PLOS ONE*, 8(5), e65370. <https://doi.org/10.1371/journal.pone.0065370>

- Blackman, A., Pfaff, A., & Robalino, J. (2015). Paper park performance: Mexico's natural protected areas in the 1990s. *Global Environmental Change*, 31, 50–61. <https://doi.org/10.1016/j.gloenvcha.2014.12.004>
- Brenes, C. L. M., Jones, K. W., Schlesinger, P., Robalino, J., & Vierling, L. A. (2018). The impact of protected area governance and management capacity on ecosystem function in Central America. *PLOS ONE*, 13(10), e0205964. <https://doi.org/10.1371/journal.pone.0205964>
- Brum, F. T., Pressey, R. L., Bini, L. M., & Loyola, R. (2019). Forecasting conservation impact to pinpoint spatial priorities in the Brazilian Cerrado. *Biological Conservation*, 240, 108283. <https://doi.org/10.1016/j.biocon.2019.108283>
- Buntaine, M. T., Hamilton, S. E., & Millones, M. (2015). Titling community land to prevent deforestation: An evaluation of a best-case program in Morona-Santiago, Ecuador. *Global Environmental Change*, 33, 32–43. <https://doi.org/10.1016/j.gloenvcha.2015.04.001>
- Burton, C. & Venton, C.C. (2009). Case study of the Philippines National Red Cross: community-based disaster risk management programming, Available at: https://preparecenter.org/wp-content/sites/default/files/pnrc_report_part_3_annexes_final.pdf.
- Carmenta, R., Blackburn, G. A., Davies, G., De Sassi, C., Lima, A., Parry, L., Tych, W., & Barlow, J. (2016). Does the establishment of sustainable use reserves affect fire management in the humid tropics? *PLOS ONE*, 11(2), e0149292. <https://doi.org/10.1371/journal.pone.0149292>
- Castelli, G., Foderi, C., Guzman, B. H., Ossoli, L., Kempff, Y., Bresci, E., & Salbitano, F. (2017). Planting Waterscapes: Green Infrastructures, Landscape and Hydrological Modeling for the Future of Santa Cruz de la Sierra, Bolivia. *Forests*, 8(11), 437. <https://doi.org/10.3390/f8110437>
- Chabba, M., Bhat, M. G., & Sarmiento, J. P. (2022). Risk-based benefit-cost analysis of ecosystem-based disaster risk reduction with considerations of co-benefits, equity, and sustainability. *Ecological Economics*, 198, 107462. <https://doi.org/10.1016/j.ecolecon.2022.107462>
- Cologne & ITTrms E V. (2017). Economic Evaluation of Proposed Ecosystem-based Adaptation Measures in Tha Di and Chi River Basins. : , Available at: https://tuewas-asia.org/wp-content/uploads/2017/10/1-ITT_ECOSWat_EconomicEvaluation_FinalReport_16-02-2016-ECOSWat_Feedback-answered_gm.pdf.
- Cross, N. R. (2008). Cost-benefit analysis of a Nepal Red Cross Society disaster risk reduction programme. Kathmandu, Nepal: Nepal Red Cross.
- Dancer, A. (2013). Do community-conserved areas in Tanzania achieve conservation goals? An initiative-wide study using remote imagery and matching methods

- Dang, K. B., Burkhard, B., Müller, F. & Dang, V. B. (2018). Modelling and mapping natural hazard regulating ecosystem services in Sapa, Lao Cai province, Vietnam. *Journal Article*
- Dang, K. B., Burkhard, B., Müller, F., & Van, D., DO. (2018). Modelling and mapping natural hazard regulating ecosystem services in Sapa, Lao Cai province, Vietnam. *Paddy and Water Environment*, 16(4), 767–781. <https://doi.org/10.1007/s10333-018-0667-6>
- Desbureaux, S., Aubert, S., Brimont, L., Karsenty, A., Lohanivo, A. C., Rakotondrabe, M., Razafindraibe, A. H. & Razafiarijaona, J. (2015). The impact of Protected Areas on Deforestation? An Exploration of the Economic and Political Channels for Madagascar's Rainforests (2001-12). HAL (Le Centre Pour La Communication Scientifique Directe).
- Desbureaux, S., Aubert, S., Brimont, L., Karsenty, A., Lohanivo, A. C., Rakotondrabe, M., Razafindraibe, A. H., & Razafiarijaona, J. (2015). The impact of Protected Areas on Deforestation? An Exploration of the Economic and Political Channels for Madagascar's Rainforests (2001-12). HAL (Le Centre Pour La Communication Scientifique Directe). <https://hal.science/hal-01176860>
- Dewi, S. P. & Kurniati, R. (2022). Revealing Cost and Benefit of Vegetative Approach to Mitigate Riverbank Landslide in Semarang Coastal Villages. *IOP Conference Series: Earth and environmental science*, 1082(1), 012030-012030.
- Dewi, S. P., & Kurniati, R. (2022). Revealing the cost and benefit of a vegetative approach to mitigate riverbank landslide in Semarang coastal villages. *IOP Conference Series: Earth and Environmental Science*, 1082(1), 012030. <https://doi.org/10.1088/1755-1315/1082/1/012030>
- DFID 2013. (2013). The Economics of Early Response and Resilience: Summary of Findings. Available at: https://assets.publishing.service.gov.uk/media/57a08a0bed915d622c000521/61114_Summary_of_Findings_Final_July_22.pdf.
- Djanibekov, U., & Khamzina, A. (2014). Stochastic economic assessment of afforestation on marginal land in irrigated farming system. *Environmental and Resource Economics*, 63(1), 95–117. <https://doi.org/10.1007/s10640-014-9843-3>
- Feng, C., Cao, M., Wang, W., Wang, H., Liu, F., Zhang, L., Du, J., Zhou, Y., Huang, W., & Li, J. (2021). Which management measures lead to better performance of China's protected areas in reducing forest loss? *Science of the Total Environment*, 764, 142895. <https://doi.org/10.1016/j.scitotenv.2020.142895>
- Fleischmann, A. S., Collischonn, W., De Paiva, R. C. D., & Tucci, C. E. M. (2019). Modelling the role of reservoirs versus floodplains on large-scale river hydrodynamics. *Natural Hazards*, 99(2), 1075–1104. <https://doi.org/10.1007/s11069-019-03797-9>
- Gaveau, D. L.A., Curran, L. M., Paoli, G. D., Carlson, K. M., Wells, P., Rimba-Besse, A., Ratnasari, D., Leader-Williams, N. (2012). Examining protected area effectiveness in Sumatra: the importance of regulations governing unprotected lands. *Conservation Letters*, 5(2), 142-148.

Gaveau, D., Curran, L. M., Paoli, G. D., Carlson, K. M., Wells, P. L., Rimba, A. B., Ratnasari, D., & Leader-Williams, N. (2012). Examining protected area effectiveness in Sumatra: the importance of regulations governing unprotected lands. *Conservation Letters*, 5(2), 142–148. <https://doi.org/10.1111/j.1755-263x.2011.00220.x>

Gaveau, D., Kshatriya, M., Sheil, D., Sloan, S., Molidena, E., Wijaya, A., Wich, S. A., Ancrenaz, M., Hansen, M. C., Broich, M., Guariguata, M. R., Pacheco, P., Potapov, P., Turubanova, S., & Meijaard, E. (2013). Reconciling forest conservation and logging in Indonesian Borneo. *PLOS ONE*, 8(8), e69887. <https://doi.org/10.1371/journal.pone.0069887>

Golub, A. & Golub, E. S. (2016). Cost-benefit analysis of adaptation strategy in Bangladesh. Available at: <https://www.researchgate.net/publication/305386811>.

Ha, T. T. P., Van Dijk, J., & Visser, L. (2014). Impacts of changes in mangrove forest management practices on forest accessibility and livelihood: A case study in mangrove-shrimp farming system in Ca Mau Province, Mekong Delta, Vietnam. *Land Use Policy*, 36, 89–101. <https://doi.org/10.1016/j.landusepol.2013.07.002>

Hallegatte, S. (2012). A cost-effective solution to reduce disaster losses in developing countries: Hydro-Meteorological services, early warning, and evacuation. In World Bank policy research working paper. <https://doi.org/10.1596/1813-9450-6058>

Haque, A. K. E., Brander, L., Brouwer, R., Akter, S., & Mahmud, S. (2013). The environmental and social impacts of flood defences in rural Bangladesh. In Cambridge University Press eBooks (pp. 296–314). <https://doi.org/10.1017/cbo9781139225311.018>

Holland 2008. (2008). Fiji Technical Report, an economic analysis of flood warning in Navua, Fiji.

IFRC 2011. (2011). Breaking the waves Impact analysis of coastal afforestation for disaster risk reduction in Viet Nam. Available at: https://preparecenter.org/wp-content/sites/default/files/mangrove_impact_report_final_low_april_2011.pdf.

Jones, K. W., & Lewis, D. J. (2015). Estimating the counterfactual impact of conservation programs on land cover outcomes: the role of matching and panel regression techniques. *PLOS ONE*, 10(10), e0141380. <https://doi.org/10.1371/journal.pone.0141380>

Karanja, J., & Saito, O. (2017). Cost-benefit analysis of mangrove ecosystems in flood risk reduction: a case study of the Tana Delta, Kenya. *Sustainability Science*, 13(2), 503–516. <https://doi.org/10.1007/s11625-017-0427-3>

Kayum, S., Shimatani, Y., & Minagawa, T. (2022). Evaluation of Pandanus Trees as a Means of Eco-DRR against Storm Surge Wave on Saint Martin’s Island, Bangladesh. *Water*, 14(11), 1781. <https://doi.org/10.3390/w14111781>

Khan, F., Mustafa, D. & Kull, D. (2008). Evaluating the costs and benefits of disaster risk reduction under changing climatic conditions: A Pakistan case study. Available at: <https://pure.iiasa.ac.at/id/eprint/8693/>.

Khan, J. U., Durand, F., Bertin, X., Testut, L., Krien, Y., Islam, A. K. M. S., Pezerat, M., & Hossain, S. (2021). Towards an efficient storm surge and inundation forecasting system over

the Bengal delta: chasing the Supercyclone Amphan. *Natural Hazards and Earth System Sciences*, 21(8), 2523–2541. <https://doi.org/10.5194/nhess-21-2523-2021>

Khogali, H. & Zewdu, D. (2009). Impact and Cost Benefit Analysis: A Case Study of Disaster Risk Reduction Programming In Red Sea State, Sudan. Available at: http://www.preventionweb.net/files/globalplatform/entry_bg_paper~sudanredseaimpactandcostbenefitanalysis2009.pdf.

Kiely, L., Spracklen, D. V., Arnold, S., Papargyropoulou, E., Conibear, L., Wiedinmyer, C., Knote, C., & Adrianto, H. A. (2021). Assessing costs of Indonesian fires and the benefits of restoring peatland. *Nature Communications*, 12(1). <https://doi.org/10.1038/s41467-021-27353-x>

Kim, D. H. & Anand A. (2021). Effectiveness of Protected Areas in the Pan-Tropics and International Aid for Conservation. *Geomatics*, 1(3), 335-346.

Kim, D., & Anand, A. (2021). Effectiveness of protected areas in the Pan-Tropics and international aid for conservation. *Geomatics*, 1(3), 335–346. <https://doi.org/10.3390/geomatics1030019>

Kull, D., Singh, P., Chopde, S. & Wajih, S. (2008). Evaluating costs and benefits of flood reduction under changing climatic conditions: the case of the Rohini River Basin, India Available at: <https://pure.iiasa.ac.at/id/eprint/8692/>.

Bayas, J. C. L., Marohn, C., Dercon, G., Dewi, S., Piepho, H., Joshi, L., Van Noordwijk, M., & Cadisch, G. (2011). Influence of coastal vegetation on the 2004 tsunami wave impact in West Aceh. *Proceedings of the National Academy of Sciences of the United States of America*, 108(46), 18612–18617. <https://doi.org/10.1073/pnas.1013516108>

Lin, W., Yang, F., Zhou, L., Xu, J., & Zhang, X. (2017). Using modified Soil Conservation Service curve number method to simulate the role of forest in flood control in the upper reach of the Tingjiang River in China. *Journal of Mountain Science*, 14(1), 1–14. <https://doi.org/10.1007/s11629-016-3945-z>

Walters, B. B. (2004). Local management of mangrove forests in the Philippines: successful conservation or efficient resource exploitation? *Human Ecology*, 32(2), 177–195. <https://doi.org/10.1023/b:huec.0000019762.36361.48>

Maher, J., & Song, X. (2013). Linking Remote Sensing and Economics: Evaluating the effectiveness of protected areas in reducing tropical deforestation. 2013 Annual Meeting, August 4-6, 2013, Washington, D.C. <https://ideas.repec.org/p/ags/aaea13/150562.html>

McNally, C., Uchida, E., & Gold, A. J. (2011). The effect of a protected area on the tradeoffs between short-run and long-run benefits from mangrove ecosystems. *Proceedings of the National Academy of Sciences of the United States of America*, 108(34), 13945–13950. <https://doi.org/10.1073/pnas.1101825108>

Menéndez, P., Losada, I. J., Beck, M. W., Torres-Ortega, S., Espejo, A., Narayan, S., Díaz-Simal, P. & Lange, G. M. (2018). Valuing the protection services of mangroves at national scale: The Philippines. *Ecosystem services* 34, 24-36.

- Menéndez, P., Losada, Í. J., Beck, M. W., Torres-Ortega, S., Espejo, A. G., Narayan, S., Díaz-Simal, P., & Lange, G. (2018). Valuing the protection services of mangroves at national scale: The Philippines. *Ecosystem Services*, 34, 24–36. <https://doi.org/10.1016/j.ecoser.2018.09.005>
- Nelson, A. & Chomitz, K. M. (2011). Effectiveness of strict vs. multiple use protected areas in reducing tropical forest fires: A global analysis using matching methods. *PLoS ONE*, 6(8).
- Nelson, A., & Chomitz, K. M. (2011). Effectiveness of Strict vs. Multiple Use Protected Areas in Reducing Tropical Forest Fires: A Global Analysis Using Matching Methods. *PLOS ONE*, 6(8), e22722. <https://doi.org/10.1371/journal.pone.0022722>
- Nolte, C. (2014). Governance, Management, and Conservation Success of Protected Areas in Brazil and Colombia.
- Nolte, C. (2014). Governance, management, and conservation success of protected areas in Brazil and Colombia. *Deep Blue* (University of Michigan). <https://hdl.handle.net/2027.42/110381>
- Posner, A. & Georgakakos, K. P. (2017). Quantifying the impact of community-scale flood mitigation. *International Journal Of Disaster Risk Reduction*, 24, 189-208.
- Posner, A., & Georgakakos, K. P. (2017). Quantifying the impact of community-scale flood mitigation. *International Journal of Disaster Risk Reduction*, 24, 189–208. <https://doi.org/10.1016/j.ijdr.2017.06.001>
- Rai, R. K., Homberg, M. J. C. V., Ghimire, G. P., & McQuistan, C. (). Cost-benefit analysis of flood early warning system in the Karnali River Basin of Nepal. *International Journal of Disaster Risk Reduction*, 47,
- Sarathchandra, C., Gbadamassi, G. O. D., Ranjitkar, S. & Zhai D L. (2018). Effectiveness of protected areas in preventing rubber expansion and deforestation in Xishuangbanna, Southwest China. *Land Degradation & Development*, 29(8), 2417-2427.
- Sarathchandra, C., Xu, J., & Harrison, R. D. (2018). Effectiveness of protected areas in preventing rubber expansion and deforestation in Xishuangbanna, Southwest China. *Proceedings of the 5th European Congress of Conservation Biology*. <https://doi.org/10.17011/conference/eccb2018/107006>
- Sarker, A. H. M. R, Nobi, M. N., Røskaft, E., Chivers, D. J. & Suza, M. (2020). Value of the Storm-Protection Function of Sundarban Mangroves in Bangladesh. *Journal Of Sustainable Development*, 13(3), 128-128.
- Sarker, A. H. M. R., Nobi, M. N., Røskaft, E., Chivers, D. J., & Suza, M. (2020). Value of the Storm-Protection Function of Sundarban mangroves in Bangladesh. *Journal of Sustainable Development*, 13(3), 128. <https://doi.org/10.5539/jsd.v13n3p128>
- Shah, P. & Baylis, K. (2015). Evaluating Heterogeneous Conservation Effects of Forest Protection in Indonesia. *PLOS ONE*, 10(6), e0124872-e0124872.

Additional references

Akber, M.A., Patwary, M.M., & Islam, M.A. et al. (2018). Storm protection service of the Sundarbans mangrove forest, Bangladesh. *Nat Hazards* 94, 405–418 .
<https://doi.org/10.1007/s11069-018-3395-8>

Arrieta A, Sarmiento JP, Chabba M, & Chen W. (2020). Valuing disaster risk reduction neighborhood interventions in informal settlements of Latin American and the Caribbean. *PLoS One*. Nov 30; 15(11):e0242409. doi: 10.1371/journal.pone.0242409. PMID: 33253246; PMCID: PMC7703912.

Binam, J.N., Place, & FKalinganire, A. et al. (2015) Effects of farmer managed natural regeneration on livelihoods in semi-arid West Africa. *Environ Econ Policy Stud* 17, 543–575.
<https://doi.org/10.1007/s10018-015-0107-4>

Bonn: Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. (2017). *Valuing the Benefits, Costs and Impacts of Ecosystem-based Adaptation Measures: A sourcebook of methods for decision-making*.
http://www.adaptationcommunity.net/wpcontent/uploads/2017/12/EbA-Valuations-Sb_en_online.pdf

Cavallo, Eduardo A. and Noy, Ilan, The Economics of Natural Disasters: A Survey (December 2009). IDB Working Paper No. 35, Available at SSRN: <https://ssrn.com/abstract=1817217> or <http://dx.doi.org/10.2139/ssrn.1817217>

Chabba, M, Mahadev, G. Bhat, & Sarmiento, J. P. (2022). Risk-based benefit-cost analysis of ecosystem-based disaster risk reduction with considerations of co-benefits, equity, and sustainability, *Ecological Economics*, 198, 107462
<https://doi.org/10.1016/j.ecolecon.2022.107462>.

Cohen-Shacham, E., Andrade, A., Dalton, J., Dudley, N., Jones, M., Kumar, C., ... & Walters, G. (2019). Core principles for successfully implementing and upscaling Nature-based Solutions. *Environmental Science & Policy*, 98, 20-29.

Coulibaly, J.Y., Chiputwa, B., Nakelse, T., & Kundhlande, G. (2017). Adoption of agroforestry and the impact on household food security among farmers in Malawi. *Agricultural Systems*, 155, 52-69, <https://doi.org/10.1016/j.agsy.2017.03.017>

CRED. (2022) Disasters in numbers. Brussels: CRED; 2023. This document is available at: https://cred.be/sites/default/files/2022_EMDAT_report.pdf

Cumpston, M. , Li, T. , Page, M. J. , Chandler, J. , Welch, V. A. , Higgins, J. P. , & Thomas, J. (2019). Updated guidance for trusted systematic reviews: A new edition of the Cochrane Handbook for Systematic Reviews of Interventions. *Cochrane Database of Systematic Reviews*, 10(ED000142), 14651858.

Dissanayaka, K.D.C.R., Tanaka, N., & Vinodh, T.L.C. (2022) Integration of Eco-DRR and hybrid defense system on mitigation of natural disasters (Tsunami and Coastal Flooding): a review. *Nat Hazards*. 110, 1–28. <https://doi.org/10.1007/s11069-021-04965-6>

Drummond, M., & Sculpher, M. (2005). Common methodological flaws in economic evaluations. *Medical care*, 115-II14.

Dube, E., & Munsaka, E. (2018). The contribution of indigenous knowledge to disaster risk reduction activities in Zimbabwe: A big call to practitioners. *Jamba*. Mar 26;10(1):493. doi: 10.4102/jamba.v10i1.493. PMID: 29955265; PMCID: PMC6014067.

Ekpeni, N. M., & Ayeni, A. O. (2018). Global Natural Hazard and Disaster Vulnerability Management. In *Handbook of Research on Environmental Policies for Emergency Management and Public Safety* (pp. 83-104). IGI Global.

Emergency Events Database (EM-DAT). CRED International Disaster Database; Universite Catholique de Louvain: Brussels, Belgium

Estrella, M. & Saalismaa, N., (2013). Ecosystem-based DRR: An overview. In: *The Role of Ecosystems in Disaster Risk Reduction*. s.l.:s.n., pp. 26-47.

Estrella, M., & Salisma, N. (2013) Ecosystem-based disaster risk reduction (Eco-DRR): An overview. In. *The role of ecosystems in disaster risk reduction*. UN University Press.

Faivre, N., Fritz, M., Freitas, T., De Boissezon, B., & Vandewoestijne, S. (2017). Nature-Based Solutions in the EU: Innovating with nature to address social, economic and environmental challenges. *Environmental research*, 159, 509-518.

FAO, IFAD, UNICEF, WFP and WHO. 2022. *The State of Food Security and Nutrition in the World 2022. Repurposing food and agricultural policies to make healthy diets more affordable*. Rome, FAO. <https://doi.org/10.4060/cc0639en>

Francesconi, W., Vanegas-Cubillos, M., & Bax, V. (2022). Carbon footprints of forest degradation and deforestation by “Basic-Needs Populations”: A review. *Carbon Footprints*.

Hatje, V., Copertino, M., Patire, V. F., Ovando, X., Ogbuka, J., Johnson, B. J., ... & Creed, J. C. (2023). Vegetated coastal ecosystems in the Southwestern Atlantic Ocean are an unexploited opportunity for climate change mitigation. *Communications Earth & Environment*, 4(1), 160.

The Joanna Briggs Institute Reviewers' Manual 2014: the systematic review of economic evaluation evidence. <https://doi.org/10.46658/JBIMES-20-07>

Kayum, S., Shimatani, Y., & Minagawa, T., (2022). Evaluation of Pandanus Trees as a Means of Eco-DRR against Storm Surge Wave on Saint Martin's Island, Bangladesh. *Water*. 14(11):1781. <https://doi.org/10.3390/w14111781>

Kharb, A., Bhandari, S., Moitinho de Almeida, M., Castro Delgado, R., Arcos González, P., & Tubeuf, S. (2022). Valuing human impact of natural disasters: a review of methods. *International journal of environmental research and public health*, 19(18), 11486.

Knutson, T. R. (2008). Global warming and hurricanes: An overview of current research results. *NOAA Geophysical Fluid Dynamics Laboratory*, 3.

Kossin, J. P., Knapp, K. R., Olander, T. L., & Velden, C. S. (2020). Global increase in major tropical cyclone exceedance probability over the past four decades. *Proceedings of the National Academy of Sciences*, 117(22), 11975-11980

Li L, Liu C, Liu J, & Cheng B, (2021) Has the Sloping Land Conversion Program in China impacted the income and employment of rural households? *Land Use Policy*, 109, 105648, <https://doi.org/10.1016/j.landusepol.2021.105648>

- Mack, E. A., Sauls, L. A., Jokisch, B. D., Nolte, K., Schmook, B., He, Y., ... & Henebry, G. M. (2023). Remittances and land change: A systematic review. *World Development*, 168, 106251.
- Martínez-García, V., Martínez-Paz, & J. M., Alcon, F. (2022) The economic value of flood risk regulation by agroecosystems at semiarid areas. *Agricultural Water Management*, 266, 107565, <https://doi.org/10.1016/j.agwat.2022.107565>.
- McNally, C.G., Uchida, E., & Gold, A.J. (2011). The effect of a protected area on the tradeoffs between short-run and long-run benefits from mangrove ecosystems. *Social Sciences*. 108 (34), 13945-13950 <https://www.pnas.org/doi/10.1073/pnas.1101825108>
- McVittie, A., Cole, L., Wreford, A., Sgobbi, A., & Yordi, B. (2018). Ecosystem-based solutions for disaster risk reduction: Lessons from European applications of ecosystem-based adaptation measures. *International journal of disaster risk reduction*, 32, 42-54.
- Moench, M., & The Sheltering Team. (2014). Sheltering from a gathering storm: Synthesis report. Boulder, CO: ISET-International
- Moos C, Bebi P, Schwarz M, Stoffel M, Sudmeier-Rieux K, Dorren, L. (2018) Ecosystem-based disaster risk reduction in mountains. *Earth-Science Reviews*, 177, 497-513, <https://doi.org/10.1016/j.earscirev.2017.12.011>
- Naumann, G., Alfieri, L., Wyser, K., Mentaschi, L., Betts, R. A., Carrao, H., ... & Feyen, L. (2018). Global changes in drought conditions under different levels of warming. *Geophysical Research Letters*, 45(7), 3285-3296.
- Nehren, U., Thai, H., Marfai, M.A., Raedig, C., Alfonso, S., Sartohadi, H., & Castro, C. (2016). Ecosystem Services of Coastal Dune Systems for Hazard Mitigation: Case Studies from Vietnam, Indonesia, and Chile. *Environmental Science*, DOI:10.1007/978-3-319-43633-3_18
- Ngcamu, B. S., & Chari, F. (2020). Drought influences on food insecurity in Africa: A Systematic literature review. *International Journal of Environmental Research and Public Health*, 17(16), 5897.
- Parry, M.L., Canziani, O., Palutikof, J., Van Der Linden, P. and Hanson, C. (2007) IPCC Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, 976
- Pratiwi, A., & Suzuki, A. (2019). Reducing Agricultural Income Vulnerabilities through Agroforestry Training: Evidence from a Randomised Field Experiment in Indonesia. *Bulletin of Indonesian Economic Studies*, 55(1), 83-116, DOI: 10.1080/00074918.2018.1530726
- Quandt, A. H., Neufeldt, J. T., & McCabe. (2017). The role of agroforestry in building livelihood resilience to floods and drought in semiarid Kenya. *Ecology and Society*, 22(3):10. <https://doi.org/10.5751/ES-09461-220310>
- Quandt, A.H., Neufeldt, J. T., & McCabe (2019). Building livelihood resilience: what role does agroforestry play? *Climate and Development*, 11(6), 485-500, DOI: 10.1080/17565529.2018.1447903
- Rentschler, J., Salhab, M., & Jafino, B. A. (2022). Flood exposure and poverty in 188 countries. *Nature communications*, 13(1), 3527.

Royal Society (2014) Resilience to extreme weather The Royal Society Science Policy Centre report 02/14 Issued: November 2014 DES3400. Available at: <https://royalsociety.org/~media/policy/projects/resilience-climate-change/resilience-full-report.pdf>

Saran, A. & White, H. (2018) Evidence and gap maps: a comparison of different approaches. *Methods Research Paper. Campbell Systematic Reviews* 14 (1), 1-38. <https://doi.org/10.4073/cmdp.2018.2>

School of Public Policy, University of Massachusetts Amherst, MA, USA. Vicarelli, M., Anamaria, G., Kerry, J., Asiel, A., Htike, A., Nelson, J., Mooring, J., Nujhat, P., & Yin, Y. W.. (2022). Ecosystem-based Disaster Risk Reduction and Community Resilience in India: a Cost-Benefit and Equity Analysis.

Scoones, I. (1998). Sustainable Rural Livelihoods: A Framework for analysis..IDS WORKING PAPER 72. Brighton: Institute of Development Studies.

Secretariat of the Convention on Biological Diversity. (2009). Review of the Literature on the Links Between Biodiversity and Climate Change: Impacts, adaptation, and mitigation.

Shreve, C.M., & Kelman, I. (2014). Does mitigation save? Reviewing cost-benefit analyses of disaster risk reduction. *International Journal of Disaster Risk Reduction*, 10(Part A), <https://doi.org/10.1016/j.ijdr.2014.08.004>

Specialist Unit for Review Evidence (SURE) 2015. Questions to assist with the critical appraisal of qualitative studies available at: <http://www.cardiff.ac.uk/specialist-unit-for-review-evidence/resources/critical-appraisalchecklists>

Suckall, N., & Soares, M.B. (2022). Evaluating the benefits of weather and climate services in South Asia: a systematic review. *Reg Environ Change* 22, 104. <https://doi.org/10.1007/s10113-022-01947-7>

Sudmeier-Rieux, K. et al. (2021) Scientific evidence for ecosystem-based disaster risk reduction. *Nature Sustainability*, 4(9), pp. 803-810. [243702.pdf \(gla.ac.uk\)](https://doi.org/10.1038/s41893-021-02437-2)

Sufri, S., Dwirahmadi, F., Phung, D., & Rutherford, S. (2020). A systematic review of community engagement (CE) in disaster early warning systems (EWSs). *Progress in Disaster Science*, 5, 100058

Thi Phung Ha, T., van Dijk, H., & Visser, L. (2014). Impacts of changes in mangrove forest management practices on forest accessibility and livelihood: A case study in mangrove-shrimp farming system in Ca Mau Province, Mekong Delta, Vietnam. *Land Use Policy*, 36, 89-101, <https://doi.org/10.1016/j.landusepol.2013.07.002>

Thorlakson, T., & Neufeldt, H. (2012). Reducing subsistence farmers' vulnerability to climate change: evaluating the potential contributions of agroforestry in western Kenya. *Agric & Food Secur* 1,15. <https://doi.org/10.1186/2048-7010-1-15>

Tricco, A. C., Langlois, E., Straus, S. E., & World Health Organization. (2017). Rapid reviews to strengthen health policy and systems: a practical guide.

UNISDR, U. (2009). Making disaster risk reduction gender-sensitive: Policy and practical guidelines.

United Nations Environment Assembly agrees Nature-based Solutions definition UNEA (2022) Available at: <https://www.naturebasedsolutionsinitiative.org/news/united-nations-environment-assembly-nature-based-solutions-definition/> Accessed

United Nations Office for Disaster Risk Reduction: Geneva, Switzerland. Center, A. D. R. (2015). Sendai framework for disaster risk reduction 2015–2030. <https://www.undrr.org/terminology/hazard#:~:text=Hazards%20may%20be%20single%2C%20sequential,or%20magnitude%2C%20frequency%20and%20probability>

Warner, J.F., van Staveren, M.F., & van Tatenhove, J., Cutting dikes, cutting ties? Reintroducing flood dynamics in coastal polders in Bangladesh and the Netherlands, *International Journal of Disaster Risk Reduction*, 32, 106-112, <https://doi.org/10.1016/j.ijdr.2018.03.020>.

Watson, C. S. (2022). Enhancing disaster risk resilience using greenspace in urbanising Quito, Ecuador, *Natural Hazards and Earth System Sciences*, 22(5), 1699–1721. doi:10.5194/nhess-22-1699-2022.

White, H. (2014). Current challenges in impact evaluation. *The European Journal of Development Research*, 26(1), 18-30.

Winterwerp, J.C., Albers, T., Anthony, E.J., Friess, D.A., Gijón Mancheño, A., & Moseley, K. et al. (2020). Managing erosion of mangrove-mud coasts with permeable dams – lessons learned. *Ecological Engineering*, 158, 106078, <https://doi.org/10.1016/j.ecoleng.2020.106078>.

World Meteorological Association. (2021). WMO atlas of mortality and economic losses from weather, climate and water extremes (1970–2019). Technical Report. On average, there are about 6,800 natural disasters that happen every year worldwide.

World Bank. (2022). *Global Economic Prospects*. Washington, D.C. <https://openknowledge.worldbank.org/handle/10986/36519>

Zhang, Y., Zhao, W., Chen, X., Jun, C., Hao, J., Tang, X., & Zhai, J. (2021) Assessment on the Effectiveness of Urban Stormwater Management. *Water*. 13(1):4. <https://doi.org/10.3390/w13010004>.

Appendix A Benchmark studies used in piloting of search strategy

Akber, M.A., Patwary, M.M., Islam, M.A. et al. (2018). Storm protection service of the Sundarbans mangrove forest, Bangladesh. *Nat Hazards* 94, 405–418. <https://doi.org/10.1007/s11069-018-3395-8>.

Arrieta A, Sarmiento JP, Chabba M, Chen W. Valuing disaster risk reduction neighborhood interventions in informal settlements of Latin American and the Caribbean. *PLoS One*. (2020) Nov 30;15(11):e0242409. doi: 10.1371/journal.pone.0242409. PMID: 33253246; PMCID: PMC7703912.

Binam, J.N., Place, F., Kalinganire, A. et al. (2015). Effects of farmer managed natural regeneration on livelihoods in semi-arid West Africa. *Environ Econ Policy Stud* 17, 543–575. <https://doi.org/10.1007/s10018-015-0107-4>.

Coulibaly, J.Y., Chiputwa, B., Nakelse, T., Kundhlande, G. (2017). Adoption of agroforestry and the impact on household food security among farmers in Malawi, *Agricultural Systems*, 155, 52-69, <https://doi.org/10.1016/j.agry.2017.03.017>.

Dube E, Munsaka E. (2018). The contribution of indigenous knowledge to disaster risk reduction activities in Zimbabwe: A big call to practitioners. *Jamba*. Mar 26;10(1):493. doi: 10.4102/jamba.v10i1.493. PMID: 29955265; PMCID: PMC6014067.

Emerton, L. (2017) Valuing the Benefits, Costs and Impacts of Ecosystem-based Adaptation Measures: A sourcebook of methods for decision-making, Bonn: Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. http://www.adaptationcommunity.net/wpcontent/uploads/2017/12/EbA-Valuations-Sb_en_online.pdf.

Li L, Liu C, Liu J, Cheng B. (2021) Has the Sloping Land Conversion Program in China impacted the income and employment of rural households?, *Land Use Policy*, 109, 105648, <https://doi.org/10.1016/j.landusepol.2021.105648>.

Chabba, M, Mahadev G. Bhat, & Juan Pablo Sarmiento. (2022). Risk-based benefit-cost analysis of ecosystem based disaster risk reduction with considerations of co-benefits, equity, and sustainability, *Ecological Economics*, 198, 107462 <https://doi.org/10.1016/j.ecolecon.2022.107462>.

Dissanayaka, K.D.C.R., Tanaka, N. & Vinodh, T.L.C. Integration of Eco-DRR and hybrid defence system on mitigation of natural disasters (Tsunami and Coastal Flooding): a review. *Nat Hazards* 110, 1–28 (2022). <https://doi.org/10.1007/s11069-021-04965-6>.

Kayum S, Shimatani Y, Minagawa T. (2022) Evaluation of Pandanus Trees as a Means of Eco-DRR against Storm Surge Wave on Saint Martin's Island, Bangladesh. *Water*. 14(11):1781. <https://doi.org/10.3390/w14111781>.

McNally, C.G., Uchida, E., Gold, A.J. (2011) The effect of a protected area on the tradeoffs between short-run and long-run benefits from mangrove ecosystems, *108* (34), 13945-13950 <https://www.pnas.org/doi/10.1073/pnas.1101825108>.

Martínez-García V, Martínez-Paz JM, Alcon F. (2022) The economic value of flood risk regulation by agroecosystems at semiarid areas. *Agricultural Water Management*, 266, 107565, <https://doi.org/10.1016/j.agwat.2022.107565>.

Moench, M., & The Sheltering Team. (2014). Sheltering from a gathering storm: Synthesis report. Boulder, CO: ISET-International

- Moos, C., Bebi, P., Schwarz, M., Stoffel, M., Sudmeier-Rieux, K., Dorren, L. (2018). Ecosystem-based disaster risk reduction in mountains, *Earth-Science Reviews*, 177, 497-513, <https://doi.org/10.1016/j.earscirev.2017.12.011>.
- Nehren, U., Thai, H., Marfai, M.A., Raedig, C., Alfonso, S., Sartohadi, H., Castro, C. (2016). Ecosystem Services of Coastal Dune Systems for Hazard Mitigation: Case Studies from Vietnam, Indonesia, and Chile}, *Environmental Science*, DOI:10.1007/978-3-319-43633-3_18.
- Pratiwi, A., Suzuki, A. (2019). Reducing Agricultural Income Vulnerabilities through Agroforestry Training: Evidence from a Randomised Field Experiment in Indonesia, *Bulletin of Indonesian Economic Studies*, 55(1), 83-116, DOI: 10.1080/00074918.2018.1530726.
- Quandt, A., H. Neufeldt, and J. T. McCabe. 2017. The role of agroforestry in building livelihood resilience to floods and drought in semiarid Kenya. *Ecology and Society* 22(3):10. <https://doi.org/10.5751/ES-09461-220310>.
- Quandt, A., H. Neufeldt & J. T. McCabe (2019) Building livelihood resilience: what role does agroforestry play? *Climate and Development*, 11(6), 485-500, DOI: 10.1080/17565529.2018.1447903.
- Shreve, C.M. Kelman, I. (2014) Does mitigation save? Reviewing cost-benefit analyses of disaster risk reduction, *International Journal of Disaster Risk Reduction*, 10, Part A, <https://doi.org/10.1016/j.ijdrr.2014.08.004>.
- Suckall, N., Soares, M.B. (2022). Evaluating the benefits of weather and climate services in South Asia: a systematic review. *Reg Environ Change* 22, 104. <https://doi.org/10.1007/s10113-022-01947-7>.
- Thorlakson, T., Neufeldt, H. (2012). Reducing subsistence farmers' vulnerability to climate change: evaluating the potential contributions of agroforestry in western Kenya. *Agric & Food Secur* 1, 15. <https://doi.org/10.1186/2048-7010-1-15>.
- Thi Phung Ha, T., van Dijk, H., Visser, L. (2012) Impacts of changes in mangrove forest management practices on forest accessibility and livelihood: A case study in mangrove-shrimp farming system in Ca Mau Province, Mekong Delta, Vietnam, *Land Use Policy*, 36, 2014, 89-101, <https://doi.org/10.1016/j.landusepol.2013.07.002>.
- Vicarelli, Marta, Anamaria Georgescu, Kerry Judge, Asiel Arroyo, Htike Htike Aung, Jennifer Nelson, Jessica Mooring, Nujhat Purnata, Yin Yin Win. (2022). "Ecosystem-based Disaster Risk Reduction and Community Resilience in India: a Cost-Benefit and Equity Analysis". *School of Public Policy, University of Massachusetts Amherst, MA, USA*.
- Warner, J.F., van Staveren, M.F., van Tatenhove, J. (2018). Cutting dikes, cutting ties? Reintroducing flood dynamics in coastal polders in Bangladesh and the Netherlands, *International Journal of Disaster Risk Reduction*, 32, 106-112, <https://doi.org/10.1016/j.ijdrr.2018.03.020>.
- Watson, C. S. (2022) Enhancing disaster risk resilience using greenspace in urbanising Quito, Ecuador, *Natural Hazards and Earth System Sciences*, 22, 5, 1699–1721. doi:10.5194/nhess-22-1699-2022.
- Winterwerp, J.C., Albers, T., Anthony, E.J., Friess, D.A., Gijón Mancheño, A., Moseley, K. et al. (2020) Managing erosion of mangrove-mud coasts with permeable dams – lessons learned. *Ecological Engineering*, 158, 106078, <https://doi.org/10.1016/j.ecoleng.2020.106078>.
- Zhang Y, Zhao W, Chen X, Jun C, Hao J, Tang X, Zhai J. (2021). Assessment on the Effectiveness of Urban Stormwater Management. *Water*. 13(1):4. <https://doi.org/10.3390/w13010004>.

Appendix B Study screening tool

Review Screening Tool

1 Is the study an exact duplicate of a study you have screened before?

If YES then EXCLUDE - Duplicate-Note the study ID of the study that is a duplicate

2 Was the study Published since the year 2000

If NO then EXCLUDE-Publication Year before 2000

3 Is the study published in English?

If NO then EXCLUDE-Non-English

4 Does the study concern a population within a country or countries classified as low- or middle-income

If NO, then EXCLUDE - High Income Country Add a note of the Country Name in question

5 Does the study include an eligible population?

Population affected by Natural Hazards if No, then Exclude

6 Is the study Intervention Eco-system Based Disaster Risk Reduction (Eco-DRR)- Green Infrastructure: landscape/vegetation based elements, such as trees, parks and forests; Blue Infrastructure: water-based elements, such as rivers, canals and ponds; Hybrid Infrastructure (Green/Blue) Combine blue-green infrastructure with grey engineering structures such as permeable pavements and bioswale drainage AND Non-structural measures Knowledge, policies, governance, laws, public awareness raising, training and education for disaster prevention and preparedness e.g. Early Warning Systems, Capacity Building / Governance, Land Use Planning

If NO then EXCLUDE-No Relevant Intervention

7 Is the study described as a systematic review and/or Meta-analysis

If Yes then EXCLUDE -SR for Reference Searching

- 8 Is the study's primary impact identification/estimation strategy any of the following:
- a) Randomized evaluation (includes RCTs, cluster RCTs, natural experiments, randomly assigned studies, randomized field trials or randomized controlled experiments)
 - b) Statistical matching or weighting methods such as Propensity score matching (PSM), Propensity score weighting, and synthetic controls
 - c) Difference-in-differences (DID), or a fixed effects model with a baseline version of the dependent variable included in the analysis (e.g., repeated-measures ANOVA or regression with a time × treatment interaction term).
 - d) Instrumental variable (IV) estimation (or other methods using an instrumental variable such as the Heckman Two-Step approach, endogenous switching regression model (ESRM), or two-stage least-squares (2SLS))
 - e) Regression discontinuity design (RDD) or fuzzy-RDD.
 - f) Interrupted time series (ITS)
 - g) Modeling studies
 - h) Cost-effectiveness studies, Cost analysis
 - i) Small n' impact evaluations, qualitative studies making causal claims using Realist evaluation; General Elimination Methodology (GEM); Process Tracing and Contribution analysis; Most Significant Change (MSC), Success Case Method (SCM) and Outcome Harvesting (OH).
-

If NO then EXCLUDE-Study Design Irrelevant

- 9 Does the study report at least one Natural Capital Outcome I.e. Prevention and mitigation of hazards; Impacts on natural capital (e.g. soil erosion, coastal erosion, tree cover, flooding) Vulnerability to shocks, such as environmental shocks, can be broken down into (i) the likelihood of being exposed to the shock, and (ii) the ability to withstand the shock
-

If NO then EXCLUDE-No Relevant Primary Outcome

- 10 IF YOU HAVE REACHED THIS POINT AND HAVE NOT APPLIED A CODE BY ANY OF THE ABOVE QUESTIONS "INCLUDE".

Appendix C Codebook and variable definitions

Year of Publication	Info (2000 - 2023)
Type of Publication	<ul style="list-style-type: none"> ○ Journal article ○ Published report/ Working Paper ○ Thesis/Dissertation ○ Ongoing (protocol)
Region	
Country/ies where the study was conducted	
Location (Rural, Urban, Peri-Urban, Refugee camp etc.)	<ul style="list-style-type: none"> Rural Urban Peri-Urban Others (Specify) Not Clear
Study Method	<ul style="list-style-type: none"> Large n Small n Modelling studies Cost-effectiveness
Study Design	<ul style="list-style-type: none"> ○ Experimental design (Randomized controlled trial, RCT) ○ Quasi-experimental design (QED) (study with non-random assignment of intervention) ○ Qualitative causal design ○ Modelling Study ○ Economic evaluation (e.g. cost-effectiveness)
Types of Intervention	<ul style="list-style-type: none"> Structural Measures Non-structural Measures
Sub-type of intervention	<ul style="list-style-type: none"> Structural Measures ○ Green ○ Blue

	<ul style="list-style-type: none"> ○ Hybrid Non-structural Measures ○ Capacity Building ○ Land use planning ○ Early Warning System
Name of the Eco-DRR intervention	Name of the Intervention (Specify)
Brief Description of the intervention	
Type of ecosystem	<ul style="list-style-type: none"> ○ Coastal ○ Upland/ mountain ○ Wetland (including mangrove) ○ Forest (excluding mangrove) ○ Other (specify)
Outcomes	Hazard Prevention /Hazard Mitigation Natural Capital Outcome Human Development Outcome Other Outcome (specify)
Funding Source	
Research question(s)	
Country and setting	Please add if the evaluation is conducted in provinces/districts/nationwide/regional
Scale of evaluation	District-level National level Regional level Multi-country
Type of economic evaluation (based on coder assessment NOT as written by authors)	CBA (includes NPV, IIR/ERR, and BCR) CEA CUA Any other
Study perspective (means whose costs and benefits are measured.	Ex-post perspective Macro-Economic Perspective Sectoral perspective

	<p>Societal perspective (all costs and benefits are measured)</p> <p>Fiscal/government (govt income and expenditure)</p> <p>Multi-criteria evaluations</p> <p>Others (specify)</p>
Time horizon (as noted by the author)	Specify
Assumptions (as noted by the author)	Specify
Discount rate	<p>3%</p> <p>6%</p> <p>10%</p> <p>20%</p> <p>Others (specify)</p>
Costing year/base year	specify
Currency/currencies	specify
Population characteristics	Specify where the evaluation was carried out, cohort size
Intervention	Intervention characteristics (name the interventions/projects for example in the study Haque, Meghna Dhonogoda Irrigation Project (MDIP) project
Intervention site	Project site details on geography
Comparator	Details of the control site or in case of baseline scenarios-specify.
Economic evaluation estimates	<p>List all the economic evaluation methods used (SPECIFY)</p> <p>Benefit-cost ratio (BCR)</p> <p>Net Present Value (NPV)</p> <p>Internal Rate of Return (IRR) or Economic rate of return</p> <p>Willingness-to-pay (WTP)</p> <p>Value of Statistical Life (VSL) Analysis</p> <p>Cost-Effectiveness Ratio (CER)</p>
Cost (here you need to list all the costs, ideally as a	(Specify).....

table indicating if it is total cost or cost/item)	Items of cost	In million (specify currency) at (specify discount rate) in (specify year)
	<p>Description of cost (not for coding but for understanding, what needs to be coded in the tables)</p> <p>Costs may be</p> <p>1/ Market prices or shadow prices</p> <p>2/ Average or marginal costs</p> <p>Papers won't necessarily say marginal costs but for example, the Hallegate paper says that most of the requirements for EWS already in place so costs (meaning marginal costs) are low.</p> <p>Direct Costs: Direct costs are expenses that can be directly attributed to a specific project or activity. These costs can be easily identified and allocated to ECO-DRR. Examples of direct costs include:</p> <ol style="list-style-type: none"> 1. Materials: The cost of purchasing the necessary resources for the project, such as construction materials, equipment, and tools. 2. Labor: The salaries and wages paid to employees directly involved in the project, such as construction workers or engineers. 3. Equipment Rental: The cost of renting equipment required for the project, such as bulldozers or cranes. 4. Services: The fees paid to consultants or contractors who perform specific tasks or deliver specialized services for the project. <p>Indirect Costs</p> <p>Indirect costs are expenses that cannot be directly attributed to a specific project or activity but are still necessary for the project's operation. These costs are typically allocated based on a predetermined allocation method. Examples of indirect costs include:</p> <ol style="list-style-type: none"> 1. Overhead: The cost of general and administrative activities, such as utilities, insurance, office rent, and office supplies. 	

	<p>2. Maintenance: The cost of maintaining and repairing equipment and facilities that are used by multiple projects or departments.</p> <p>3. Marketing and Promotion: The cost of promoting the project or raising awareness about its potential benefits.</p> <p>4. Research and Development: The cost of conducting research or testing to improve the project's effectiveness or efficiency.</p> <p>Intangible Costs</p> <p>Intangible costs refer to the non-monetary values that are sacrificed when making a decision. These costs are often subjective and difficult to quantify in monetary terms. Examples of intangible costs in ECO-DRR (Economic Crisis and Disaster Risk Reduction) cost-benefit analysis include:</p> <ol style="list-style-type: none"> 1. Social Costs: Social costs refer to the negative externalities or negative impacts on society that arise from the implementation of a particular project or policy. These costs can include loss of biodiversity, pollution, disruption to traditional livelihoods, and displacement of communities. 2. Cultural Costs: Cultural costs refer to the negative impacts on cultural heritage, traditions, and identity due to development projects or policy changes. These costs can include the loss of historical landmarks, erosion of indigenous cultures, and damage to intangible cultural heritage. 3. Environmental Costs: Environmental costs refer to the negative impacts on the natural environment caused by human activities. These costs can include loss of biodiversity, habitat destruction, water pollution, and greenhouse gas emissions. 4. Health Costs: Health costs refer to the negative impacts on human health due to development projects or policy changes. These costs can include increased exposure to pollutants, exposure to infectious diseases, and heightened stress levels. <p>Opportunity Costs (This is an approach to measuring costs not a separate cost category. The opportunity cost of capital is one reason we discount. The opportunity cost of labour is captured by using the shadow wage rate, not the market wage rate etc.)</p> <p>Opportunity costs refer to the benefits that could have been gained by choosing an alternative course of action. In ECO-</p>
--	--

	<p>DRR cost-benefit analysis, opportunity costs are often associated with the alternative investments or projects that may have been pursued in the absence of the chosen project. Examples of opportunity costs in ECO-DRR cost-benefit analysis include:</p> <ol style="list-style-type: none"> 1. Investment Opportunities: Opportunity costs can include the potential benefits that could have been gained by investing in alternative sectors or projects. These opportunities can include job creation, economic growth, and technological advancements. 2. Resource Allocation: Opportunity costs can include the potential benefits that could have been achieved by allocating resources to alternative projects or initiatives. These resources can include financial resources, human resources, and infrastructure. 3. Risk Management: Opportunity costs can include the potential benefits that could have been achieved by managing risks differently. These risks can include natural disasters, economic crises, and geopolitical instability. 4. Social Development: Opportunity costs can include the potential benefits that could have been achieved through social development initiatives. These initiatives can include education, health programs, and social support services.
<p>Benefits or unit of effectiveness (indicate briefly how each benefit is evaluated)</p>	<p>Specify (with cost elements)</p> <p>List all the benefits as a result of the ECO-DRR interventions.</p> <p>Damage averted</p> <ul style="list-style-type: none"> • Housing benefits • Assets • Agriculture/crop • Livestock/fodder • Infrastructure • Livelihood/wages <p>Health and Safety</p> <ul style="list-style-type: none"> • Health • Lives saved <p>Productivity gains</p>

	<ul style="list-style-type: none"> • Investment in more productive technologies <p>Risk reduction</p> <ul style="list-style-type: none"> • Hazard probability • Vulnerability assessments • Damage assessments • Exposure assessments • Benefits of risk reduction
Results	Based on NPV, BCR, IRR
Author's conclusion	
Measures of uncertainty	
Sensitivity analysis	Specify results/tables (give ranges)

Appendix D Assessment tools

Evaluations using statistical designs

<i>Item</i>	<i>Description</i>	<i>Key</i>	<i>Notes</i>
Intervention	Is the intervention named and described, including all relevant components?	High: full and clear description, so that the main components and how they are delivered are clear Medium: Partial description Low: Little or no description	
Evaluation questions	Are the evaluation questions clearly stated?	High: full and clear description, so that the main components and how they are delivered are clear Medium: Partial description Low: Little or no description	
Study design	Use the study design coding	High: A randomised study Medium: Non-randomised study (quasi-experiment) Low: single time-point before versus after	
Outcomes	Are the outcomes clearly defined? Where appropriate do they use an existing, validated measurement tool?	High: full and clear definition using validated instruments where available (a researcher wishing to use these outcomes would have sufficient information to do so) Medium: Partial definition. May use validated instruments but without sufficient references to the source. Low: Little or no definition	

Sample size (power calculation)	Do the authors report a power calculation as the basis for sample size?	<p>High: Power calculation report and sample size meet the necessary sample size</p> <p>Medium: Power calculation mentioned and sample size meets the necessary sample size</p> <p>Low: No mention of power calculation.</p>
Attrition	<p>Reported for endline and longest follow-up.</p> <p>Calculate overall attrition and differential attrition (see example below). It is often necessary to calculate from the table of results. If sample size varies by outcome calculate for highest attrition.</p>	<p>High: total attrition <20% and differential attrition <10 percentage points</p> <p>Medium: total attrition >20% or differential attrition >10 percentage points</p> <p>Low: total attrition >20% and differential attrition >10 percentage points</p>
Overall (including questions for all studies)	The overall score uses the weakest link in the chain principle i.e., is the lowest score on any item	<p>High: High on all items</p> <p>Medium: No lower than medium on any item</p> <p>Low: At least one low</p>

Economic evaluations

Was a well-defined question posed in an answerable form? Consider: • Is it clear what the authors were trying to do?	Yes/Can't tell/ No
Was a comprehensive description of the competing alternatives given (i.e. can you tell who did what to whom, where and how often)?	Yes/Can't tell/ No
Was there evidence that the programme's effectiveness had been established? Consider: Was the study attached to the economic evaluation of an RCT? How valid was the study design used? (N.B. You may want to appraise it using an appropriate checklist).	Yes/Can't tell/ No
Were all the important and relevant outcomes and costs for each alternative identified? Consider: • What perspective(s) was/were taken, e.g. health service, patient, society.	Yes/Can't tell/ No
Were outcomes and costs measured accurately in appropriate units (e.g. hours of nursing time, number of physician visits, years of life gained) before evaluation?	Yes/Can't tell/ No
Were the outcomes and costs valued credibly? Consider: • Were opportunity costs considered	Yes/Can't tell/ No
Were outcomes and costs adjusted for different times at which they occurred (discounting)?	Yes/Can't tell/ No
Was an incremental analysis of the outcomes and costs of alternatives performed?	Yes/Can't tell/ No
Was a sensitivity analysis performed? Consider: • Were all the main areas of uncertainty considered?	Yes/Can't tell/ No
Did the presentation and discussion of the results include all, or enough, of the issues that are of concern to purchasers?	Yes/Can't tell/ No
Were the conclusions of the evaluation justified by the evidence presented?	Yes/Can't tell/ No
Overall	Yes/Can't tell/ No

Modelling Studies

Is the model clearly stated?	Yes/ No/ Partly
Are all assumptions specified?	Yes/ No/ Partly
Is the model appropriate to answer the research questions?	Yes/ No/ Partly
Are the model coefficients based on (calibrated against) data rather than assumed?	Yes/ No/ Partly
Are the data used for calibration from the area in which the intervention takes place?	Yes/ No/ Partly
Is the model dynamic?	Yes/ No/ Partly
Was the model tested against data from the project area which were not used in model calibration?	Yes/ No/ Partly
The model should be calibrated against a subset of the available data and then the model performance, ie predicted values of endogenous variables, assessed against actual data using the remainder of the data not used for calibration	
Are the results reported?	Yes/ No/ Partly
Is a sensitivity analysis presented?	Yes/ No/ Partly
Do any recommendations for policy and practice clearly follow from the model results?	Yes/ No/ Partly
Overall assessments. Critical items to me are 1, 3, 4, 5, 8 and, 9	Yes/ No/ Partly

Appendix E Table of included studies

<i>Study Name</i>	<i>Region</i>	<i>Population and location</i>	<i>Intervention</i>	<i>Type of hazard</i>	<i>Study design</i>	<i>Outcome domain</i>	<i>Confidence assessment</i>
Aguirre (2021)	Latin America & Caribbean	The paper is about the protected areas and their proximity to the roads in PERU. 225 protected areas, comprising approximately 22.93 million hectares	Non- Structural Measures Land Use Planning Establishing protected natural areas (PNA)	Environmental Hazards- Deforestation	Large n: non-randomized assignment (QEDs and BA Designs) Difference in difference	Hazards Prevention The deployment of greater protection of areas has reduced deforestation by around 6.5 km ² per 400 km ² .	Low Due to no mention of Power Calculation
Andam (2013)	Latin America & Caribbean	The author randomly selected 15,813 parcels to comprise the sample for analysis, of which 1,219 were protected before 1997 in Costa Rica	Land Use Planning Establishment of a protected area	Environmental Hazards- Deforestation	Non- randomized assignment (QEDs) Matching protected areas and unprotected areas	Natural Capital Outcome Increased the amount of re-growth Increased the amount of regrowth observed between 1960 and 1997 beyond that which would have otherwise occurred and prevented erosion.	Medium
Anderson (2018)	Latin America & Caribbean	Peru The study area is the lowland Peruvian Amazon.	Non- Structural Measures – Land Use Planning	Environmental Hazards- Deforestation	Propensity score matched difference-in-	Hazard Mitigation Decreases in deforestation range from 0.2%	Low The study reported low due

		<p>The area is deforestation at a 1-ha resolution derived by the Peruvian Ministry of Environment using remotely sensed Landsat data, and 2) land use concession polygon data from the Government of Peru. The two are used together to assess deforestation in overlapping land use allocations.</p>	<p>(Overlapping Land Use allocations)</p> <p>Comparison- non-overlapping land use allocations</p> <p>Overlapping land allocations are cases in which the same parcel of land is allocated to more than one use, such as logging concessions overlapping with oil concessions, Indigenous territories overlapping with logging concessions, or non-timber forest product concessions overlapping with protected areas. Cases of overlapping allocations in Peru are primarily assumed to be unintentional; different government bodies allocated the same land for different uses, likely due to a lack of coordination. Traditionally,</p>		<p>differences methods</p>	<p>to 6% in overlapping allocations as compared to non-overlapping allocations. The difference we found in deforestation between overlapping and non-overlapping land use allocations is comparable to other studies that evaluated the effectiveness of a single land use allocation using similar matching methods.</p> <p>The results mentioned that deforestation is consistently lower in overlapping land use allocations as compared to non-overlapping land use allocations, regardless of the type of allocation</p>	<p>to power calculation.</p>
--	--	---	--	--	----------------------------	---	------------------------------

			<p>conservation is predicated on allocating land exclusively for conservation – e.g., in Peru, protected areas, wildlife management, and complementary protected areas. In addition to these demarcated allocations, conservation goals may be met in lands that are allocated for other uses, such as logging, non-timber forest products, indigenous areas, oil concessions, or buffer zones. 72% of the Peruvian Amazon is allocated. Of all allocated lands that are forested, 25% is comprised of overlapping allocations, so it is important to examine the relationship between these land uses and conservation</p>				
--	--	--	---	--	--	--	--

			outcomes such as forest cover				
Ayala-Garcia (2022)	Latin America & Caribbean	A panel of 746 Colombian municipalities with a medium and high risk of landslides	<p>Non- structural measures</p> <p>Capacity Building</p> <p>Land Use Planning</p> <p>Early Warning System</p> <p>The preemptive investment covers the following groups of expenditures: (i) information systems to monitor weather conditions; (ii) building resilient infrastructure to protect human settlements and public and private infrastructure; (iii) relocating population living in risk-prone areas to safer locations; and (iv) educational programs about natural disaster risk.</p>	Geological or geophysical hazards Landslides	Quasi-Experimental Instrument Variable	<p>Hazard Mitigation</p> <p>Human Development Outcome</p> <p>Findings indicate that one more unit of preemptive investment (COP\$ 1,000 per capita) reduces the future occurrence of landslides by 2%, the number of people affected by 5.1%, and the number of dead, injured and disappeared by 1%</p>	<p>Low</p> <p>Due to no power calculation</p>
BenYishay (2017)	Latin America & Caribbean	196 communities in Brazil	<p>Non- Structural Measures- Land Use Indigenous Lands Project (PPTAL)</p> <p>Brazil Indigenous Lands Project</p>	Environmental Hazards Deforestation	propensity score matching and community-level fixed effects	Natural Capital Outcome – Forest Cover - effects that are 0.8% of the sample mean forest cover	Medium

			(PPTAL), which formalized the land rights of 106 Indigenous communities covering more than 38 million hectares of largely forested area between 1995 and 2008			Normalized Difference Vegetation Index (NDVI)	
Beresford (2013)	Sub Saharan Africa	45 protected n Important Bird Areas (IBAs) to those from 48 unprotected IBAs in sub-Saharan Africa and Madagascar (from BirdLife International's World Bird Database [WBDB])	Non- structural intervention – Land Use Protected Areas Protected areas (PAs) In 2010, the Parties of the Convention on Biological Diversity (CBD) agreed to increase the total coverage of land in PAs from current levels of c. 13% to 17% by 2020	Environmental Hazards Deforestation	Matching	Hazard Mitigation Land Cover Changes The findings suggested that rates of loss of natural land cover were 58% lower inside protected IBAs than inside unprotected IBAs.	Low
Blackman (2015)	Latin America and the Caribbean	56 NPAs comprising more than 6.5 million hectares had been created. The final sample comprises 137,632 plots, 5574 of which are	Mexico's natural protected areas (NPAs) 56 NPAs comprising more than 6.5 million hectares had been created, but the creation and	Environmental Hazards Deforestation	Matching And propensity score matching	Hazard Prevention and Mitigation The paper finds out that from the matching analysis of all samples that on average, pre1993 NPAs cut	Low

		inside pre-1993 NPAs and 132,058 of which are outside all NPAs.	administration of NPAs were not coordinated at the national level. Mexico's 1988 comprehensive environmental law provided the legal underpinnings for the National System of Natural Protected Areas (Sistema Nacional de Areas Protegidas, SINAP), administered by the Ministry of the Environment.			deforestation by 43–51 per cent. NPAs reduced deforestation inside their borders by 56–72 per cent and reduced it by 23–29 per cent outside	
Brenes (2018)	Latin America and the Caribbean	Trifinio Region of Central America; tri-national region (southern Guatemala (45%), western Honduras (40%), and northern El Salvador (15%). The population in the region was nearly 900,000 people in 2011. The study focuses on 12 state-managed forest PAs that were	Sixteen Protected Areas have been created in Trifinio, including a transboundary PA aimed at safeguarding water resources for nearly three million people living downstream. The study focuses on 12 PAs.	Environmental Hazards Deforestation	Propensity score matching	Natural Capital Outcome Normalized Difference Vegetation Index (NDVI)- The positive annual changes in NDVI ranging between 0.2–0.4 in all sub-groups. High decentralized PAs maintain greenness with mean NDVI values between 1–3	Low Not reported power calculation.

		established in 1987—five PAs are in Guatemala, six in Honduras, and one in El Salvador.				points higher than outside PAs; their impact on enhancing NDVI ranges between 2–8%-points. More centralized PAs experience changes in greenness around 5%-points, and have mean NDVI values that are 2%-points higher than unprotected areas	
Brum (2019)	Latin America and the Caribbean	The sample included 71 PAs (27 of SP and 44 of SU) and 29 ILs in Cerrado, Brazil	Impact of a conservation intervention (Protected Areas) In Brazil, PAs are governed by the Sistema Nacional de Unidade de Conservação (SNUC, MMA, 2003), which classifies the PAs into two different management regimes: strictly protected areas (SPs) and sustainable use areas (SUs). Besides	Environmental Hazards Deforestation	Difference n Difference	Natural Capital 66% had a positive projected impact in avoiding native vegetation loss (21 SPs, 24 SUs, 21 ILs)	Low

			<p>PAs, Indigenous lands (ILs) also have been regarded as important for biodiversity conservation in Brazil</p> <p>The Brazilian government has programs to slow down vegetation loss in the Cerrado, such as the Action Plan for Prevention and Control of Deforestation and Fire in the Cerrado (PPCerrado, MMA, 2014), but the main strategy for Cerrado conservation is still the establishment of PAs.</p>				
Buntaine (2015)	Latin America and the Caribbean	41 Community	<p>Programa de Sostenibilidad y Unio[´]n Regional Sur (PSUR program)- support the conservation and Kutuku[´] Protected Forest area, as well as strengthen Indigenous land rights.</p>	Environmental Hazards Deforestation	Difference in Difference	Hazard Prevention: The estimates of the treatment effect indicates reduced deforestation,	Low

Carmenta (2016)	Latin America and the Caribbean		Sustainable use reserves (SURs)	Forest Fires Deforestation	Interrupted time series (including C-ITS)	Hazard Prevention: Sustainable use reserves (SURs) protect Amazonian forests from wildfires And deforestation	Low
Dancer (2013)	Sub-Saharan Africa		Community Conserved areas	Deforestation		Enhanced Vegetation Index values were highest for WMAs in Coastal Forest Mosaic in comparison to all unprotected areas	Medium
Desbureaux (2015)	Sub-Saharan Africa	24 historic PAs and 31 NPAs impacting 109 and 126 municipalities	Protected Areas (PAs)	Deforestation	Matching	Deforestation is only 0.2% lower than in unprotected forests in the majority of our Estimates. .	Low
Feng (2021)	East Asia & Pacific	227 PAs mainly protecting forest ecosystems in China	Protected Areas (PAs)	Deforestation	Matching (PSM)	118 PAs (52.68%) had positive effects in reducing deforestation (E>0, P< 0.05) compared with	Medium

						their matched control sites. Thirty-seven PAs (16.52%) had negative effects ($E < 0$, $P < 0.05$), and 69 PAs (30.80%) had nonsignificant effects ($P > 0.05$)	
Gaveau (2012)	East Asia & Pacific		Protected area in Sumatra	Deforestation	PSM	Logging concessions have been a relatively effective means of maintaining forest cover	Low
Gaveau (2013)	East Asia & Pacific		Forest Conservation	Deforestation	PSM	Natural forest timber concessions and protected areas have slowed forest cover loss in Kalimantan.	Low
Ha (2014)	East Asia & Pacific	four communities of Ca Mau and Bac Lieu provinces	Forrest allocation/certificates	Deforestation		Natural Capital and Human Development Outcome-mangroves sustained; Access to mangrove and forest benefits, Balance of forestry and shrimp income. Access to	Low

						mangrove-shrimp aquaculture and benefits	
Jones (2015)	Europe & Central Asia And Latin America & Caribbean	In Ecuador, the study region is about 600 sq km around the northwestern border of Cuyabeno Faunal Wildlife Reserve, a protected area in the northeastern Ecuadorian Amazon. In Russia, Protected areas	Payments for ecosystem services (PES)- Ecuador- PES.Ecuador implemented a national PES program, known as Socio Bosque. The program targets forested lands that include a combination of multiple ecosystem service benefits, risk of deforestation, and populations with high degrees of social marginality. 63 households enrolled in the program in 2010. Russia-Protected Areas. In Russia, our analysis focuses on the effect of four 'strict' protected areas—known as zapovedniks in Russia	Deforestation	Matching and Panel Regression	Four-tenths of a percentage point reduction in the average annual deforestation rate between 2011 and 2013 for parcels that enrolled in PES compared to parcels that did not enrol	Medium
Kim (2021)	Global	Targets. Thirty-four tropical countries received	Convention on Biological Diversity (CBD)	Deforestation		Deforestation is avoided by protected forests,	Low

		total international aid for biodiversity conservation of				and forest loss is avoided.	
Maher (2013)	Latin America & Caribbean	Protected Areas (PAs), which currently cover 54% of forested areas in the Brazilian Amazon	Reduce emissions from deforestation and forest degradation and enhance forest carbon stocks (REDD+) REDD+ have spurred governments in tropical regions to establish vast networks of Protected Areas (PAs), which currently cover 54% of forested areas in the Brazilian Amazon	Deforestation		Progress in land use and land cover change	Low
McNally (2011)	Sub Saharan Africa		Saadani National Park (SANAPA) in Tanzania mangrove protection effort undertaken to preserve biodiversity in Saadani National Park (SANAPA) in Tanzania	Deforestation		mangrove protection mangrove cover page 3 The expansion of mangrove protection through the creation of SANAPA and enhanced enforcement led to markedly different future for the mangrove forest species and the biodiversity within	Low

						change in income and use of mangroves as fuel	
Nelson (2011)	Global		Conservation and sustainable management of forests have been motivated by biodiversity and livelihood concerns for decades.	Forest Fires	Matching	The conclusion that protected areas are effective at reducing fire incidence in forests is seen to be robust. Forest Protection	Low
Nolte (2014)	Latin America & Caribbean	Convention on Biological Diversity (CBD)	Protected Areas in Brazil and Colombia	Deforestation		Our outcome of interest is the occurrence of forest fires during the period 2000-2010 as a proxy for deforestation, the major driver of land-cover change and carbon emissions in the Amazon Basin	Low
Sarathchandra (2018)	East Asia & Pacific	Protected Areas Xishuangbanna, harbours, China	Protected areas (PAs)	Deforestation	Matching	protected area - reduced deforestation	Low
Shah (2015)	East Asia & Pacific	The paper is about the effectiveness of seven new national parks that were established in Indonesia after 1999 comprising	Structural Measures Land Use Planning (Protected Areas)	Environmental Hazards-Deforestation	Large n: non-randomized assignment (QEDs and BA Designs) Difference in difference	Natural Capital Forest Cover: The median marginal effect of treatment at the national level is a 1.1% increase in forest cover within the	Low Due to no mention of Power Calculation

		an area of 23,275 square kilometers.				protected area boundary	
Tabor (2017)	Sub-Saharan Africa	The study area used the boundaries of the CAZ REDD+ project area. The study area overlapped with 88 fokontany, 25 communes, 5 districts, and 2 regions, Madagascar	Structural Measures- Forest restoration and land use planning Non- structural Measures- Capacity Building Forest Conservation and REDD+ projects	Environmental Hazards- Deforestation Forest Fires	Non- randomized assignment (QEDs) Regression	Hazards Prevention and mitigation Reduce the deforestation and incidence of Forest fires. In 2010, investments on average were associated with a 27% reduction in percent deforestation (p-value<0.10). The data represented a 14–18% decrease in fire detections due to the presence of an investment	Low
Tersitsch (2017)	Latin America & Caribbean	Brazil- Forest conservation policy	Structural Measures- Green Infrastructure – Forest restoration and land use planning	Environmental Hazards- Deforestation	Large n: non-randomized assignment (QEDs and BA Designs) Difference in difference	Hazards Prevention and Mitigation reduce deforestation and forest fires. Natural Capital- Forest Covers	Medium
West (2022)	Latin America & Caribbean	Brazil, Protected Areas	Protected areas (PAs) In Brazilian	Deforestation	Matching	Prevention and Mitigation	Low

			PAs are managed based on the National System of Protected Areas (SNUC; Portuguese acronym; Federal Law no. 9985 of 2000.)			average annual forest loss from our PA sample was 0.07	
--	--	--	---	--	--	--	--

<i>Study Name</i>	<i>Country</i>	<i>Population/ Location</i>	<i>Intervention</i>	<i>Type of Hazards</i>	<i>Study Design</i>	<i>Outcome Domain</i>	<i>Confidence Rating</i>
Baig (2015)a	Philippines		Structural measures-Blue Infrastructure-Mangrove replanting and protection	Hydrometeorological hazards-Tropical cyclones & flooding	CBA	1. Damages averted: Least cost, BCR, NPV, Avoided damages, annualised NPV and TEV	Medium
Baig (2015)b	Philippines		Structural measures and non-structural measures Infrastructure-Wetland restoration & Capacity building	Hydrometeorological hazards-Tropical cyclones & flooding	CBA	1. Damages averted 2. Health and safety 3. Productivity gains unit of measurement is TEV & WTP	Medium
Chabba (2022)	Peru-231 households in peri-urban Lima municipality	Boca de Sapo (BdS) is a ~14-hactere urban forest on the mountainside above the burgeoning El Volante (the park covers about has more than 3500 trees and plants.)	Structural measure-Green infrastructure-Forest restoration and Green space	Geological or geophysical-Earthquake, landslide and rockslide	CBA	Risk Reduction: Hazard probability and vulnerability: BCR, NPV and WTP	Medium
Meier (2016)a	Thailand-Huai Sai Bat, a sub-basin of the Chi River Basin;	Thailand-Huai Sai Bat, a sub-basin of the Chi River Basin; approx. 65.000 people living in the Huai Sai Bat Basin.	Three Eco-DRR measures: Structural measures-(1)Green infrastructure-Trees & (2)Hybrid infrastructure-sustainable drainage & (3) Blue infrastructure-Wetland restoration: Maintenance of a	Hydrometeorological hazards -Drought & Environmental hazard-soil degradation	CBA	1. Damages averted and 2. Risk reduction 2. NPV, ANPV and BCR	

<i>Study Name</i>	<i>Country</i>	<i>Population/ Location</i>	<i>Intervention</i>	<i>Type of Hazards</i>	<i>Study Design</i>	<i>Outcome Domain</i>	<i>Confidence Rating</i>
			permanent water surface by the design of ponds, oxbows, etc.,				
Meier (2016)b	Thailand: The Tha Di river basin:	Thailand: The Tha Di river basin: 145,000 inhabitants with over 60% living in urban areas.	Structural measure: Blue infrastructure-wetland restoration Four EBA measures: 1) flood control with wetland development 2) constructed wetland 3) conventional wastewater treatment plant (WWTP). 4) riparian zone improvement,	Hydrometeorological hazards-Floods & droughts	CBA	1. Damages averted: NPV, ANPV, BCR	
Golub (2016)	Bangladesh	Kulhna district-6.40 million people	Structural measure-Blue infrastructure-Mangrove restoration and protection	Hydrometeorological hazard: Flood	CBA	1. Damages averted (infrastructure and crops) & 2. Risk reduction (hazard probability): BCR and total benefits	Medium
Hague (2013)	Bangladesh	The Matlab North thana is about 120 km south of Dhaka with a population of nearly 299 000 (2001 census data) Cohort size: a total of 589 households from the project area and 672 households from Homna and Matlab South	Hybrid infrastructure>sustainable drainage> Meghna Dhonogoda Irrigation Project (MDIP) project. The project consists of 64 km of embankment, 282 km of canal system for irrigation, and 125 km of drainage canals.	Hydrometeorological hazard: Flood	CBA	1. Damages averted: Agriculture/crop, Livestock/fodder, Infrastructure, Livelihood/wages 2. Health and safety: Lives saved and health-Net benefits and NPV	Medium

<i>Study Name</i>	<i>Country</i>	<i>Population/ Location</i>	<i>Intervention</i>	<i>Type of Hazards</i>	<i>Study Design</i>	<i>Outcome Domain</i>	<i>Confidence Rating</i>
Hallegatte (2012)	Multicountry		Non-structural Intervention> Early warning systems Includes 1) local observation systems; (2) local forecast capacity; (3) increased capacity to interpret forecasts and translate them into warnings; (4) communication tools to distribute and disseminate information	Hydrometeorological hazard: Flood	CBA	1. Damages averted: infrastructure & health and safety: lives saved: Net benefits	Low
Holland (2008)	Fiji-Navua town.	The total population living across the two provinces that Navua serves was over 21,000. drainage area covers 1070 km ² with the river extending 91 km. The sample size for the economic survey: 293	Non-structural measure- Early warning system include flood forecasting based on rainfall and river level monitoring; and dissemination of flood alerts and warnings to emergency agencies and the general public	Hydrometeorological hazard: Flood	CBA	1. Damages averted:(livelihood, infrastructure) & health and safety (lives saved): 1. Net benefits, 2. NPV 3. Return on investments	Medium
IFRC (2011)	Vietnam	Vietnam; - Dai Hop (Hai Phong province); Thai Do (Thai Binh); Nam Tinh (Thai Binh); Giao An (Nam Dinh) and Dien Bich (Nghe An)	Structural- Blue Infrastructure – Mangrove Reforestation Community-based Mangrove Reforestation and Disaster Preparedness Programme, implemented by Viet Nam Red Cross between 1994 and 2010.	Hydrometeorological hazard: Flood and cyclones	CBA	1. Damages averted 2. Risk reduction 3. Health and safety (lives saved): BCR 1 only includes protective and direct economic benefits, as these represent the real benefit that will materialize over	Medium

<i>Study Name</i>	<i>Country</i>	<i>Population/ Location</i>	<i>Intervention</i>	<i>Type of Hazards</i>	<i>Study Design</i>	<i>Outcome Domain</i>	<i>Confidence Rating</i>
						time. BCR 2 also incorporates ecological benefits into its calculation	
Kiely (2021)	Indonesia	Indonesia-22 protected areas which contain peatland in Sumatra, 8 are Wildlife reserves and 12 are National Parks with only 1 Grand Forest Park and 1 Nature Recreation Park.	Structural-green infrastructure-forest restoration The Indonesian government has committed to restoring 2.49 million hectares of degraded peatland	Environmental hazard: Forest fires	CBA	1. Damages averted: lives saved and infrastructure: Economic savings	Low
Karanja (2017)	Tana Delta, Kenya	Tana Delta, Kenya-estimated population of 85,823 as per the 2009 census	Structural-Blue infrastructure-Mangroves restoration and protections	Hydrometeorological hazard: Flood	CBA	1. Damages averted housing, agriculture, crops, livestock and infrastructure) & 2. Risk reduction (hazard probability and vulnerability assessment): Net Benefits	Medium
Khan (2008)	Pakistan	Lai floodplain in the Rawalpindi/Islamabad conurbation -Cohort size: About 400,000 out of the two million residents of the twin cities live in the 100-year floodplain along the Lai River,	Non-Structural Measures > Early Warning System and land use planning; Structural measures: blue infrastructure-wetland restoration	Hydrometeorological hazard: Flood	CBA	1. Risk reduction: hazard probability and vulnerability assessment 2. Health and safety: lives saved 3. damages averted: infrastructure, crops: NPV	Low
Kull (2008)	India	The Rohini River, a part of the Gangetic	Structural measures: Hybrid	Hydrometeorological hazard: Flood	CBA	1. Risk reduction: hazard probability	Low

<i>Study Name</i>	<i>Country</i>	<i>Population/ Location</i>	<i>Intervention</i>	<i>Type of Hazards</i>	<i>Study Design</i>	<i>Outcome Domain</i>	<i>Confidence Rating</i>
		Basin-8 villages were selected, with 10% of households in each village surveyed, resulting in a total of 208 households surveyed.	infrastructure>sustainable drainage> non-structural-early warning systems and capacity building River embankment			and vulnerability assessment 2. Health and safety: lives saved 3. damages averted: infrastructure, crops: BCR	
Menéndez (2018)	Philippines		Structural:blue: mangrove Mangrove protection	Hydrometeorological hazards: flood and cyclones	CBA	1. Damages averted: infrastructure 2. Health and safety: lives saved: TEV	Low
Nepal Red Cross (2008)	Nepal	9,000 people in 15 vulnerable communities, selected as a result of a baseline survey in the disaster-prone districts of Saptari, Panchthar and Ilam	Structural-hybrid-sustainable drainage & non-structural-Capacity building The formation of community DRR units & contingency planning, improved central communication systems, strengthening capacity of regional warehouses holding relief items,	Geological or geophysical-Earthquake, landslide and rockslide & hydrometeorological: flood and drought	CBA	1. Damages averted: crops and infrastructure 2. Risk reduction: hazard probability and health and safety: lives saved. Net benefits and BCR	Medium
Rai (2020)	Nepal	Lower Karnali River Basin in Nepal		Geological or geophysical-Earthquake, landslide and rockslide & hydrometeorological: flood and drought	CBA	1. Damages averted: crops and infrastructure 2. Risk reduction: hazard probability and health and safety: lives saved. Net benefits and BCR	Medium

<i>Study Name</i>	<i>Country</i>	<i>Population/ Location</i>	<i>Intervention</i>	<i>Type of Hazards</i>	<i>Study Design</i>	<i>Outcome Domain</i>	<i>Confidence Rating</i>
UNDP (2015a)	Nepal	Panchase region in the districts of Kaski, Parbat and Syangja through 17 Village Development Committees (VDCs)	Structural measure: Green infrastructure: green space plantation of broom grass (Thysanolaena maxima) in degraded grasslands in Chitre VDC;	Hydrometeorological hazard: Flood and drought & Geological or geophysical hazard- landslide, rockslide	CBA	1. Damages averted- livestock/fodder, livelihood/wages & 2. Benefits of risk reduction: NPV, BCR and Internal Rate of Return	Low
UNDP (2015b)	Peru	The region of Lima and the Pachacayo watershed in the region of Junín	Non-structural measure- land use planning sustainable grassland management -manage grazing and rangelands	Environmental hazard: soil degradation	CBA	1. Damages averted- livestock/fodder, livelihood/wages & 2. Benefits of risk reduction: NPV, BCR and Internal Rate of Return	Low
Venton (2004)	India	Bihar: Five villages – three that had had DMP interventions (Kothiya Balwahi, Lavatola and Godihari), and two that had not (Narvidarya Paswan Tola and Narvidarya Sahani Tola).	Non-Structural Intervention> Capacity Building	Hydrometeorological hazards: Flood	CBA	1. damages averted: infrastructure 2. health and safety: lives saved: BCR and NPV	Medium
White (2010)	Nepal	Kailali District	Non-Structural Measures>Capacity Building & Ealy Warning systems	Hydrometeorological hazards: Flood and Environmental degradation	CBA	1. Risk assessment: hazard probability	Medium
Dang (2018)	Vietnam		Regulating ecosystem services (RES) from different land use (not an intervention except you	Landslide (also models soil erosion, but that is not a disaster)	Modelling	RES in paddy areas better protects against soil erosion than it does landslides. One-third	Moderate

<i>Study Name</i>	<i>Country</i>	<i>Population/ Location</i>	<i>Intervention</i>	<i>Type of Hazards</i>	<i>Study Design</i>	<i>Outcome Domain</i>	<i>Confidence Rating</i>
			can regulate land use patterns)			of paddy offers no natural RES so ought to be re-forested (this is what they say not what I recommend).	
Kayum (2022)	Bangladesh		Pandanus Trees	Storm surge	Modelling	Pandanus trees can reduce the surge height from an average of 3.89m to 3.58m, which will ultimately preserve 75% of the area of the island. The minimum required patch width for the Pandanus tree belt was calculated as 4.53 m.	High
Watson (2022)	Ecuador		Greenspaces in urban planning, and designation of those greenspaces for emergency accommodation.	Landslides, floods, volcanoes, and earthquakes.	Modelling	Currently, officially designated green spaces to be used in the event of a disaster could take only 2-14% of the population living within 800m (taken to be less than a 10-minute walk). This figure would increase to 8-40% if other green spaces were also so designated. The ex-ante analysis,	High

<i>Study Name</i>	<i>Country</i>	<i>Population/ Location</i>	<i>Intervention</i>	<i>Type of Hazards</i>	<i>Study Design</i>	<i>Outcome Domain</i>	<i>Confidence Rating</i>
						which uses models of the risks of hazards based on ecological characteristics, finds that the expected spatial expansion of Quito will be into areas of increased risk of hazard	
Zhang et al (2020)	China		Sponge City's strategy to reduce flooding from stormwater	Flooding	Modelling	The volume capture ratio of annual runoff was 91%, which is higher than the control target of 80%. The suspended solids reduction rate was 56%, which meets the requirement of planning indicators.	Moderate
Barbedo (2014)	Brazil		River restoration, compact urban development, construction of connected lakes, opening of new channels complementing existing drainage network, river dredging (hybrid blue-grey technology)	Flooding	Modelling	River flooding was eliminated across floodplains for 5-yearly rainfall events; flooding was reduced (and eliminated in some areas) across flood plains for 25-year extreme rainfall events; the study presents magnitudes of change in flooding maximum depth (e.g.	

<i>Study Name</i>	<i>Country</i>	<i>Population/ Location</i>	<i>Intervention</i>	<i>Type of Hazards</i>	<i>Study Design</i>	<i>Outcome Domain</i>	<i>Confidence Rating</i>
						50cm less than under the baseline scenario). Time series of water flow volumes (m ³ /second) for the two rivers are also presented, indicating a reduction in one river and a slight increase in the other.	
Castelli (2017)	Bolivia		Four different scenarios were compared to a base case (scenario 1): complete urbanisation (scenario 2), urbanisation with green infrastructure (scenario 3), urbanisation with green infrastructure and agroforestry (scenario 4), and complete afforestation using agroforestry (scenario 5)	This study is about balance in the water cycle. The potential hazards addressed might include flooding, although the paper does not refer to flooding (or drought or other rapid-onset disasters). The paper states "The SWAT watershed model (Scenario 1 [which is the base case]) was used to evaluate the spatial distribution of runoff generation, which is seen as a hazard for the city of Santa Cruz, and percolation to the shallow aquifer, which	Modelling	The paper finds increases in surface runoff and reductions in percolation to the shallow aquifer and recharge to deep aquifer, from the worst-case scenario (2 full urbanisation), over the base case scenario 1. Green infrastructure (scenario 3) performs slightly better but is still worse than the base case. Green infrastructure with agroforestry (scenario 4) fully alleviates the run-off but only partially addresses the	

<i>Study Name</i>	<i>Country</i>	<i>Population/ Location</i>	<i>Intervention</i>	<i>Type of Hazards</i>	<i>Study Design</i>	<i>Outcome Domain</i>	<i>Confidence Rating</i>
				is seen as an ecosystem service of the Pirai River system that contributes to deep aquifer recharge and river discharge in dry periods as lateral flow or base flow." (p.6)		percolation problems. Agroforestry (scenario 5) fully addresses the runoff and improves shallow and deep groundwater recharge.	
Bayas (2011)	Indonesia		Tree belts/coastal vegetation (180 transects perpendicular to over 100 km on the west coast of Aceh)	Tsunami (2004) - storm surge and flooding	Modelling	Role of coastal vegetation: The study found that the existing coastal vegetation in front of settlements significantly reduced human casualties by an average of 5%, while distance to the coast was the dominant determinant of impact. These "shields" acted as a buffer against the advancing waves, providing some protection. the protective potential of coastal vegetation depends on its spatial arrangement. Properly located	

<i>Study Name</i>	<i>Country</i>	<i>Population/ Location</i>	<i>Intervention</i>	<i>Type of Hazards</i>	<i>Study Design</i>	<i>Outcome Domain</i>	<i>Confidence Rating</i>
						vegetation was essential for effective coastal risk management.	
Posner (2017)	Haiti		community-scale flood mitigation measures- includes hillslope revegetation alternatives, channel revegetation alternatives, and gabion placement and storage-capacity alternatives	Floods	Modelling	Channel vegetation: The results obtained from the five different scenarios of channel roughness coefficients indicate that as the roughness coefficient increases, the maximum discharge at the catchment outlet also increases (0.055):Discharge: 28.34 m ³ /s, 0.075:Discharge: 30.60 m ³ /s, 0.095:Discharge: 32.85 m ³ /s, 0.115:Discharge: 35.20 m ³ /s, 0.135:Discharge: 37.50 m ³ /s. Design storms: Through analysis of the rain gauge record, it was found that the 100-yr storm has an intensity of 400 mm/day and the	

<i>Study Name</i>	<i>Country</i>	<i>Population/ Location</i>	<i>Intervention</i>	<i>Type of Hazards</i>	<i>Study Design</i>	<i>Outcome Domain</i>	<i>Confidence Rating</i>
						<p>1.1-yr storm has an intensity of 47 mm/day. The shape of these curves suggests that storms of all sizes have relatively short durations.</p> <p>Hillslope vegetation: hillslope vegetation has significant impacts on the 1-yr storm, this impact is reduced dramatically when storms of larger magnitudes fall on the area (5, 10 or 35-yr return period).</p> <p>Gabions: the presence of gabions leads to an increase in peak discharge for return periods ranging from 1-yr to 35-yr. The magnitude of this increase depends on the roughness condition, with $n=0.095$ and $n=0.135$ showing larger increases compared to $n=0.055$.</p>	

<i>Study Name</i>	<i>Country</i>	<i>Population/ Location</i>	<i>Intervention</i>	<i>Type of Hazards</i>	<i>Study Design</i>	<i>Outcome Domain</i>	<i>Confidence Rating</i>
Fleischmann (2019)	Brazil		Reservoirs and floodplains	Flooding	Modelling	For a 10-year flood in Taió, there would be a peak reduction of 43% due to floodplains and 61% due to the synergic effects of floodplains and reservoirs. Thus, an 18% reduction from the scenario without floodplains and reservoirs could be attributed to reservoirs (plus synergic effects between reservoirs and floodplains). Total peak reductions in Taió, Ituporanga and Ibirama, located relatively close to the dams, reach values as high as 60–70%. Floodplain effects in Ibirama and Ituporanga (i.e., Itajaí do Norte and Itajaí do Sul rivers) are negligible, as also seen in the flood frequency curves, but are responsible for reductions as high as	Moderate

<i>Study Name</i>	<i>Country</i>	<i>Population/ Location</i>	<i>Intervention</i>	<i>Type of Hazards</i>	<i>Study Design</i>	<i>Outcome Domain</i>	<i>Confidence Rating</i>
						60% in Taió and Rio do Sul cities. Regarding reservoirs, in Taió and Ituporanga there is a maximum reservoir peak reduction for events between 5 and 15 years. For more extreme events, smaller attenuation is expected due to the increasing flood volume.	
Lin (2017)	China		Forest reconstruction (forest type)	Flooding	Modelling	The transformation of 59.35 km ² of coniferous forests to broad-leaved forests had a limited reduction effect on flood peak discharge and flood volume. Added with 61.75 km ² bamboo forest is replaced by broadleaved forest, (1) flood peak discharge of 10-year return period event was reduced to 7-year event, and the reduction rate for	Moderate

<i>Study Name</i>	<i>Country</i>	<i>Population/ Location</i>	<i>Intervention</i>	<i>Type of Hazards</i>	<i>Study Design</i>	<i>Outcome Domain</i>	<i>Confidence Rating</i>
						small floods was 21%- 28%; (2) the reduction rate of flood volume increased dramatically by 9%-14% for moderate floods, and 18%-35% for small floods. The results indicated that bamboo forest reconstruction was an effective solution for flood reduction in the URTR.	

Appendix F Confidence assessments

Effectiveness studies

<i>Study</i>	<i>Study Design (RCT, QED, BAD)</i>	<i>Intervention (Full & clear Description so that the main components and how they are delivered are clear)</i>	<i>Outcomes (Full & clear Description using validated instruments where available a researcher wishing to use these outcomes would have sufficient information to do so)</i>	<i>Power calculations (The power calculation report and sample size meet the necessary sample size)</i>	<i>Attrition (overall attrition<20% and differential attrition<10 percentage points)</i>	<i>Evaluation Questions (A full and clear description)</i>	<i>Overall</i>
Aguirre (2021)	Medium	High	High	Medium	Not reported	High	Low
Andam (2013)	Medium	Medium	High	Low	Not reported	High	Medium
Anderson (2018)	Medium	High	High	Low	Not reported	Medium	Low
Ayala-Garcia (2022)	Medium	Medium	High	Low	Not relevant	Medium	Low
BenYishay (2017)	Medium	High	High	Low	Not reported	High	Low
Beresford (2013)	Medium	Low	Medium	Medium	Not reported	Medium	Low
Blackman (2015)	Medium	High	High	Medium	Not reported	High	Medium
Brenes (2018)	Medium	High	High	Low	Not reported	High	Medium
Brum (2019)	Medium	High	Medium	Low	Not reported	High	Low
Buntaine (2015)	Medium	High	Medium	Low	Not reported	High	Low
Carmenta (2016)	Medium	High	High	Medium	Not reported	High	Low
Dancer (2013)	Medium	Medium	Medium	Low	Not reported	High	Low
Des bureaux (2015)	Medium	High	High	Low	Not reported	High	Low
Gaveau (2012)	Medium	High	High	Low	Not reported	High	Low
Gaveau (2013)	Medium	High	Medium	Medium	Not reported	Medium	Low
Feng (2021)	Medium	Medium	High	Medium	Not reported	Medium	Medium
Ha (2014)	Medium	High	Medium	High	Not relevant	Medium	Medium
Jones (2015)	Medium	High	High	Low	Not reported	High	Medium

<i>Study</i>	<i>Study Design (RCT, QED, BAD)</i>	<i>Intervention (Full & clear Description so that the main components and how they are delivered are clear)</i>	<i>Outcomes (Full & clear Description using validated instruments where available a researcher wishing to use these outcomes would have sufficient information to do so)</i>	<i>Power calculations (The power calculation report and sample size meet the necessary sample size)</i>	<i>Attrition (overall attrition<20% and differential attrition<10 percentage points)</i>	<i>Evaluation Questions (A full and clear description)</i>	<i>Overall</i>
Kim (2021)	Medium	Medium	Medium	Low	Not reported	Medium	Low
Maher (2013)	Medium	Medium	Medium	Low	Not reported	High	Low
McNally (2011)	Medium	High	High	Low	Not reported	Medium	Low
Nelson (2011)	Medium	High	High	Low	Not relevant	High	Low
Nolte (2014)	Medium	Medium	Medium	Low	Not reported	High	Low
Sarathchandra (2018)	Medium	Medium	Medium	Low	Not reported	High	Low
Shah (2015)	Medium	High	Medium	Low	Not relevant	High	Low
Tabor (2017)	Medium	High	High	Medium	Not reported	High	Medium
Tersitsch (2017)	Medium	High	High	High	Not reported	High	Medium
West (2022)	Medium	High	High	Medium	Not reported	High	Medium

Economic evaluations

	Was a well-defined question posed in an answerable form?	Was a comprehensive description of the competing alternatives given?	Was there evidence that the programme's effectiveness had been established?	Were all the important and relevant outcomes and costs for each alternative identified?	Were the outcomes and costs measured accurately in appropriate units?	Were the outcomes and costs valued credibly?	Were the outcomes and costs adjusted for different times at which they occurred (discounting)?	Was a sensitivity analysis performed?	Did the presentation and discussion of the results include all, or enough, of the issues that are of concern to purchasers?	Were the conclusions of the evaluation justified by the evidence presented?	Overall confidence in the study's findings
Baig (2015)	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No	Yes	Moderate
Burton (2009)	Yes	Yes	Yes	No	Yes	Yes	No	No	No	Yes	Low
Chabba (2022)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	High
Golub (2016)	Yes	No	No	No	Yes	Yes	Yes	Yes	No	Yes	Low
Hague (2013)	Yes	Yes	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Moderate
Hallegatte (2012)	Yes	Yes	No	No	Yes	No	No	No	No	Yes	Low
Holland (2008)	Yes	Yes	No	No	Yes	Yes	No	Yes	Yes	Yes	Moderate
IFRC (2011)	Yes	Yes	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Moderate
Karanja (2017)	Yes	Yes	No	Yes	Yes	No	No	No	Yes	Yes	Low
Kiely (2021)	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Moderate
Khan (2008)	Yes	Yes	No	No	No	No	Yes	No	No	Yes	Low
Kull (2008)	Yes	Yes	No	No	No	No	Yes	Yes	No	Yes	Low
Meier (2016)	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Moderate
Menéndez (2018)	Yes	Yes	No	No	No	No	No	No	No	Yes	Low
Nepal Red Cross (2008)	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Moderate
Rai (2020)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	High
Sarkar (2020)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Moderate

	<i>Was a well-defined question posed in an answerable form?</i>	<i>Was a comprehensive description of the competing alternatives given?</i>	<i>Was there evidence that the programme's effectiveness had been established?</i>	<i>Were all the important and relevant outcomes and costs for each alternative identified?</i>	<i>Were outcomes and costs measured accurately in appropriate units?</i>	<i>Were the outcome costs valued credibly?</i>	<i>Were outcomes and costs adjusted for different times at which they occurred (discounting)?</i>	<i>Was a sensitivity analysis performed?</i>	<i>Did the presentation and discussion of the results include all, or enough, of the issues that are of concern to purchasers?</i>	<i>Were the conclusions of the evaluation justified by the evidence presented?</i>	<i>Overall confidence in the study's findings</i>
UNDP (2015)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	High
Venton (2004)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	High
White (2010)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	High

Modelling studies

<i>Paper</i>	<i>Barbedo (2014)</i>	<i>Bayas (2011)</i>	<i>Castelli (2017)</i>	<i>Dang (2018)</i>	<i>Fleischman n (2019)</i>	<i>Kayum (2022)</i>	<i>Lin (2017)</i>	<i>Posner (2017)</i>	<i>Watson (2022)</i>	<i>Zhang et al (2020)</i>
Model clearly specified	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Model assumptions stated	No	Yes	No	Yes	Yes	Yes	Partially	No	Yes	Yes
Model appropriate to research questions	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Calibrated on data	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Partly
Calibrated on local data	Partially	Yes	No	Yes	Yes	Yes	Partially	Yes	Yes	Partly yes
Dynamic	Yes	Yes	Partially	No	Yes	No	Yes	Yes	No	No
Tested	No	Partially	Partially	No	Yes	No	Yes	Yes	Yes.	No
Clear findings	No	Yes	Partially	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sensitivity analysis	Yes	No	Yes	Partly	Partly	Yes	Partially	Yes	Yes	Yes
Recommendations from analysis	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Overall	Low	Moderate	Low	Moderate	Moderate	High	Moderate	Low	High	Moderate

Appendix G Data collection from economic evaluations

<i>Study</i>	<i>Population/ country</i>	<i>Time horizon; discount rate; currency</i>	<i>Ecosystem; hazard type</i>	<i>Eco-DRR activity and intervention</i>	<i>Comparator</i>	<i>Outcome-benefits measure</i>	<i>Cost-effectiveness results</i>	<i>Sensitivity analysis</i>
Baig (2015)	Philippines - Barangay Silonay, Calapan City includes 1, 407 residents (724 males and 683 females) in 304 households.	20 Years; 10%; USD. PHP	Coastal & River/Wetland; Hydro-meteorological hazards- Tropical cyclones & flooding	Structural measures- Blue Infrastructure- Mangrove replanting and protection	Alternate treatment	Hazard mitigation- Damage averted (infrastructure, livelihood and crop/agriculture	ANPV for Mangrove protection was USD 74,150 and mangrove replanting was USD 69,650. BCR for Mangrove protection: was 1.49 and Mangrove planting 1.36	ANPV USD 14,877 (3% discount rate); USD 9818 (8% discount rate & USD 6259 (15%) Mangrove replanting USD 68567 (3%)

<i>Study</i>	<i>Population/ country</i>	<i>Time horizon; discount rate; currency</i>	<i>Ecosystem; hazard type</i>	<i>Eco-DRR activity and intervention</i>	<i>Comparator</i>	<i>Outcome-benefits measure</i>	<i>Cost-effectiveness results</i>	<i>Sensitivity analysis</i>
Baig (2015)	Philippines- -Cagayan De Oro River Basin: total household population of 137,465	20 Years; 10%; USD. PHP	Coastal & River/Wetland; Hydrometeorological hazards- Tropical cyclones	Non-structural measure- Capacity building- payment for environmental services (PES) scheme. Structural measures-Blue infrastructure- Wetland restoration- Rehabilitation and preservation of the River Basin	Business-as-usual	Hazard mitigation- Damage averted (houses, livestock/fodder, livelihood and agriculture/crop Human development outcome- Productivity gains (fishing and recreational value)	Total economic value USD 5.1-6.1 million per year. Not valued quantitatively	Not reported
Burton (2009)	Philippines: residents under natural hazard threat	15 years; discount rate not specified	River/wetland; Hydrometeorological hazards: Flood	Structural measure-hybrid infrastructure- green roof, green façade, green dykes Integrated Based Disaster Preparedness Program (ICBDP)	disaster response operations undertaken by the Philippines National Red Cross	Hazard mitigation: Damage averted (housing, livestock/fodder, livelihood and agriculture/crop	BCR of footbridge- 24; BCR seawall- 4.9; BCR-0.7 dykes	

<i>Study</i>	<i>Population/ country</i>	<i>Time horizon; discount rate; currency</i>	<i>Ecosystem; hazard type</i>	<i>Eco-DRR activity and intervention</i>	<i>Comparator</i>	<i>Outcome-benefits measure</i>	<i>Cost-effectiveness results</i>	<i>Sensitivity analysis</i>
Chabba (2022)	Peru-231 households in peri-urban Lima municipality	50 years; 4.2%; USD	Mountain/forest; Geological or geophysical- Earthquake, landslide and rockslide	Structural measure-Green infrastructure- Forest restoration and Green space Boca de Sapo (BdS) is a ~14-hactere urban forest on the mountainside above the burgeoning El Volante (the park covers about has more than 3500 trees and plants.)	'baseline scenario' risk with mitigation and risk without mitigation	Hazard Prevention- Risk Reduction: Hazard probability and vulnerability	BCR-DRR benefits alone (0.06). BCR with tangible property rights co-benefits (1.18) and BCR with willingness-to-pay (WTP) for non-market co-benefits (1.70) NPV DRR-only scenario (-\$1,087,000); DRR + property rights ((\$1,100,000) and the DRR + property rights + WTP (\$3,200,000	At 6% discount rate (BCR 1.12, NPV \$13,400). At 4% (average BCR 1.14, NPV \$17,000), At 2% discount BCR 2.35 and NPV \$203,000.

<i>Study</i>	<i>Population/ country</i>	<i>Time horizon; discount rate; currency</i>	<i>Ecosystem; hazard type</i>	<i>Eco-DRR activity and intervention</i>	<i>Comparator</i>	<i>Outcome-benefits measure</i>	<i>Cost-effectiveness results</i>	<i>Sensitivity analysis</i>
							Scenario 3 ("Hybrid") NVP (92.849.818), BCR (1,50) and total cost (187.416.645)	
				Structural measures- (1)Green infrastructure-Trees & (2)Hybrid infrastructure-sustainable drainage & (3) Blue infrastructure-Wetland restoration			Scenario 1 ("Engineering") provides a negative NPV (-12.575.938) and a BCR smaller than one (0.94).	
Meier (2016)	Thailand-Huai Sai Bat, a sub-basin of the Chi River Basin; approx. 65.000 people living in the Huai Sai Bat Basin.	25 years; 3%; THB	River/wetland; Hydrometeorological hazards - Drought & Environmental hazard-soil degradation		"Business as usual" (dredging)	Risk reduction (hazard probability-soil erosion)	Scenario 2 ("EbA") (NPV 902.735.762) and BCR (2.72) but relatively high total costs (524.657.741).	Not reported

<i>Study</i>	<i>Population/ country</i>	<i>Time horizon; discount rate; currency</i>	<i>Ecosystem; hazard type</i>	<i>Eco-DRR activity and intervention</i>	<i>Comparator</i>	<i>Outcome-benefits measure</i>	<i>Cost-effectiveness results</i>	<i>Sensitivity analysis</i>
Meier (2016)	Thailand: The Tha Di River basin: is home to approximately 145,000 inhabitants, with a significant proportion residing in urban areas. Urbanization and land use changes have implications for water resources and ecosystem services.	5, 10 & 25 years; 3%; THB	River/wetland; Hydrometeorological hazards- Floods & droughts	Structural measure: Blue infrastructure-wetland restoration Four EBA measures: 1) flood control with wetland development 2) constructed wetland 3) conventional wastewater treatment plant (WWTP). 4) riparian zone improvement,	Non-Eco DRR (concrete weirs) and a conventional wastewater treatment plant (WWTP).	Hazard mitigation: Damage averted (Agriculture/ crop)	Flood control with wetland costs (TBH 22.344.738) is higher than the benefits (TBH 15.522.460) in the short term (5 years), In the middle term (10 years), BCR of 1.24, and in the long term (25 years), reaching a BCR of 2.32. A riparian zone-BCR in the middle and long term with a BCR of 1.05 and 2.02.	Not reported
Golub (2016)	Bangladesh; Kulhna district-6.40 millions people	50 years; 5%	River/wetland; Hydrometeorological hazard: Flood	Structural measure-Blue infrastructure-Mangrove restoration and protection	Baseline scenario-business as usual	Hazard mitigation: Damage averted (infrastructure and crops) & 2. Risk reduction (hazard probability)	BCR is 3. And adjusted BCR is 3.3.	Discount rate at 3% (BCR 3.40), 5% (BCR 2.76), 10% (BCR 1.74).

<i>Study</i>	<i>Population/ country</i>	<i>Time horizon; discount rate; currency</i>	<i>Ecosystem; hazard type</i>	<i>Eco-DRR activity and intervention</i>	<i>Comparator</i>	<i>Outcome-benefits measure</i>	<i>Cost-effectiveness results</i>	<i>Sensitivity analysis</i>
Haque (2013)	Bangladesh: The Matlab North thana Cohort size: a total of 589 households	50 years, 10%; USD	River/wetland; Hydrometeorological hazard: Flood	Hybrid infrastructure>sustainable drainage> Meghna Dhonogoda Irrigation Project (MDIP) project.	Matlab South: Area outside the project area (control group)	Hazard mitigation: Damage averted: Agriculture/crop, livestock/fodder, Infrastructure livelihood/wages	NPV -1080 million Taka (US\$ -15.6 million), IRR of 5.32%	Not reported
Hellegate (2012)	Multicounty	discount rate N/A USD	River/wetland; Hydrometeorological hazard: Flood	Non-structural Intervention> Early warning systems	Business as usual	Hazard mitigation: Damage averted: assets, infrastructure Human development outcomes: lives saved	Avoided Asset Losses: Between \$300 million and \$2 billion per year due to natural disasters. Lives Saved: An average of 23,000 lives saved annually Additional Economic Benefits-\$3 billion and \$30 billion per year	Not reported

<i>Study</i>	<i>Population/ country</i>	<i>Time horizon; discount rate; currency</i>	<i>Ecosystem; hazard type</i>	<i>Eco-DRR activity and intervention</i>	<i>Comparator</i>	<i>Outcome-benefits measure</i>	<i>Cost-effectiveness results</i>	<i>Sensitivity analysis</i>
Holland (2008)	Fiji-Navua town. Total population 21,000. The sample size for the economic survey: 293	20 years and 10%; FJ\$	River/wetland; Hydrometeorological hazard: Flood	Non-structural measure-Early warning system	Baseline scenario as usual (without warning system)	Hazard mitigation: Damage averted: livelihood, infrastructure Human development outcomes: health and safety-lives saved	Net Benefits: between FJ\$2.1 million and FJ\$4.2 million. NPV: FJ\$0.04 million and FJ\$0.4 million ROI: ranges from 1.1 to 2.2.	At a 7% discount rate-benefits are estimated to rise to around FJ\$2.5-5.0 million. At 3% FJ\$3.4-6.7 million.
IFRC (2011)	Vietnam; - Residents in Dai Hop (Hai Phong province); Thai Do (Thai Binh); Nam Tinh (Thai Binh); Giao An (Nam Dinh) and Dien Bich (Nghe An)	31 years; 7.23%; USD	Coastal; Hydrometeorological hazard: Flood and cyclones	Structural- Blue Infrastructure – Mangrove afforestation Afforestation along coastline	Business as usual	Hazard mitigation: Damage averted and . health and safety (lives saved) Hazard prevention: Risk reduction	BCR 1 (protective and direct economic benefits) 18.61 (Thai Do) and 68.92 (Giao An). BCR 2 (includes ecological benefits) 28.86 (Dai Hop) and 104.96 (Giao An).	Not reported

<i>Study</i>	<i>Population/ country</i>	<i>Time horizon; discount rate; currency</i>	<i>Ecosystem; hazard type</i>	<i>Eco-DRR activity and intervention</i>	<i>Comparator</i>	<i>Outcome-benefits measure</i>	<i>Cost-effectiveness results</i>	<i>Sensitivity analysis</i>
Kiely (2021)	Indonesia-22 protected areas which contain peatland in Sumatra,	Not mentioned by the author; USD	Mountain/forest; Environmental hazard: forest fires	Structural-green infrastructure-forest restoration The Indonesian government has committed to restoring 2.49 million hectares of degraded peatland	Baseline scenario	Hazard mitigation: Damage averted: infrastructure/as sets Human development outcomes: lives saved	Economic savings of US\$8.4 billion from 2004 to 2015.	Not reported
Karanja (2017)	Tana Delta, Kenya-estimated population of 85,823 as per the 2009 census. Cluster A consisted of villages unprotected by mangrove forests. Cluster B with narrow mangrove belts. Cluster C encompassed a wide mangrove forest.	2.5 years; N/A; USD	Coastal; Hydrometeorological hazard: Flood	Structural-Blue infrastructure-Mangroves restoration and protections	Control (cluster A)	Hazard mitigation: Damage averted housing, agriculture, crops, livestock and infrastructure) & 2. Risk reduction (hazard probability and vulnerability assessment):	Net benefits are US\$238/ha/yr and US\$311/ha/yr in clusters B and C, respectively.	Not reported

<i>Study</i>	<i>Population/ country</i>	<i>Time horizon; discount rate; currency</i>	<i>Ecosystem; hazard type</i>	<i>Eco-DRR activity and intervention</i>	<i>Comparator</i>	<i>Outcome-benefits measure</i>	<i>Cost-effectiveness results</i>	<i>Sensitivity analysis</i>
Khan (2008)	Pakistan; Residents in Lai floodplain Cohort size: About 400,000	30 YEARS, 12%; USD and PKR	River/wetland; Hydrometeorological hazard: Flood	Non-Structural Measures > Early Warning System and land use planning; Structural measures: blue infrastructure-wetland restoration (1) Expressway/channel; river improvements; (2) early warning system; (3) relocation of houses along flood plain and restoration of area with wetland	Business as usual	1) Hazard mitigation: Infrastructure 2) Human development outcomes: lives saved 3) Hazard prevention: Risk reduction: hazard probability	1) NPV and BCR of Community pond & River improvement: PKR 1,359 million and BCR 8.5-9.25 2) The early warning system NPV PKR 412 million and BCR 0.96 3) NPV of relocation/restoration PKR 15,321 million and BCR: 1.34)	Not reported

<i>Study</i>	<i>Population/ country</i>	<i>Time horizon; discount rate; currency</i>	<i>Ecosystem; hazard type</i>	<i>Eco-DRR activity and intervention</i>	<i>Comparator</i>	<i>Outcome-benefits measure</i>	<i>Cost-effectiveness results</i>	<i>Sensitivity analysis</i>
Kull (2008)	India: The Rohini River, a part of the Gangetic Basin-8 villages-208 households surveyed.	43 years; 10%;INR	River/wetland; Hydrometeorological hazard: Flood	Structural measures: Hybrid infrastructure>sustainable drainage> non-structural-early warning systems and capacity building River embankment	Two intervention areas	Hazard prevention: Risk reduction: hazard probability Hazard mitigation: damages averted to crop/ agriculture Human development outcomes: lives saved	River embankment: BCR 4.6 BCR capacity-building and early warning systems 2.5	0-20%
Menéndez (2018)	Philippines	20-years; USD	Coastal; Hydrometeorological hazards: flood and cyclones	Structural: blue: mangrove Mangrove protection	Scenario without mangroves	Hazard mitigation-Damages averted: Infrastructure Human development outcomes: lives saved	TEV \$3200/year of direct flood reduction benefits. Restoring mangroves to their 1950 distribution would bring additional benefits of 453 million	Not reported

<i>Study</i>	<i>Population/ country</i>	<i>Time horizon; discount rate; currency</i>	<i>Ecosystem; hazard type</i>	<i>Eco-DRR activity and intervention</i>	<i>Comparator</i>	<i>Outcome-benefits measure</i>	<i>Cost-effectiveness results</i>	<i>Sensitivity analysis</i>
Nepal Red Cross (2008)	Nepal: Residents in in districts of Saptari, Panchthar and Ilam- 9,000 people in 15 vulnerable communities	15 years and 10%; NPR and USD	Mountain/forest; Geological or geophysical- Earthquake, landslide and rockslide & hydrometeorological: flood and drought	Structural-hybrid-sustainable drainage tree planting on river beds and capacity building formation of community DRR units, emergency fund, first aid training, supply of a rickshaw ambulance	Scenario without the DRR programme	Hazard mitigation: Damages averted: crops and infrastructure Hazard prevention: risk reduction: hazard probability	BCR: 18.6. Net benefits: 33 million NPR.	BCR 14.8 at a 15% discount rate

<i>Study</i>	<i>Population/ country</i>	<i>Time horizon; discount rate; currency</i>	<i>Ecosystem; hazard type</i>	<i>Eco-DRR activity and intervention</i>	<i>Comparator</i>	<i>Outcome-benefits measure</i>	<i>Cost-effectiveness results</i>	<i>Sensitivity analysis</i>
Rai (2020)	Lower Karnali River Basin in Nepal- 453 households-farmers	5%, 20 Years; PR	River/wetland; Hydrometeorological hazards: Flood	Non-structural: early warning system	Business as usual	Hazard prevention: risk reduction	NPV is NPR 1.80 billion (USD 16.70 million) BCR is 83, IRR is 409%.	Scenario I (two-year interval to recover) BCR-63.38 Scenario II (risk of losing cash is reduced by 75%)-BCR-46.15 Scenario III (no risk of damage) BCR-26.15 Scenario IV-BCR-73 Scenario V: BCR-24.34
Sarkar (2020)	Bangladesh-southwestern Bangladesh districts of <i>Bagerhat, Khulna, Satkhira, and Barguna</i> . Cohort size-1,525 households,	2015, USD	Hydrometeorological hazard: tropical cyclones	Structural: blue: mangrove Mangrove protection-The Sundarbans Reserve Forest (SRF)	No intervention (far off from SRF)	Hazard mitigation: Damages averted: Storm protection	Damage-cost-avoided (DCA) due to protective functions of the mangroves-USD 543.30 million-	Not reported

<i>Study</i>	<i>Population/ country</i>	<i>Time horizon; discount rate; currency</i>	<i>Ecosystem; hazard type</i>	<i>Eco-DRR activity and intervention</i>	<i>Comparator</i>	<i>Outcome-benefits measure</i>	<i>Cost-effectiveness results</i>	<i>Sensitivity analysis</i>
UNDP (2015)	Nepal-Panchase region in the districts of Kaski, Parbat and Syangja through	15 years and 10%; NPR	Mountain/forest; Hydrometeorological hazard: Flood and drought & Geological or geophysical hazard- landslide, rockslide	Structural measure: Green infrastructure: green space plantation of broom grass (Thysanolaena maxima) in degraded grasslands in Chitre VDC;	BAU scenario: without intervention	Hazard mitigation: Damages averted livestock/fodder, livelihood/wages & 2. benefits of risk reduction	Broom grass NPV-NRs 277,392 NPV BAU NRs 29,618 BCR 1.3 IRR 21 %	Not reported
UNDP (2015)	Peru: Region of Lima and the Pachacayo watershed in the region of Junín	9 years and 4%; USD	Mountain/forest; Environmental hazard: soil degradation	Non-structural measure-land use planning sustainable grassland management - manage grazing and rangelands	BAU scenario: without intervention	Hazard mitigation: Damages averted livestock/fodder, livelihood/wages & 2. benefits of risk reduction:	NPV: \$841,902.95 IRR 20% BCR 1.27	At a 9% discount rate: NPV \$401,617.64, BCR: 1.09 and Internal rate of return is 20%

<i>Study</i>	<i>Population/ country</i>	<i>Time horizon; discount rate; currency</i>	<i>Ecosystem; hazard type</i>	<i>Eco-DRR activity and intervention</i>	<i>Comparator</i>	<i>Outcome-benefits measure</i>	<i>Cost-effectiveness results</i>	<i>Sensitivity analysis</i>
Venton (2004)	India-Bihar: Five villages – three that had had DMP interventions (Kothiya Balwahi, Lavatola and Godihari), and two that had not (Narvidarya Paswan Tola and Narvidarya Sahani Tola).	10%, 20 years	River/wetland; Hydrometeorological hazards: Flood	Non-Structural Intervention> Capacity Building Flood Evacuation Centre Management Group	No intervention	Hazard mitigation: damages averted: Infrastructure Human development outcomes: lives saved	NPV: Rs 3,679,502 (£45,994) BCR-3.76	Discount Rate 15% CBA- 3.17 NPV - Rs 2,449,842 (£30,623)
White (2010)	Nepal; Kailali District	10 years, 10% ; Euro	River/wetland; Hydrometeorological hazards: Flood and Environmental degradation	Non-Structural Measures>Capacity Building & Early Warning Systems	Non-DRR communities (Communities with no intervention)	Hazard mitigations: Risk assessment: hazard probability Hazard mitigation: damages averted to crops and assets	BCR 3.49.	BCR 2.32 (0% DR), 2.16 (5%DR), 1.94 (12%) and at benefit duration 10 years-5.81 (0%), 4.66 (5%), 3.49 (12%)

Appendix H Excluded qualitative evaluations

- Akber M A. M.M., Islam, M.A, P., & Rahman, M. R. (2018). Storm protection service of the Sundarbans mangrove forest, Bangladesh. *Natural Hazards*, 94, 405–418. <https://doi.org/https://doi.org/10.1007/s11069-018-3395-8>
- Devkota, B. D., Omura, H., Kubota, T., & Morita, K. (2006). State of vegetation, erosion climatic conditions and re-vegetation technology in Mid Hill area of Nepal. *Journal of the Faculty of Agriculture, Kyushu University*, 51(2), 361–365. <https://www.scopus.com/inward/record.uri?eid=2-s2.0-33845653246&partnerID=40&md5=b0c572953d5396aacd135e3f30fb23f2>
- Dwikorita, K., F, F. T., Sudarno, I., Budi, A., Djoko, L., & W, B. P. (2011). Landslide hazard and community-based risk reduction effort in Karanganyar and the surrounding area, central Java, Indonesia. *Journal of Mountain Science*, 8(2), 149–153. <https://doi.org/10.1007/s11629-011-2107-6>
- Nehren, U., Thai, H. H. D., Marfai, M. A., Raedig, C., Alfonso, S., Sartohadi, J., & Castro, C. (2016). Ecosystem services of coastal dune systems for hazard mitigation: Case studies from Vietnam, Indonesia, and Chile. *Ecosystem-Based Disaster Risk Reduction and Adaptation in Practice*, 42, 401–433. https://doi.org/https://doi.org/10.1007/978-3-319-43633-3_18
- Qu, A, t, Neufeldt, H., & McCabe, J. T. (2017). The role of agroforestry in building livelihood resilience to floods and drought in semiarid Kenya. *Ecology and Society*, 22(3), 1708–3087. <https://doi.org/https://www.jstor.org/stable/26270151>
- Qu, A, t, Neufeldt, H., & McCabe, J. T. (2019). Building livelihood resilience: what role does agroforestry play? *Climate and Development*, 11(6), 485–500. <https://doi.org/https://doi.org/10.1080/17565529.2018.1447903>
- Risti, R., Radi, B., Miljanovi, V., Trivan, G., Ljuji, M., Leti, L., & Savi, R. (2013). Blue-green corridors as a tool for mitigation of natural hazards and restoration of urbanized areas: A case study of Belgrade city. *Spatium*, 30, 18–22. <https://doi.org/10.2298/SPAT1330018R>
- Sahai, A. N. (2009). Four years beyond tsunami Contours of a roadmap for a coordinated multi-hazard (including tsunami) risk management action plan for tsunami-affected villages in Tamil Nadu: an overview of ongoing/projected initiatives. *Disaster Prevention and Management*, 18(3), 249–269. <https://doi.org/10.1108/09653560910965628>
- Samarakoon, M. B., Norio, T., & Kosuke, I. (2013). Improvement of the effectiveness of existing Casuarina equisetifolia forests in mitigating tsunami damage. *Journal of Environmental Management*, 114, 105–114. <https://doi.org/10.1016/j.jenvman.2012.10.050>
- Walters, B. B. (2004). Local management of mangrove forests in the Philippines: successful conservation or efficient resource exploitation? *Human Ecology*, 32, 177–195. <https://doi.org/https://doi.org/10.1023/B:HUEC.0000019762.36361.48>

Warner, J. F., F, van S. M., & J, van T. (2018). Cutting dikes, cutting ties? Reintroducing flood dynamics in coastal polders in Bangladesh and the Netherlands. *International Journal of Disaster Risk Reduction*, 32, 106–112.
<https://doi.org/https://doi.org/10.1016/j.ijdr.2018.03.020>

Winterwerp J C. T., Anthony, E. J., Friess, D. A., Man, A., Muhari, A., Naipal, S., Noordermeer, J., & Oost, A. (2020). Managing erosion of mangrove-mud coasts with permeable dams—lessons learned. *Ecological Engineering*, 158, 106078.
<https://doi.org/https://doi.org/10.1016/j.ecoleng.2020.106078>

Appendix I PRISMA checklist

Section and Topic	Item #	Checklist item	Response
Title			
Title	1	Identify the report as a systematic review.	Rapid systematic review (RSR)
ABSTRACT			
Abstract	2	See the PRISMA 2020 for Abstracts checklist.	NA
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	Y
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	Y
METHODS			
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	Y
Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	Y
Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used.	Y
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.	Y
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process.	Y
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which results to collect.	Y
	10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.	Y
Study risk of bias assessment	11	Specify the methods used to assess the risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study whether they worked independently, and if applicable, details of automation tools used in the process.	Y

Effect measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results.	NA
Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)).	NA
	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.	NA
	13c	Describe any methods used to tabulate or visually display the results of individual studies and syntheses.	Y
	13d	Describe any methods used to synthesise results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	Y
	13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta-regression).	NA
	13f	Describe any sensitivity analyses conducted to assess the robustness of the synthesised results.	NA
Reporting bias assessment	14	Describe any methods used to assess the risk of bias due to missing results in a synthesis (arising from reporting biases).	Y
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	NA
RESULTS			
Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	Y
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	Y
Study characteristic	17	Cite each included study and present its characteristics.	Y
Risk of bias in studies	18	Present assessments of risk of bias for each included study.	Y
Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	NA
Results of syntheses	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	NA
	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	NA
	20c	Present results of all investigations of possible causes of heterogeneity among study results.	NA

	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesised results.	NA
Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.	NA
Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	NA
DISCUSSION			
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	Y
	23b	Discuss any limitations of the evidence included in the review.	Y
	23c	Discuss any limitations of the review processes used.	Y
	23d	Discuss the implications of the results for practice, policy, and future research.	Y
OTHER INFORMATION			
Registration and protocol	24a	Provide registration information for the review, including the register name and registration number, or state that the review was not registered.	Y
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	Y
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	NA
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.	Y
Competing interests	26	Declare any competing interests of review authors.	Y
Availability of data, code and other materials	27	Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from studies; data used for all analyses; analytic code; any other materials used in the review.	Y

Source: Page et al. (2021).

Appendix J Evidence and gap map

Available as a supplementary file.